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Energy balance of electric city car

Tutor: Prof. Andrea Tonoli
Prof. Massimiliana Carello
Supervisor: Ing. Luca Lovato
Candidate: Chensi Wang

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1 Introduction

1.1 Project Background

Due to the global energy shortage, the environmental protection and the bottleneck of the development of traditional automobile industry. Due to the advantage of lightweight, environmental protection, less energy consumption and lower noise characteristics of the electric vehicle. Electric vehicles are receiving more and more attention from various countries. Presently, electric vehicles are in a stage of rapid development.

The electric vehicle is a kind of vehicle that uses the electric motor as power system wholly or partially. Electric vehicles include pure electric vehicles, hybrid electric vehicles and fuel cell electric vehicles. The characteristics of electric vehicles are as follows: no exhaust emission, good environmental protection effect; low noise, only 25% of the noise of traditional vehicles; high thermal efficiency, nearly 50% higher than that of traditional fuel vehicles; less waste heat, which can effectively reduce the urban "heat island effect"; more energy can be recycled; energy structure can be improved to solve the problem of energy substitution of automobiles. The electric car has the advantages of simple structure, convenient use, and maintenance, etc.

As the project is to design an electric vehicle for the Chinese market with high performance. During this project, we should design the electric vehicle based on the Chinese government policies on electric vehicles, the development of the electric vehicle in China and the proportion of different types of electric vehicle in Chinese electric vehicle market. All we need to consider not only to design a better performances electric vehicle but also for matching the Chinese electric vehicle market.

1.1.1 history of electric vehicle development

The first electric vehicle was born between 1832 and 1839 when the Scottish Roberts were born. The first electric car was built by Edison with a speed of 20 miles per hour in 1880. The first practical production electric vehicle was built in 1884 by Thomas Parker in London using specially designed high-capacity rechargeable batteries own to him[1][2][3].

Around the 1970s, considering both the gasoline price and the prices for fuel or the electric car, the total cost of ownership was not much different. Therefore, although the price of electric vehicles is much more expensive than fuel car, the sales of electric vehicles still exceed the fuel vehicles. In 1912, the number of electric vehicles in the United States and Europe was about 50,000, accounting for 40% of the entire automobile market, and fuel vehicles accounted for only 22%. The rest are steam-driven vehicles. With the discovery of oil all over the world around the 1920s, the price of gasoline quickly fell to affordable levels, at the same time roads and gas stations was gradually improved. Unfortunately, during this period electric cars have not made breakthroughs in battery technology and operating for a long time. Electric vehicles have gradually replaced by internal combustion engine-driven fuel vehicles and disappear in the 1930s.

After entering the second half of the twentieth century, after two successive oil crises in the world's largest automobile market dominated by the United States, automobile companies and the public began to re-focus on new energy vehicles led by electric vehicles. In 2010, the global oil price continued to rise, the voice of environmental protection became increasingly strong, and the positive demand of consumers for low-carbon life and many other factors, the development of electric vehicles was once again put on the agenda by governments and major automotive enterprises. In fact, 2010 is also a key year for the start of the electric vehicle market.

In recent years, many counties began to courage to develop electric cars. In view of the positive effects of the development of electric vehicles on energy security, energy saving and emission reduction, peak-filling and valley-filling of power system, frequency modulation and standby, many governments and enterprises in many countries, such as automobile companies and power companies, have taken various measures to promote the development of electric vehicles[4][5][6].

Under the background of global warming, oil prices rising and fossil fuels declining. The development of electric vehicles has become an alternative way to improve energy efficiency, promote renewable energy development, save energy conservation and reduction emissions. The development of electric vehicles will help reduce the dependence of transportation on oil and gasoline resource. Due to the variety of power generation energy, if the proportion of clean energy in the power system is high, the wide application of electric vehicles will significantly reduce CO2 emissions. In addition, in some developed countries, the power consumption cost per km of electric vehicles is only about 1/3 of the fuel consumption cost of fuel vehicles[7], which can significantly save vehicle costs for owners[7]. Moreover, compared with other new energy vehicles such as hydrogen-fueled vehicles, electric vehicles can adapt to existing power facilities and require less additional investment.

1.1.2 Governments policy for develop electric vehicles

From a global perspective, the reason why governments should vigorously promote the development of electric vehicles is closely related to controlling greenhouse gas emissions and suppressing global temperature rise. According to the IEA International Energy Agency, the transportation sector contributes 23% of global greenhouse gas emissions. To control global greenhouse gas emissions, electrification in the transportation sector, especially in the automotive sector, is one of the effective ways in the long run.

China's industrial policy changes for new energy vehicles can be roughly divided into three stages are named, the government's macro-strategic planning stage (2001-2006), the establishment of industry access rules and comprehensive subsidies stage (2007-2015), and the post-subsidies stage (2016-present).

On November 1st, 2007, the Rules for "the Administration of New Energy Vehicle Production Access" came into effect it marked the beginning of the second stage. This rule specifies the definition of new energy vehicles, the qualifications of new energy vehicles manufacturers, production access conditions and declaration requirements. In 2009, for the first time, the government issued a subsidy policy for energy-saving and new energy vehicles, subsidizing energy-saving and new energy vehicles in the field of public services. In 2010, the government launched a pilot subsidy scheme for private purchases of new energy vehicles, with a subsidy of 3,000 yuan per kWh, a maximum subsidy of 50,000 for plug-in hybrids and a maximum subsidy of 60,000 for pure electric vehicles[8].

In addition to financial subsidies, in the "Draft Energy Conservation and New Energy Industry Plan", there is also a significant tax bias on new energy vehicles: purchasing pure electric vehicles and plug-in hybrid electric vehicles will be exempted from vehicle purchase tax in 2011-2020. From 2011 to 2015, vehicle purchase tax, consumption tax and vehicle and ship tax will be reduced by half for medium and heavy hybrid vehicles[9]. And adjustment of the value-added tax rate for enterprises selling new energy vehicles and their key components to 13%. In addition to the local subsidy policy, local governments also use a series of non-fiscal stimulus measures, such as singing the horn alone, unlimited travel, to encourage consumers to buy new energy vehicles.

On May 24, 2014, the development of new energy vehicles was raised to the height of national strategy. In November 2016, the State Council issued the "13th Five-Year Plan for the Development of Strategic Emerging Industries". In the plan, the annual production and sales of new energy vehicles will exceed 2 million by 2020, with a cumulative production and sales of more than 5 million vehicles.

In the third stage, the state has made a series of adjustments to the subsidy policy. For electric cars, in the "post-subsidy" policy period, besides the collective decline of subsidy range, the subsidy amount for different endurance miles has been adjusted differently. In 2016, the subsidy amount for high endurance miles has increased compared with 2015, while the subsidy amount for low endurance miles has been further reduced. The policy's encouragement attitude towards high endurance mileage and high energy density are further clarified.

1.1.3 Classification of Electric cars

The most important difference between new energy vehicles and fuel vehicles is that fuel vehicles use gasoline, diesel and other pollutants. New energy vehicles mainly use non-fuel power devices and use clean energy. In the process of energy conversion into power, it reduces the emission of carbon dioxide and other polluted air, at the same time it plays a certain role in protecting the ecological environment. Generally speaking, new energy vehicles use new technologies to provide power and new structures to improve performance. Therefore, the efficiency of new energy vehicles is higher than that of fuel vehicles.

At present, new energy vehicles include pure electric vehicles, plug-in hybrid electric vehicles, and programmed electric vehicles. Plug-in electric vehicles are mostly used in the production of a bus, because they have stronger power and longer endurance than pure electric vehicles. Pure electric vehicles are mostly used for smaller cars.

The pure electric vehicles, as the name implies, they mean to get rid of the "fuel consumption" of traditional fuel-fired vehicles. Electric power acts like the whole power source, which is different from the engine of fuel-fired vehicles. Pure electric vehicles use electric motors to operate, and the whole body is powered by electricity, which is different from the short-term "refueling" of fuel-fired vehicles as a supplement. In the way of energy, pure electric vehicles must be charged externally, and from the point of view of the existing pure electric vehicles on the market, the charging efficiency cannot meet the efficient needs of consumers. At the same time, because the travel of pure electric vehicles is all dependent on batteries, the anxiety of the range has always existed. The average energy of pure electric vehicle batteries meets the requirements of the Interim Measures for the Management of Financial Subsidy Funds for Private Purchase of New Energy Vehicles, which is not less than 15 kW. H. At the same time, it also meets the requirements of obtaining a financial subsidy of up to 60,000 yuan.

From the literal meaning of plug-in hybrid electric vehicle, its existence is not equivalent to the pure electric power supply. The supply and output of hybrid electric vehicle are also defined on the basis of fuel vehicles. Therefore, the most fundamental benchmark object of a plug-in hybrid electric vehicle is a hybrid vehicle, but compared with other vehicles, the plug-in external interface has become its representative.

Similarly, because it is driven by the coexistence of battery packs and fuel categories, it has the advantages of both electric and fuel vehicles in body performance. It has the unique quiet and comfortable driving of electric vehicles, as well as the feel of driving of fuel vehicles. However, because of this, the pricing of the plug-in hybrid vehicles is generally much more expensive than that of fuel vehicles. The average electric range of the plug-in hybrid electric vehicle is 52.4 km. In pure electric mode, the maximum average speed of plug-in hybrid electric vehicle is 136 km/h. But China's new energy policy has always maintained reservations about hybrid vehicles, even plug-in hybrid vehicles. The recent draft of "New Energy Policy Consultation" is to exclude plug-in hybrid vehicles. From this point of view, it seems not a wise thing to design a plug-in hybrid vehicle for the Chinese market.

Extended Range Electric Vehicle (EV) is a new member in the classification of new energy vehicles. It is a small branch of Plug-in Hybrid Electric Vehicle. It has the same body structure as a Plug-in Hybrid Vehicle. The difference is that the addition of Extended Range Mode makes the function of the engines of these vehicles change qualitatively, not driving Under the condition that battery consumption is going to be exhausted, but there is no existing condition to supplement battery energy, automotive engines start to run with the existence of electric power supplement, and then supplement the existing energy supply of automobiles. Therefore, extended-range electric vehicles have made a stronger breakthrough in the range, and extended-range electric vehicles are the new trend of development and research of many new energy electric vehicle manufacturers. The battery energy and motor parameters of the EPV are located at. Between plug-in hybrid electric vehicle and pure electric vehicle, it can be considered that the extended range electric vehicle is a form of transition from a plug-in hybrid electric vehicle to a pure electric vehicle.

Generally speaking, the biggest difference among pure electric vehicle, plug-in hybrid and extended-range electric vehicle is the power source, which is different from pure battery supply of the pure electric vehicle. Both plug-in hybrid and extended-range electric vehicle have automotive generators and can support the fuel category. At present, the plug-in hybrid and extended-range electric vehicle can partly solve the mileage of the pure electric vehicle. So, the current market advantage is more significant, but after the end of the future fuel era, pure electric vehicles will become the largest positioning standard in the automotive market.

1.1.4 Challenges facing the electric vehicle

In September 2016, UBS released a report on consumer acceptance of electric vehicles. The report selected 10,000 consumers in the world's six major auto markets as the survey targets and finally found that consumers are mainly for pure electric vehicles. Concerns focus on high selling prices, limited cruising range, insufficient number of charging stations, and short battery life. Among them, the high price is the primary reason why most people are not willing to buy electric cars.

A survey conducted by Goldman Sachs in 2016 also found that 50% of consumers believe that the high price is the main factor affecting the purchase of electric vehicles, followed by limited cruising range and insufficient charging.

Electric vehicles appear as substitutes for fuel vehicles. Similar to the situation when fuel vehicles began to spread rapidly, the rapid decline in cost through technological advancement and efficiency improvement has become the primary factor affecting the popularity of electric vehicles. Regardless of whether it is an electric car or a fuel car, it is composed of components such as a power system, a vehicle body, a chassis, an automotive electronic system, and interior and exterior trim, but the cost ratio of each part is not the same. For pure electric vehicles, the battery and powertrain systems account for up to 50% of the total cost, while for fuel vehicles, the engine and powertrain systems account for only 15% of the total cost. This part of the cost structure difference is the main reason why the current cost of electric vehicles is higher than that of fuel vehicles.

The difference between a fuel car and an electric vehicle power-train system is that the fuel car's powertrain system consists of the engine assembly, the gearbox assembly and the fuel tank. The power-train system of the electric vehicle is powered by the battery pack. The motor and the electric control system are composed, wherein the power battery pack replaces the fuel tank, the drive motor replaces the engine, and the electric control system replaces the gearbox assembly.

For a fuel car like the Volkswagen Golf, the internal combustion engine (ICE) costs about $2,000, the gearbox assembly costs about $1,500, the fuel tank costs $600, the other parts cost about $900, and the overall powertrain system costs $5,000. about. That is to say, the performance of the two powertrains and electric vehicles of similar performance, the current powertrain system cost difference is about 10,000 US dollars.

How to reduce costs and reduce the difference of 10,000 US dollars through technological advancement, scale effect and other means is the primary problem that needs to be solved before the industry.

In the case of the same external conditions such as vehicle weight and temperature, the cruising range of the electric vehicle is mainly determined by the battery capacity. The larger the battery capacity, the higher the cruising range. Under normal circumstances, the mileage of one-degree electricity is 6-7 kilometers. Therefore, the electric vehicle must achieve a higher cruising range. On the one hand, it can increase the battery capacity of the bicycle. On the other hand, the volume and weight of the battery that can be carried by bicycle are always limited, by increasing the battery volume per unit or weight. The amount of energy that can be carried (i.e. energy density) can also increase overall battery capacity. The core of the former is the cost issue, and the core of the latter is the technical and material issues.

From the perspective of the electric vehicles launched by the current mainstream car companies in foreign countries, although there is still a certain gap between the cruising range and the fuel vehicles, the battery capacity and cruising range are significantly higher than the domestic competitors, generally reaching the battery capacity of 30KWh or more and 300km. The above cruising ranges. In particular, Tesla, its Model S and Model X 100D versions have been extended to more than 500km, which can basically meet the inter-city traffic demand; the model 3 normal version of the production volume is close to 350km, the high-end version of the cruising range Then it reaches 500km.

At present, the main factors restricting the construction of charging facilities include long power access period and high cost, difficulty in installing nuclear reduction meters, tight urban land supply at the present stage, and difficulty in site selection, while private construction has property matching and reporting. The filing process has complex cycle times and tight parking spaces. In terms of charging operation services, there are payment interconnection and new and old standard switching problems, charging safety issues, fuel vehicle occupancy, unreasonable charging facility layout, user difficulty in finding piles, low facility utilization, and charging operations. It is difficult for enterprises to make profits and other issues.

1.1.5 The development of electric vehicles in the future

In 2018, Dyson, a British company known for its high-end hair rollers and vacuum cleaners, announced that it will build an electric car factory in Singapore, hoping to emerge in the fast-growing Asian automotive industry. The company will invest $2.6 billion in the future, including testing and research and development costs in the UK. Dyson is already manufacturing important components for electric vehicles, such as high-speed motors and batteries, and the Singapore team has already built 50 million high-speed digital motors. In the same year, Dyson re-invested £116 million for the construction of a 16-kilometer electric vehicle test track (reconstructed from a former Royal Air Force airport in the south of England), which included a flat maneuver test area. It also includes off-road tracks, high-speed tracks, simulated real-world environments, and coverage of all types of terrain to assess vehicle steering, braking and driving under normal handling.

Automobiles have greatly promoted the progress of human society, but they also brought a series of negative effects, such as serious environmental pollution and oil supply crisis. Saving energy and developing alternative energy sources are considered to be effective ways to alleviate environmental pollution and ensure energy supply. Developing alternative fuel and electric vehicle is one of the important means to solve environmental problems.

Due to the global energy shortage and the environment pollution problem to become more serious every day, many automobile manufacturers have been investing in electric vehicles. At the meatime many governments offer incentives to encourage the development of the new energy vehicles. The electric vehicle is the best solution for the new energy vehicles at present. However, the most important thing for the customers is getting a car with better performance through the same money. According to the technical development of the battery and motor, and the maturity of power generation technology. The electric vehicle would be a good solution. The challenge is that we need to build an electric vehicle which has a better performance than the traditional vehicle that supports by the fluid fuel.

1.2 Project Request

Reviewing the history of electric vehicles, we can find that environmental factors, policy factors, technical factors, and market factors are intertwined in the development process of the industry. The development of the industry is the result of the joint efforts of various factors. Electric cars have a long history, no matter the development or the decline is based on the economy. In recent years, due to the global energy shortage and environmental deterioration, electric vehicles have begun to flourish again. Countries around the world have also launched corresponding policies to support the promotion and development of electric vehicles.

In this project, the designed electric car is for the Chinese market. Considering the policy of the Chinese government on electric vehicles, the pure electric vehicles are the best choice, because it not only makes the purchaser get the best economic subsidy but also meets the requirements of the Chinese government for the development of electric vehicles. In addition, the lack of high-performance vehicles in the electric vehicle market and the increasing demands of consumers on the performance of electric vehicles. This project is to design a high-performance and high-endurance electric vehicle for the Chinese electric vehicle market.

From the view of the vehicle performance, in this project, our purpose is to design the high-performing electric vehicle with a battery pack of 106kW, which is built based on thousands of the 18650-battery cells. The vehicle should be 5.10 meters long and weighs 2100kg. The maximum power of about 700kW and at least the vehicle can autonomy at least 600km. The accelerate time for the electric car from 0 km/h to 100km/h in less than three seconds. And the maximum speed for the car can reach to 270km/h.

That is to say, this project is to design the powertrain. The powertrain can be divided into two parts: transmission system and battery system. The transmission system includes the motor, inverter and gearbox. The aim is to select the fit electric motor, inverter and gearbox to satisfy the performance of the designed electric car. The battery system is to define the battery cell that can be built the battery pack which as the only power source of the electric car and determines the distance of the electric car.

1.3 The structure of this thesis

In chapter 1, we reviewed the history of the electric cars' development, it is not a new product in recent years. The reason for initially restricted the development of electric cars is the high price and fewer endurance problems of electric cars didn't be solved. In recent years, with global energy consumption and environmental deterioration, the development of electric vehicles has been put on the agenda of various countries. New energy vehicles include pure electric vehicles, plug-in hybrid electric vehicles, and programmed electric vehicles. Considering the present market, the technologies of battery and the electric motor, the government policy, the electric vehicle will become the largest standard in the automotive market. At the same time, it also introduced the process of promoting the development of electric vehicles. At present, the development of electric vehicles is facing the challenges are limited cruising range, battery storage capacity and short battery life.

Chapter 2, before designing the electric vehicle, we must clarify several key technologies in the electric vehicle. Firstly, we should clear the motor and battery performance requirements. Then analysis several types of electric motors and batteries that commonly used in the electric vehicles. Finally, we choose the AC motor and hub motor in the motor control part. About the battery, the lithium battery is the best choice for the power source.

In chapter 3, before we can decide the specific motor, some calculation for the parameters of electric motor and battery is necessary. According to the working principle of an electric vehicle, the total transmission ratio can be determined. Then the speed and torque of the motor are determined under the condition of satisfying the maximum driving speed and acceleration of the vehicle. In the battery pack part, the capacity of the battery pack can be determined by the maximum driving distance of the electric vehicle, so that the number and combination of the battery cells can be determined.

Chapter 4, as the automobile will eventually be put into actual production, and the parameters of electric motor and battery are determined. We analyzed several brands of the electric motor, and depends on the selection of the electric motor, the inverter and gearbox can be declared. About the battery pack, we also analyzed the specific performance and price of several battery cells that satisfy the requirements on the market, and finally determined the battery cells that can be built as the battery pack. End of here the theoretical tasks are over.

In Chapter 5 we make a model of the powertrain simulate the selected motor, battery, gearbox and inverter. For the purpose of verifying our chooses can satisfy the performances of the vehicle requests. The model is built in Simulink, then running it in different conditions. Finally, all the required performances are satisfied.

Chapter 2

2 Technologies of electric vehicle

2.1 Electric vehicle motor

2.1.1 Motor performance requirements

In order to meets the requirements of an electric vehicle, like acceleration time, maximum speed and endurance distance. The electric motors should have a large starting torque, a high rotating speed, good starting performance and acceleration performance.

For the high-speed electric vehicle, the wide constant power range is necessary for the electric motor. The electric motor also needs a wide range of speed control capability, when the vehicle at a low speed the electric motor has a large torque, at high speed the motor has high power. The electric motor should also maintain good operating efficiency over a wide range of speeds/ torques.

In order to have a good acceleration effect and a long endurance distance for the electric vehicles, we should try to reduce the weight of each part of the car. In electric motor part, a lighter weight motor is a better choice.

2.1.2 Motor types

Electric vehicles use electric motors to convert electrical energy into mechanical energy to drive. Electric vehicle motors are one of the main components of electric vehicle drive systems. The electric motor has many types, wide applications, and large power coverage. The road conditions of the vehicle are complicated, and the characteristics of the electric motor must be adapted to the requirements of various complicated working conditions. following we analyze different types of motors.

As the core components of electric vehicles, electric motor motors mainly include DC motors, AC three-phase induction motors, permanent magnet brushless DC motors, and switched reluctance motors.

1) DC motor

In the early days of electric vehicle development, most electric vehicles used DC motors as drive motors. This type of motor technology is relatively mature, with easy control and excellent speed regulation. It has been the most widely used in the field of speed regulating motors. However, due to the complicated mechanical structure of the DC motor, its instantaneous overload capability and further improvement of the motor speed are limited, and in the case of long-term operation, the mechanical structure of the motor will be lost, and the maintenance cost will be increased. In addition, the spark generated by the brush during the operation of the motor causes the rotor to heat up, which may cause high-frequency electromagnetic interference and affect the performance of other electrical appliances of the vehicle. Due to the above shortcomings of DC motors, current electric vehicles have basically eliminated DC motors.

2) Synchronous motor with permanent magnets

In the field of new energy vehicles, permanent magnet synchronous motors are widely used. By controlling the input current frequency of the stator winding of the motor, the vehicle speed of the electric vehicle will eventually be controlled. Compared with other types of motors, the biggest advantage of permanent magnet synchronous motors is that they have higher power density and torque density. To put it bluntly, compared with other types of motors, permanent magnet synchronous motors are of the same mass and volume. It can provide maximum power output and acceleration for new energy vehicles. This is also the reason why the permanent magnet synchronous motor is the first choice for the majority of auto manufacturers in the new energy auto industry, which has extremely high requirements on space and self-weight. However, permanent magnet synchronous motors also have their own drawbacks. The permanent magnet material on the rotor will have magnetic decay under high temperature, vibration and overcurrent conditions, so the motor is prone to damage under relatively complicated working conditions. Moreover, the price of permanent magnet materials is relatively high, so the entire motor and its control system are costly.

3) Asynchronous motor without permanent magnets

Asynchronous motor is a kind of motor widely used in industry. Its characteristic is that the rotor is made of silicon steel sheet, and the two ends are covered with aluminum cover. The mechanical parts with no contact between the rotors are simple. The operation is reliable and durable, and the maintenance is convenient. AC asynchronous motors are more efficient than DC motors of the same power, and the quality is about one-half lighter. If the vector control method is adopted, the controllability and the wider speed range comparable to those of the DC motor can be obtained. Because of its high efficiency, high specific power and high-speed operation, AC asynchronous machine is the most widely used motor in high-power electric vehicles.

However, in the case of high-speed operation, the rotor of the motor generates severe heat, and the motor must be cooled during operation. At the same time, the drive of the asynchronous motor is complicated, the cost of the motor body is also high, and the inverter needs to provide additional no-operation during operation. The power is used to establish the magnetic field. Therefore, compared with the permanent magnet motor and the switched reluctance motor, the efficiency and power density of the asynchronous motor are low, which is not the most efficient choice for energy efficiency.

4) AC three-phase induction motor

AC three-phase induction motors are the most widely used motors. The stator and the rotor are made of silicon steel sheets and the sliding rings, commutators and the like are not in contact with each other. Simple structure, reliable operation and durability. The AC induction motor has a wide power coverage and a speed of 12,000 to 15000 r/min. Air cooling or liquid cooling can be used, and the degree of freedom of cooling is high. Adaptable to the environment and able to achieve regenerative feedback braking. Compared with the DC motor of the same power, the efficiency is higher, the quality is reduced by about half, the price is low, and the maintenance is convenient.

Among all kinds of AC motor drive systems, asynchronous motors, especially squirrel cage asynchronous motors, are the most mature and widely used. Figure 1 is a schematic diagram of squirrel cage induction motor drive system. Compared with DC motor, it has a series of advantages, such as high efficiency, wide speed range, basic maintenance-free, small volume and mass, long life, easy cooling, etc.

Although asynchronous motor has many advantages, one of the key technologies of asynchronous motor application, the inverter technology has restricted the application of asynchronous motor in electric vehicles, and the inverter technology depends on the maturity of high-power power switching device technology. By the 1960s, the development of transistor technology and the emergence of thyristor had basically solved the technical obstacles of high-power power electronic switching devices. An electronic switch composed of a group of thyristor devices under the control of microprocessors makes DC inversion easy to solve the problem of AC.

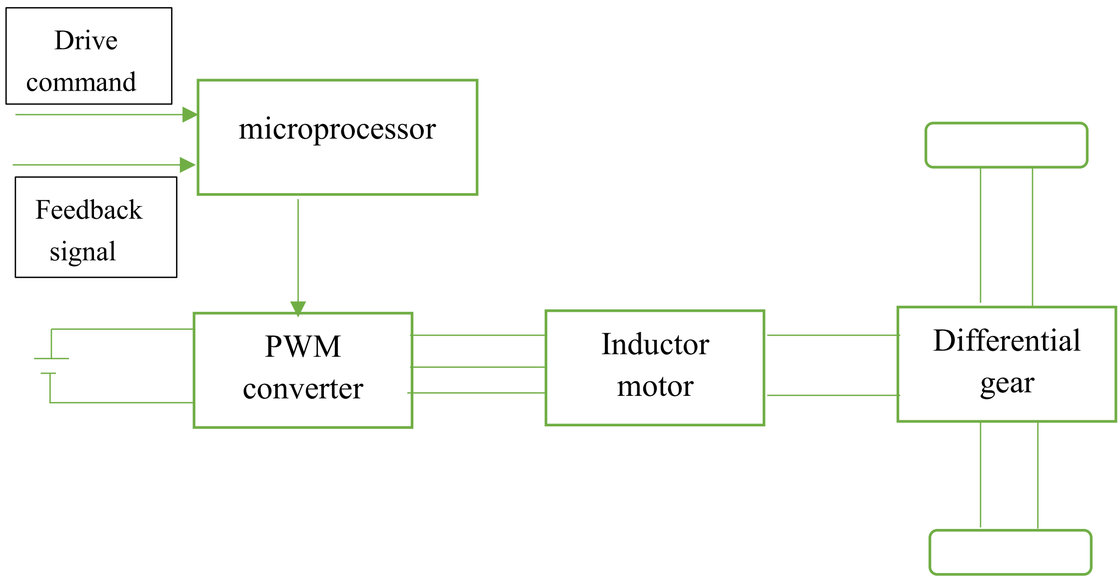


Figure 1 squirrel cage induction motor driving system

Because of the wide speed range of AC motors and the ability to achieve low-speed constant torque and high-speed constant power operation, this torque characteristic is very close to the trend of the torque characteristic curve required by the actual driving of automobiles, so there is no need for multi-speed change, only a constant-speed ratio reducer can be used. There are no clutches or gears, so the motor with fixed speed ratio is fixed together with the reducer. Electric vehicle with AC motor drive system is a new technology developed in 1990's. Although it is still in the stage of development and improvement, and the cost of trial production is relatively high, the system has shown strong vitality. Compared with DC motor system, it has the following advantages.

- The batch production price of AC drive system will be the same as that of DC system.
- The reliability of AC motor is about six times that of DC motor.
- The reliability of the whole AC drive system is about twice that of the DC system.
- The maintenance cost of DC chopper speed regulating system is about 2.5 times of AC system.
- The AC drive system saves 5%-7% of the power compared with the DC chopper speed regulation system, while it saves 25%-30% of the power compared with the DC resistance voltage and speed regulating system.

2.1.3 Hub motor

In this design we use a hub motor, which means that we have four motors that control four wheels. Wheel hub motor technology, also known as wheel-mounted motor technology, is characterized by the integration of power, transmission and braking devices into the hub, thus greatly simplifying the mechanical part of the electric vehicle.

Advantage 1: Eliminate a large number of transmission components, making the vehicle structure simpler

For conventional vehicles, clutches, transmissions, drive shafts, differentials and even transfer cases are essential, and these components are not only lightweight, but also make the structure of the vehicle more complex, and also require regular maintenance and the problem of failure rate. But the hub motor solves this problem very well. In addition to the simpler structure, vehicles driven by hub motors can achieve better space utilization and higher transmission efficiency.

Advantage 2: A variety of complex driving methods can be realized

Because the hub motor has the characteristics of a single wheel independent drive, it can be easily implemented in either the front, rear or four-wheel drive versions. Full-time four-wheel drive is very easy to implement on a wheel-motor-driven vehicle. At the same time, the hub motor can realize the differential steering of the similar tracked vehicle through different speeds of the left and right wheels or even reverse, greatly reducing the turning radius of the vehicle, and in almost special circumstances can realize the in-situ steering (but at this time, the steering mechanism of the vehicle and Tire wear is large) and is valuable for special vehicles.

Advantage 3: Easy to adopt multiple new energy vehicle technologies

Many new energy vehicles are powered by electric drives, so the hub motor drive has also come in handy. Whether it is a pure electric or fuel cell electric vehicle, or an extended-range electric vehicle, the hub motor can be used as the main driving force; even for the hybrid model, the hub motor can be used as a boost for starting or accelerating. A multi-purpose machines. At the same time, many technologies for new energy vehicles, such as brake energy recovery (i.e., regenerative braking), can also be easily implemented on in-wheel motor-driven models.

2.1.4 control technology of electric motor

There are many control modes for electric vehicle motors. Traditional linear control, for example PID, cannot meet the rigorous requirements of high-performance motor drive. Traditional variable velocity variable frequency (VVVF) control technology cannot make the motor meet the required driving performance. Asynchronous motor mostly adopts field-oriented control (FOC), which is a better control method. The principle of field-oriented control system of inductor motor is shown in Figure 2.In recent years, many advanced control strategies have been developed. It includes self-adaptive control, variable structure control, fuzzy control and neural network control, which are suitable for motor drive.

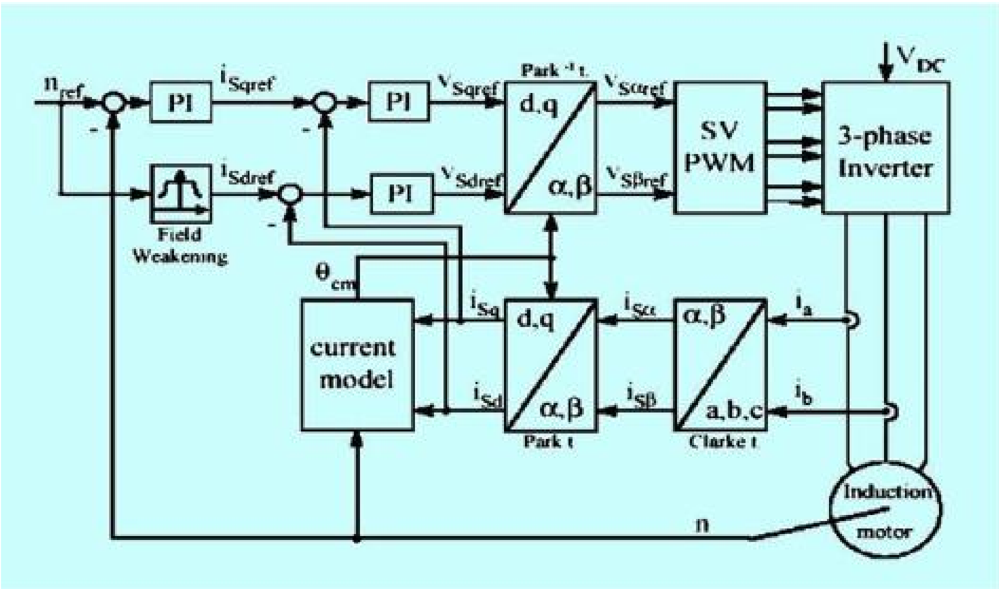


Figure 2 Field Oriented Vector Control System for inductor Motor

Self-adaptive control includes sensitivity time control (STC), model reference adaptive control (MRAC). Using STC, the parameters of the controller can be adjusted automatically according to the changes of system parameters. The key is to use a recognition module to track the changes of system parameters and update the parameters of the controller through the self-adjusting module of the controller. The ideal closed-loop control performance is obtained. Using MRAC, the response of the output model tracks the response of the reference model. Based on the adaptive algorithm which utilizes the difference between the reference model and the output of the system, the parameters of the controller are constantly adjusted to obtain the ideal closed-loop control performance. Nowadays, both MRAC and STC are used in non-commutation motor drive system of electric vehicles.

Variable structure control (VSC) has been applied to motor drive to compete with adaptive control. Using VSC, the system provides insensitive parameter characteristics, specifies error dynamics and simplifies the operation. According to the switch control theory, the system must operate in the corresponding plane according to the predetermined orbit, regardless of how the system parameters change.

Fuzzy control and neural network are also introduced into the field of motor control. Fuzzy control is a linguistic process, which is based on previous experience and tentative rules used by human beings. Neural network controllers (NNC) may explain the dynamic behavior of the system, then self-study and self-adjust. This control strategy can combine other control strategies to form new control modes, such as adaptive fuzzy control, fuzzy NNC and fuzzy VSC. In the near future, the controllers using artificial intelligence (AI) will be able to diagnose and correct errors systematically without human intervention.

The use of various high-power electronic devices, such as the use of MOSFET, IGBT, COMFET, MCT and STT, and the application of hardware such as microprocessor DSP, provides an important guarantee for the motor control method and intelligent control of electric vehicles.

2.2 Technologies of battery

2.2.1 Battery requirements performances

As the power source of electric vehicles, battery has always been regarded as an important iconic technology for the development of electric vehicles. It is also an important bottleneck restricting the development of electric vehicles. Its performance is directly related to the length of the vehicle's cruising range. After a generation of technology changes in lead-acid batteries, nickel-cadmium batteries and nickel-hydrogen batteries, today's mainstream electric vehicles (including plug-in hybrid models) have mostly switched to the embrace of lithium batteries. The reason is the lithium batteries have better energy-to-weight ratio (the amount of energy that can be stored per unit weight of battery), better high temperature and low temperature charge and discharge performance, and longer life are all important factors in the mainstream of lithium batteries. Sorted by energy efficiency, the current types of lithium batteries used in mainstream electric vehicles are lithium cobalt oxide (Tesla), lithium manganate (Prius, Lee) and lithium iron phosphate batteries.

The main performance indicators of electric vehicle power battery are specific energy, specific power and service life. The requirements of modern electric vehicle for vehicle batteries are as follows.

- High energy density (W · h/kg) and power density (W/kg)
- Long cycle life
- Convenient and rapid charging
- Low manufacturing cost
- Low internal resistance and self-discharge rate
- Non-polluting the environment
- It can work in a wide ambient temperature range.
- Less or no maintenance
- Use safety
- To meet the requirements of mass production.

2.2.2 Battery types

1) Lead-acid batteries

Lead-acid battery is a kind of electrochemical energy storage battery, which is a relatively mature electric vehicle power battery[9]. The energy is stored by the chemical reaction of two electrodes. The positive electrode uses lead dioxide, the negative electrode uses spongy lead, the electrolyte uses dilute sulfuric acid solution, and the basic voltage of a single cell is 2V. Lead-acid batteries have the advantages of good safety and low cost, but they are of high quality, small capacity and contain heavy metal lead, which easily pollute the environment. In order not to be replaced by other batteries, lead-acid batteries are developing towards colloidal batteries, that is, adding gelling agent to sulfuric acid to make sulfuric acid electrolyte from liquid to colloidal[9], which is more convenient and safer to use. Nowadays, sealed lead-acid colloidal batteries are the most widely used batteries in the field of electric vehicles.

2) Nickel metal batteries

The nickel-metal batteries used in electric vehicles are nickel-cadmium batteries and nickel-hydrogen batteries. Both batteries are alkaline batteries for energy storage. The single cell voltage is 1.2V, and the positive electrodes of the batteries are nickel hydroxide. The negative electrode of nickel-cadmium battery is cadmium metal, and the electrolyte is sodium hydroxide solution. The single cell has the characteristics of low voltage, high specific energy, light weight and long life, and can discharge deeply [10]. However, cadmium is toxic and easy to cause environmental pollution, so developed countries have banned the use of such batteries.

Compared with nickel-cadmium batteries, nickel-hydrogen batteries have no environmental pollution, lighter weight and longer battery life. They can store 30% more power than nickel-cadmium batteries, can withstand overcharge and discharge to a certain extent, and can also charge quickly. However, the cost of Ni-MH batteries is relatively high, and the inconsistency between batteries is difficult to control, which limits the use of Ni-MH batteries.

3) Lithium-ion batteries

Lithium-ion battery is also a kind of energy storage battery. It has many advantages, such as high energy density, low self-discharge, high average output voltage, no memory effect, long service life, wide working temperature range, green environmental protection, etc. The voltage of single battery is more than 3V, so it has been applied in many aspects and is widely used in electric vehicles. With the same quality battery packs, electric vehicles can carry more lithium-ion batteries, enabling them to have higher capacity and travel longer miles. However, lithium-ion batteries also have some defects, such as high production cost, poor stability of materials, and need to be managed reasonably in order to prevent dangerous accidents.

Through the above analysis and comparison, it can be seen that the performance of lithium-ion battery is the best and most in line with the power requirements of electric vehicles. However, there are many kinds of lithium-ion batteries, the most representative of which is the latest research and development of lithium iron phosphate, which has excellent performance, good safety, low cost and suitable price. It is the most ideal power battery at present. The battery management system in this paper is also designed for lithium iron phosphate batteries.

2.2.3 Battery management system

Battery is the power device of electric vehicle. Battery management system is the important link between battery pack, vehicle controller and charger[11]. Its importance is self-evident. Battery management system is the core technology of electric vehicle, and it is also the most concerned part of many electric vehicle enterprises, which belongs to the power battery system. In general, the battery management system is responsible for monitoring and managing the power battery pack, improving its efficiency, prolonging its service life, preventing the phenomenon of overcharge and over discharge of batteries, improving the reliability of the battery pack, so as to achieve the purpose of reducing operating costs and providing security for the users of electric vehicles.

The development and design of battery management system are considered from two aspects of safety and function, that is, to ensure the safe operation of electric vehicles and to make the performance of electric vehicles more superior. Therefore, the battery management system should have the following basic functions:

1) Battery state data acquisition

Data acquisition of battery status is the basis of battery management system to implement control strategy, and also the basis of battery SOC estimation. The collected data generally include the voltage of the single battery, the temperature of the battery box and the overall voltage and current of the battery set[12]. Through the collection of these data information, the working state of the battery can be known.

2) Estimation of state of charge (SOC) of batteries

Accurate estimation of battery SOC is an indispensable function of battery management system, which is to grasp the residual power of electric batteries in real time so that drivers can make reasonable arrangements. In addition, battery SOC is also an important parameter to achieve other functions. The estimation of battery SOC should be based on the total voltage and current as input and combined with the corresponding algorithm.

3) Battery Safety Protection

Battery safety protection is undoubtedly the primary and most important function of BMS for electric vehicles. Battery safety protection usually includes over-current protection, over-charge and over-discharge protection and over-temperature protection. In the process of battery charging and discharging, if the working current exceeds the safety value, corresponding safety protection measures should be taken to prevent excessive current and limit electricity. Overcharging and over discharging of batteries to prevent irreversible damage to batteries[13]. In addition, because of the chemical products in the battery, the charging and discharging process will generate a lot of heat. When the temperature is too high, measures should be taken to limit the temperature too high.

4) Battery Balance Management

Electric vehicle battery packs are generally composed of hundreds of single batteries. Because of the different manufacturing and using conditions, the characteristics of each single battery are different. These differences will seriously affect the use of battery packs, which will greatly reduce the capacity and life of battery packs. Therefore, the battery management system should balance the management of the battery pack, minimize the harm caused by the inconsistency of the battery pack, and give full play to the performance of the battery pack.

5) Battery Information Management

Battery information management includes battery information display, internal and external information exchange and historical information storage[14]. In order to facilitate the driver to understand the operation status of the vehicle, the battery management system displays the status of the battery pack in time through ECU. In addition to the internal information exchange, battery management system also needs to communicate with other systems of electric vehicles through CAN bus. Historical information storage is not an essential function. Advanced battery management system often considers this function to facilitate the analysis of battery operation status in order to be able to timely troubleshoot.

Chapter 3

3 Parameters of vehicle design

3.1 Structure and working principle of electric vehicle

3.1.1 Powertrain structure

The transmission system is one of the three core components of the new energy vehicle. The transmission system is the main execution structure of the new energy vehicle. The driving characteristics determine the main performance indicators of the car. It is an important part of the electric car. The entire drive system of an electric vehicle includes two parts, a motor drive system and its mechanical transmission mechanism. The motor drive system is mainly composed of a motor, a power converter, a controller, various detection sensors, and a power supply.

The role of the electric vehicle in the inverter is to increase the power. Inverter is the key between the motor and battery pack, in order to transform the DC to AC, which is actually a process of voltage inversion with the converter, while the motor supply the energy to the vehicle. When we through the request of the vehicle then calculate them and define both the right motor and the battery pack, final the inverter is defined.

Like traditional cars, electric vehicles are also composed of power devices, chassis, body and electrical equipment. Among them, the body and electrical equipment of electric vehicle are basically the same as that of traditional vehicle. The transmission system in chassis is simpler than that of internal combustion engine vehicle. The differences mainly concentrate on the power device and the multi-energy power assembly control system, auxiliary energy system and auxiliary control system required by different power sources, it shows in Figure 3.

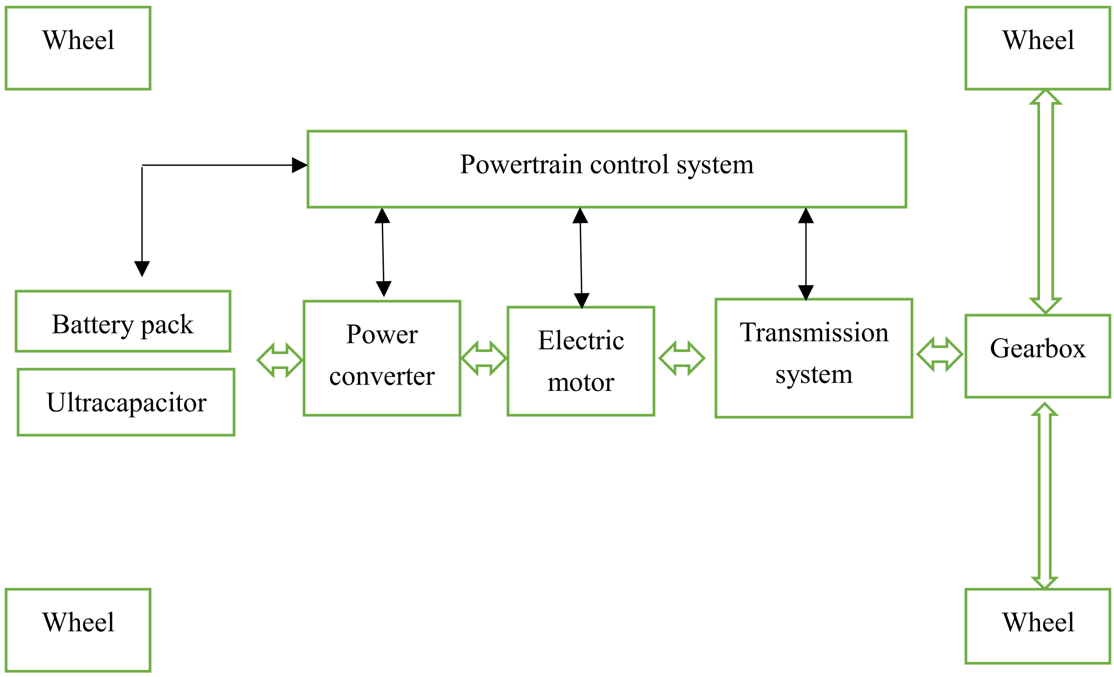


Figure 3 electric vehicle powertrain structure

The power device of electric vehicle consists of power battery and energy management system, motor drive motor and its control system.

Power battery and energy management system, also known as the main energy system, is equivalent to the fuel system of internal combustion engine vehicles. The function of power battery is to provide the energy needed for automobile operation. Energy management system is used to monitor, coordinate and regenerate energy. The early energy management system was simple, mainly a watt-hour meter. By simple conversion, it could roughly show the remaining battery power or the mileage of the car. Current energy management system is composed of current, voltage and temperature of sensor group, computer signal acquisition, processing and analysis module, multi-functional display and control execution unit. The sensor transmits the information of voltage, current and temperature of each battery to the computer when it works. The computer analyses the battery according to the model of battery charge and discharge and life index, determines the state of the battery, and directly controls the operation of the car through the system controller. Advanced energy management system can prolong battery life by five to ten times. However, the circuit is complex and expensive, and the chemical changes of batteries during charging and discharging are extremely complex. It is very difficult to accurately calculate and predict the residual power and life of batteries. At present, this technology is still in development.

Motor and its control system, the motor is equivalent to the engine of the internal combustion engine vehicle. The motor control system receives the speed and current information from the motor and the signals from the brake pedal and acceleration pedal and transmits the control information to the main control system. The information from the battery is also sent to the main control system, which further controls the driving motor to send out the required torque.

3.1.2 Working principle

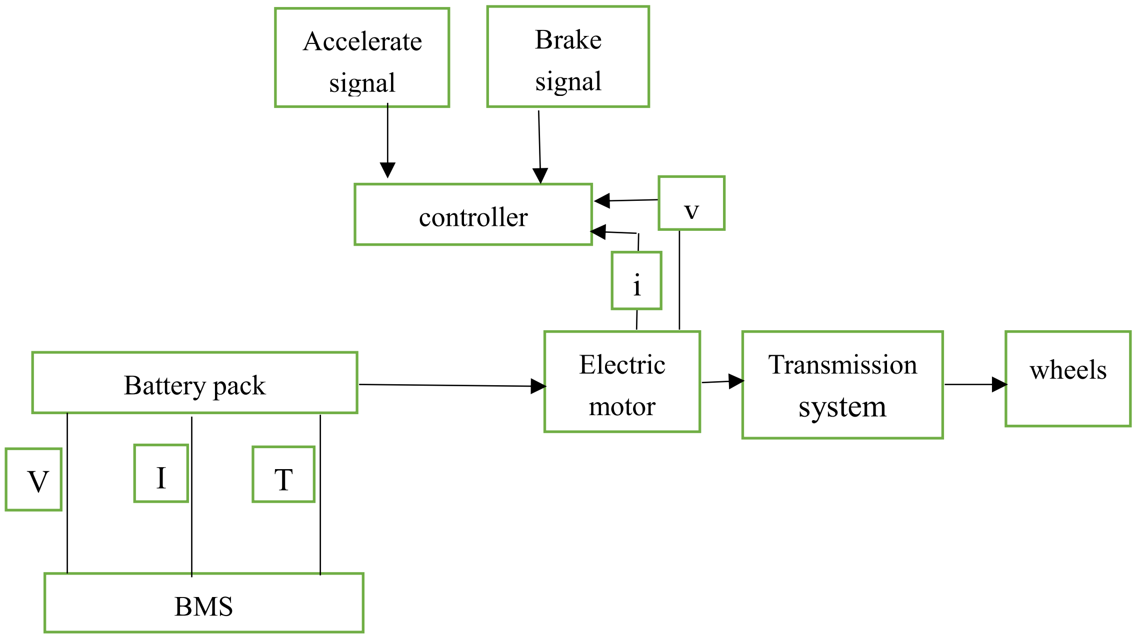


Figure 4 working principle of electric vehicle

In Figure 4, v-velocity feedback, i-current control, V-voltage, I-current, T-temperature.

The basic working principle of electric vehicles is shown in Figure 2. Batteries supply power to the motor through the control system. In the motor, electrical energy is converted into mechanical energy and transmitted to the transmission system. Finally, it is transmitted to the driving wheel, which makes the driving wheel rotate and generates the traction of the vehicle through the interaction with the ground.

3.2 parameters of electric vehicle

Before the motor parameters calculation, the requirement performance should be clear. All the requirement performance of the vehicle are shows below in the Tab 1. The physical parameters should be clear too that clearly simulate the real vehicle driving status.

Tab 1 Relative parameters of electric vehicle

Parameters of vehicle	Long	5.1	m
	Weight	2100	kg
	Power	700	kw
	Autonomy	600	km
	Tires specification	265/40 R21	mm&inch
	Exterior body width	2120	mm
	Exterior height	1418	mm
Parameters of battery	P_battery	100	KWh
Parameters of dynamics	Acceleration	3	s
	V_max	270	km/h
	Air density（ρ）	1.161	kg/m^3
Parameters of physical	C_x(C_aero)	0.28	
	Front area of vehicle	2.34	m^2
	g	9.81	m/s^2
	v_0	0	km/h
	v_1	100	km/h
	r_d	349	mm
	Rolling coefficient	0.0109	

3.3 Electric motor

3.3.1 parameters of electric motor

The parameters of electric vehicle transmission system, such as motor power and transmission speed ratio, have a significant impact on the power and economy of the vehicle. This paper mainly carries out parameter selection and matching analysis for the transmission system of an electric vehicle. Motor is the heart of electric vehicle. The choice of motor is very important for the design of transmission system of electric vehicle. The driving power of motor is too large. In order to meet the requirements of certain vehicle driving performance, this will inevitably lead to the increase of the capacities of motor and battery and the increase of vehicle cost. In addition, the number of battery cells is too much, it is difficult to arrange on the vehicle, and the weight of the vehicle increases, which limits the driving range of the vehicle. If the number of battery cells is too small, the performance of the vehicle will be affected.

The power performance evaluation index of electric vehicle is the same as that of traditional internal combustion engine vehicle, that is, the maximum vehicle speed, acceleration time and maximum climbing gradient. However, the mechanical characteristics of the motor are quite different from those of the conventional internal combustion engine, that is, the maximum power of the motor can be twice or even higher than the rated power, and the maximum power condition cannot run for a long time, so the maximum climbing degree and the maximum speed of the electric vehicle must be calculated by the rated condition of the motor.

It is very important to choose the rated power of the motor correctly. If the selection is too small, the motor often runs under overload. On the contrary, if the selection is too large, the motor often operates under-load, and the efficiency and power factor are reduced. It not only wastes electric energy, but also needs to increase the capacity of power battery and reduce the overall economic benefit.

Usually, the power of the motor should be selected initially from ensuring the expected maximum speed of the vehicle. Although the maximum speed is only an indicator of vehicle power, it essentially reflects the acceleration and climbing ability of the vehicle.

When an electric vehicle accelerates on the road, the resistances involved include rolling resistance F_{rot}, air resistance F_{aer}, slope resistance F_{pend} and acceleration resistance F_{din}. The total driving force of the electric vehicle F_v is equal to the sum of those resistances. The driving equation of the electric vehicle is:

$$F_v = F_{rot} + F_{aer} + F_{pend} + F_{din} \tag{1}$$

1) rolling coefficient

The rolling coefficient depends on vehicle travel speed, tire pressure, structure, tire material, load on the wheel, wheel size, tread contact area, operating temperature, type of road and its conditions, forces exerted in the direction of motion and in the lateral direction, Tire wear.

Constant rolling coefficient on the flat road,

$$F_{rot} = M_v \cdot g \cdot k_r \tag{2}$$

$$P_{rot} = M_v \cdot g \cdot k_r \cdot v \tag{3}$$

$$T_{rot} = M_v \cdot g \cdot k_r \cdot r_d \tag{4}$$

Rolling coefficient with correction as a function of speed:

$$F_{rot} = M_v \cdot g \cdot (f_0 + f_2 \cdot v^2) \tag{5}$$

$$P_{rot} = M_v \cdot g \cdot (f_0 + f_2 \cdot v^2) \cdot v \tag{6}$$

$$T_{rot} = M_v \cdot g \cdot (f_0 + f_2 \cdot v^2) \cdot r_d \tag{7}$$

Where, P_{rot} is rolling power [W], T_{rot} is rolling couple [Nm], F_{rot} is rolling force on the ground [N], M_v is vehicle mass [kg], v is vehicle speed $[m/s]$, r_d rolling radius [m], g gravity acceleration$[m/s^2]$, k_r rolling coefficient, f_0 is component coefficient rolling, f_2 is component coefficient rolling $[(s/m)^2]$.

2) Aerodynamic coefficient

Aerodynamic resistance depends on air density, vehicle characteristics frontal area orthogonal to the direction of motion, aerodynamic coefficient, vehicle speed.

The power consumed by an electric vehicle to travel on a horizontal road at maximum speed is:

$$F_{aer} = \frac{1}{2} \cdot \rho \cdot C_x \cdot A_f \cdot v^2 \qquad 8$$

$$P_{aer} = \frac{1}{2} \cdot \rho \cdot C_x \cdot A_f \cdot v^3 \qquad 9$$

$$T_{aer} = \frac{1}{2} \cdot \rho \cdot C_x \cdot A_f \cdot v^2 \cdot r_d \qquad 10$$

Where P_{aer} is aerodynamic power [W], F_{aer} is aerodynamic force [N], T_{aer} is aerodynamic power[Nm], C_x coefficient aerodynamic, A_f is vehicle front area $[m^2]$, ρ is air density [kg⁄m^3].

In this design, our target vehicle is a sports vehicle, so we ignore the driving situation of the vehicle on the climbing road. The rolling coefficient of the vehicle is only on the flat road which means that the F_{pend} is equal to zero.

When the vehicle driving at low speeds the contribution is essentially linked to rolling. At high speeds (> 80 ÷ 90 km / h) the main contribution is due the aerodynamics. It means that the main resistance of the vehicle in its starting state comes from rolling resistance, the main resistance of the vehicle at high speeds comes from the aerodynamics resistance.

The power consumed by an electric car to accelerate on a horizontal road surface is:

$$M_{at} = M_v \cdot \frac{I_{mot} \cdot {\tau_1}^2}{{r_d}^2} + \frac{I_{trans} \cdot {\tau_2}^2}{{r_d}^2} + \frac{I_{wheel}}{{r_d}^2} \qquad 11$$

Dynamic force:

$$F_{din} = M_{at} \cdot a \qquad 12$$

$$P_{din} = M_{at} \cdot a \cdot v \qquad 13$$

$$T_{din} = M_{at} \cdot a \cdot r_d \quad 14$$

Where, P_{din} is dynamic power earth [W], F_{din} is dynamic force earth [N], T_{din} is dynamic couple earth [Nm], M_{at} is apparent translating mass of the vehicle [kg], a is acceleration [m/s^2], I_{mot} engine inertia[kgm^2], I_{trasm} is transmission inertia [kgm^2], I_{wheel} is inertia wheels [kgm^2], τ_1 is transmission ratio $\frac{\omega_{mot}}{\omega_{wheel}}$, τ_2 is transmission ratio $\frac{\omega_{trans}}{\omega_{wheel}}$.

When the vehicle is driving on the flat road and at the maximum speed 270km/h.

Through formula of 6，7，13，17 the requirement of the total force that the vehicle is easily to defined. When the vehicle in the maximum velocity, the acceleration is equal to zero which means we neglect the dynamic force.

$$F_v = F_{rot} + F_{aer} + F_{pend} + F_{din}$$

$$= M_v \cdot g \cdot k_r + \frac{1}{2} \cdot \rho \cdot C_x \cdot A_f \cdot v^2 + M_{at} \cdot a \quad 15$$

Where we set the rolling coefficient $k_r = 0.0109$ the total force that the vehicle need is F_v $=F_{rot} + F_{aer}$=2508N

The total power of the electric vehicle is equal to the power P_{rot} consumed by the rolling resistance, the power P_{aer} consumed by the air resistance, the sum of the power point P_{din}consumed by the gradient resistance and the power P_{pend} consumed by the acceleration resistance. The power balance equation of an electric vehicle is：

Total power required:

$$P_v = F_v * v = (F_{rot} + F_{aer} + F_{pend} + F_{din}) * v \quad 16$$

At the maximum velocity, the vehicle require power $P_v = 171.92kW$. Total torque required:

$$T_v = F_v * r_d \quad 17$$

When the vehicle driving in maximum velocity, the required torque is $T_v = 875.29Nm$

The time t_a required for the electric car to accelerate from speed zero to speed v_f is:

$$t_a = \int_0^{v_b} \frac{M_{at} v_b}{P_{drive} - \frac{1}{2}\rho C_x A_f v^2 v_b - M_v g v_b k_r} dv +$$

$$\int_0^{v_f} \frac{M_{at}v}{P_{drive}-\frac{1}{2}\rho C_x A_f v^3 - M_v g v k_r} dv \qquad 18$$

There is an approximate formula for the power drive require,

$$P_{drive} = \frac{M_{at}{v_f}^2}{2t_a}(1+\frac{1}{{x_f}^2}) + \frac{1}{5}\rho C_x A_f v^3 + \frac{2}{3}M_v g v_f k_r \qquad 19$$

Where $x_f = v_f/v_b$, v_b is the base speed and v_f is the final speed. We set the constant power range x_f=3

When the vehicle on the flat road and at the maximum accelerate status from the standing still to 100km/h, in 3 second, the power required in the maximum accelerate is:

$$P_{drive} = 312.6 + 3.5 + 3.9 = 320kW$$

Where, P_{drive} is the total output power of the motor gives to the vehicle. The performance evaluation index of electric vehicles is the same as that of traditional fuel vehicles. There are two main evaluation indicators: maximum speedv_{max}, acceleration time t_f. The maximum speed of an electric vehicle is the maximum speed that can be achieved when the vehicle is fully loaded on a good road in a windless condition. The acceleration time refers to the acceleration of the electric vehicle to a certain speed after starting with the strongest power in the windless condition.

3) Hub motor parameter selection

The selection of the hub motor parameters is based on the basic parameters of the electric vehicle, including the windward area A, the total mass m of the vehicle, the maximum speed v_{max}, the acceleration and climbing ability, and the relevant parameters of the wheel hub and the tire. In order to adapt to the actual needs and reflect the rationality of the design

4) Speed determination

The determination of the motor speed is not only related to the driving speed v_a of the electric vehicle, but also related to the outer diameter r_d of the tire. As the designed vehicle is a sport car, we set the average speed on the roads is 100 km / h, the speed of the motor should be selected to work frequently around the rated speed. In this project, the rated speed of the motor is:

$$\mathrm{n}_N = \frac{v_a}{r_d} = 79.59rad/s,$$

and the maximum speed of the motor can be determined according to the maximum speed of the electric vehicle v_{max}=270 km/h, as the maximum speed of the motor

$$n_{max} = \frac{v_{max}}{r_d} = 214.90rad/s.$$

5) Power determination

The maximum power of an electric vehicle should meet the requirements of the car for the highest speed, acceleration and grade, so the maximum power of the electric motor is：

$$P_{max} \geq max\{P_{aer}, P_{rot}, P_{din}\} \quad 20$$

When the electric vehicle is driven on a horizontal road with a maximum speed of $v_{max} = 270\ km/h$, the power consumption is calculated by the formula 14 $P_{aer} = 171.92kW$. The rated power of the electric vehicle is 320 kW, and the power rating of each hub motor is 80 kW. Due to the strong overload capability of the disc permanent magnet synchronous motor, the maximum power of the electric vehicle is 800 kW, and the maximum power of each hub motor is 200 kW.

3.4 Parameters of battery pack design

According to the design requirements, the total battery capacity is 106KWh. The selection of battery pack capacity mainly considers the maximum output power and energy consumption when the vehicle is running, as to ensure the requirements of power performance and driving mileage for electric vehicles.

Selecting the number of battery packs from the maximum power required for an electric vehicle. Batteries must carry more than or equal to the maximum energy consumption of electric vehicles, so the number of batteries required is:

$$n_P = \frac{P_{emax}}{P_{bmax} \cdot \eta_e \cdot \eta_{ec} \cdot N} \quad 21$$

In it, P_{bmax}- maximum output power of a battery cell, η_e- efficiency of motor, η_{ec}- efficiency of Motor Controller, N- number of batteries contained in a single battery pack.

Number of battery packs selected by endurance distance. Before charging the car, the energy carried by battery pack must ensure that the electric vehicle can travel a certain mileage. So, the number of batteries

$$n_L = \frac{1000 \cdot L \cdot W}{C_S \cdot V_S \cdot N} \quad 22$$

In it, L- endurance distance, W- the energy consumed by an electric vehicle driving 1 km, C_s- Capacitance of a single battery, V_s- voltage of a single battery.

Determine the number of battery packs:

$$n = max\{n_P, n_L\} \quad 23$$

3.5 parameters of electric motor determination

Considering all kinds of factors, the parameters of AC asynchronous motor are selected preliminarily,

Rated power: 80kW;

Rated speed: $79.59 rad/s$;

peak power: 200kW;

Maximum speed: $214.90 rad/s$;

Rated torque: $214 Nm$;

Rated voltage: 400V

Cooling mode: water cooling;

working temperature: $-40℃ - 80℃$;

Work efficiency:$\geq 88\%$.

3.6 parameters of battery determination

The selection of power battery parameters for electric vehicle includes the selection of battery capacity and battery number.

Under the condition of working condition test, the endurance distance is not less than 600km, and the energy consumption rate is not higher than 25kWh/100km. Therefore, the total power consumption of the power battery loaded on the pure electric vehicle cannot be less than 151kWh.

However, according to the battery configuration and vehicle test results of pure electric vehicles, the energy consumption rate measured under the condition of calculating the power consumption of power grid is less than 25kWh/100km. Considering the working efficiency of chargers and the discharge efficiency of power batteries, as well as the increase of energy consumption rate caused by the increase of vehicle weight and other factors, according to the relevant literature, the total efficiency is 70%, and the total energy required for the power battery of electric vehicle is not less than 106kWh.

The parameters of lithium-ion power battery pack are as follows,

Single cell capacity:3500mAh;

Nominal voltage:3.6V;

Combination mode:8497 series connection;

Working temperature:$-20℃ - 60℃$.

Chapter 4

4 Selection of motor and battery

4.1 Motor analysis

Now we chose four motors with different brands which all of them are AC motor. We need to compare them with some features like weights (as the vehicle has four motors, the weight of the motor is significant), efficiency, reliability that could influence the vehicle performance. Through the calculation, we can get the maximum torque power, voltage, etc.

The choice of the rated power of the motor is critical. In the operation of an electric vehicle, the hub motor should always be operated near the rated power. If the rated value of the motor is too small, it will always be in an overload state during operation, which will reduce its life. If the rated value is too large, it will always be underloaded during operation, and the motor will not be fully utilized to make the electric vehicle. The overall efficiency is reduced. Generally, the power that the motor should have is initially selected from the vehicle's expected speed, acceleration.

4.1.1 Borg Warner

The first motor we choose to analyze is the HVH250-115 from Borg Warner which is a powerful electric motor. With the configuration of stable and rugged, it can be used in on/off-highway vehicles.

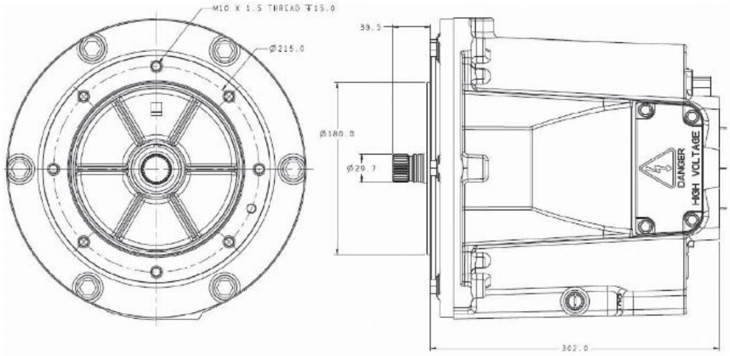
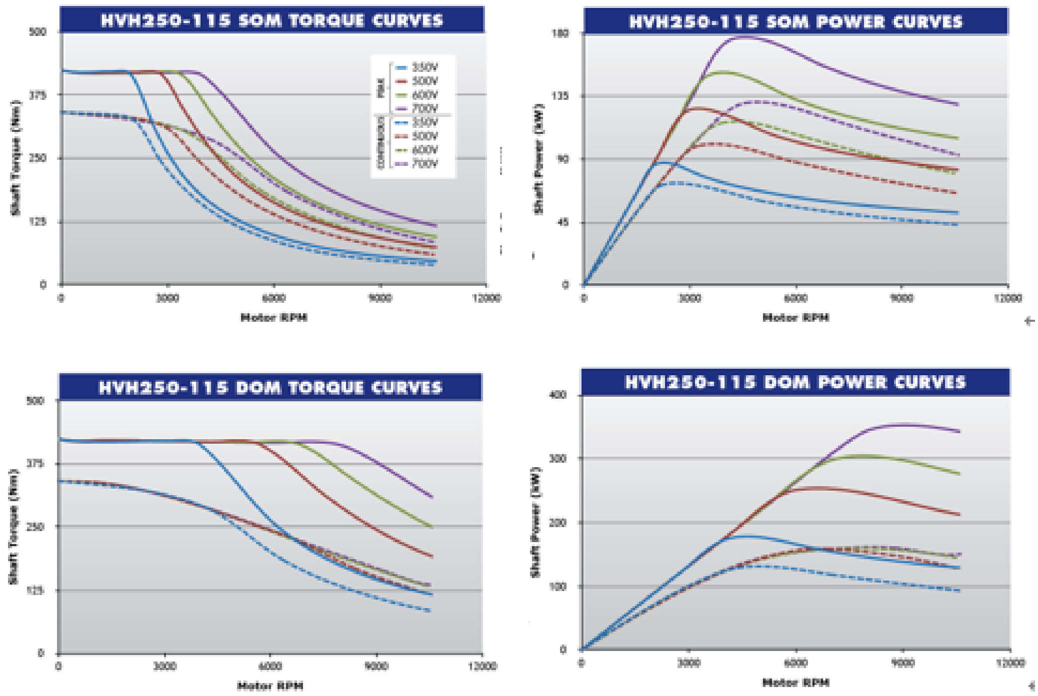
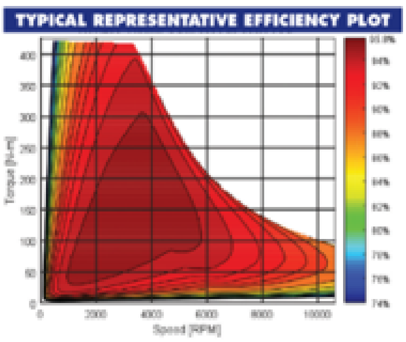


Figure 5 architecture and parameters of the HVH250-150 electric motor





OPERATING CONDITIONS	
Typical Coolant Inlet Temperature	up to 90 C
Typical Coolant Flow Rate	5 to 30 LPM
DC Bus Voltage	up to 700 V
Peak Current	300*/600** Arms
Rated Peak Operating Time	60 sec
Standard Cooling Medium	Dexron VI
MOTOR MASS DATA	
Motor Assembly	57.2 kg
Motor Rotational Inertia	0.086 kg-m^2

*series wound stator **dual path stator.

Figure 6 product details of HVH-250-150 electric motor

The rotor static and dynamic operation torque curve figures show upon, the maximum torque can reach over 400Nm, that means the motor satisfies our target motor's requirement of torque. When the motor in static operation the rotating speed reaches 2800rpm, the maximum torque starts decreasing. In the rotor dynamic and static operation power curve when the motor working between 350-500V, the maximum power is between 90-120kW, the rotating speed reaches 2000rpm which also satisfy our target motor's requirement. Now we pay attention to the efficiency of the motor, the efficiency changes with different torque and rotating speed. When the motor is working in the condition of 400Nm torque and the speed is 2000rpm, the efficiency is around 90%.

4.1.2 YASA

The second brand motor we chose is YASA. YASA has the smallest and lightest motor with the same performance level of motors. Compare with other motors that has the same performance, the YASA motor has lighter weight and higher efficiency, with YASA's unique Yokeless and Segmented Armature topology. Depends on YASA motor has excellent behavior, we analyze two motors of it.

1) YASA-750R

The YASA 750 R is a lower-speed, high-torque motor. The performance of it shows below.

Tab 2 YASA 750 R motor performance

Peak torque @450A_{RMS}	790Nm
Peak power @700V_{DC}	200kW
Peak power@400V_{DC}	100kW
Continuous torque (40°V_{DC})	400kW
Continuous power @ 3000rpm	Up to 70kW
speed	0-3250rpm
Peak efficiency	>95%
mass	37kg

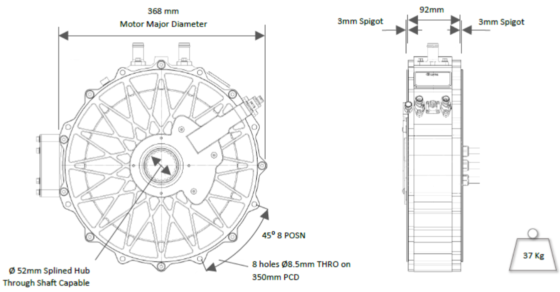


Figure 7 architecture and parameters of the 750R electric motor

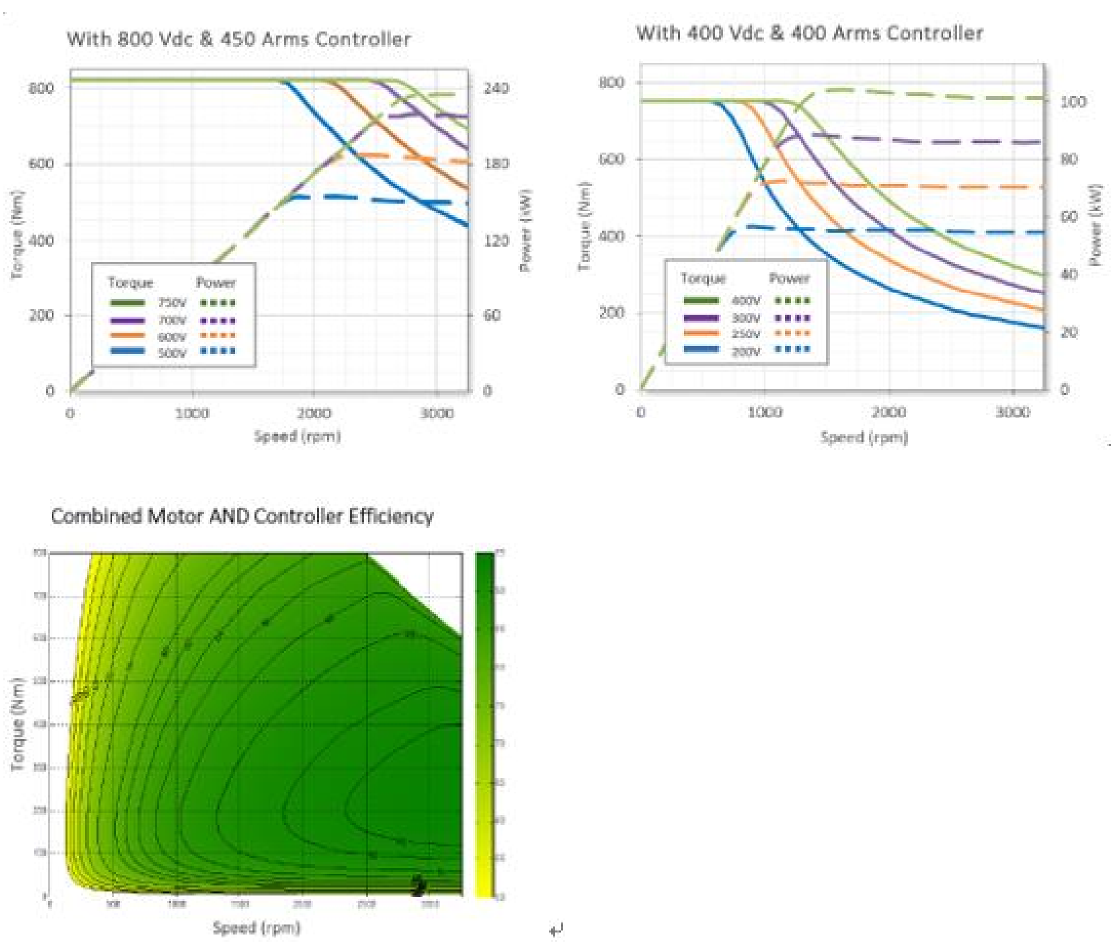


Figure 8 electrical performance of YASA-750R electric motor

In the figure of the motor works in 400V, the rotating speed is 2000 rpm, the motor power is the maximum power 100 kw. Meanwhile, the maximum torque reaches 750Nm, it is much higher than our target, but the rotating speed cannot reach our target which is 2052 rpm. In other words, the YASA-750R cannot suffice the designed vehicle requirement performance.

2) YASA P400

The YASA P400 motor is manufactured using advanced materials. The performance of it shows below.

Tab 3 YASA P400 series. Models from 20kW to 100kW continuous

Peak torque @450A_{RMS}	370Nm
Peak power @700V_{DC}	160kW
Continuous torque	Up to 300Nm
Continuous power	20kW to 100kW
speed	0-8000rpm
Peak efficiency	96%
mass	24kg

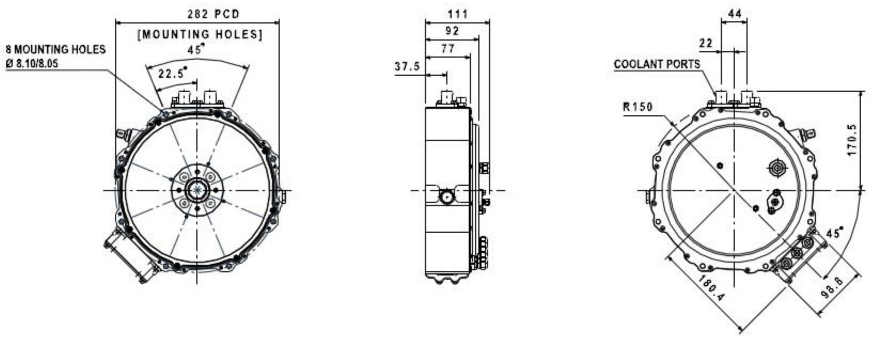


Figure 9 architecture and parameters of the P400 electric motor

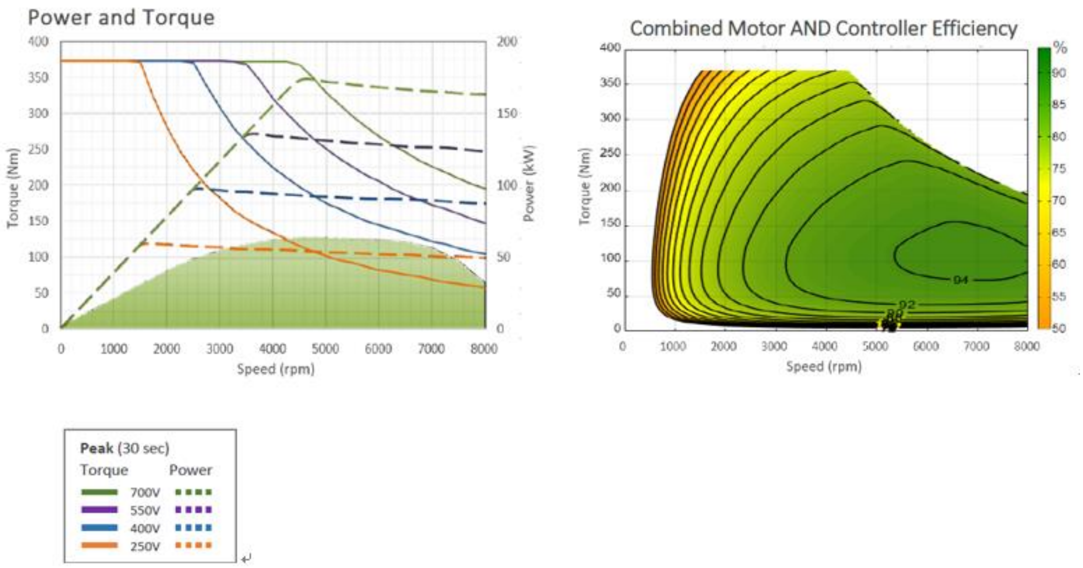


Figure 10 electrical performance of P400 electric motor

Obviously, YASA P400 is not a good chose. The reasons are the maximum torque can't reach 400Nm, on the rotating speed of 2000 rpm the power can't reach 80kw. It can't be considered in our design.

4.1.3 Brusa

The last motor we need to analyze is from Brusa, the model of the motor is HSM1-10.18.13 it is one of the most powerful Hybrid synchronous motors. The continuous power reaches to 145 kW. It works with the inverter of BRUSA DMC534 and DMC544.

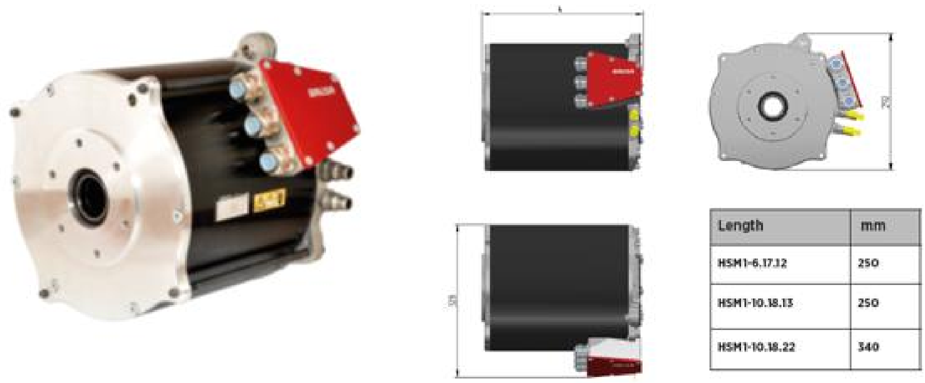


Figure 11 architecture and parameters of the HSM1-10.18.13 electric motor

Tab 4 technical data for motor with inverter DMC534 at 400V_DC

With inverter DMC534 at $400V_{DC}$	
Nominal speed	4900rpm
Continuous torque	165Nm
Max. torque (at max. inverter current)	305Nm
Continuous power	93kW
Max. power	156kW
Max. speed	13000rpm
Efficiency	95%
Weight	51.0kg

Tab 5 technical data for motor with inverter DMC544 at 400V_DC

With inverter DMC544 at $400V_{DC}$	
Nominal speed	4600rpm
Continuous torque	165Nm
Max. torque (at max. inverter current)	385Nm
Continuous power	93kW
Max. power	185kW
Max. speed	13000rpm
Efficiency	95%

Weight	51.0kg

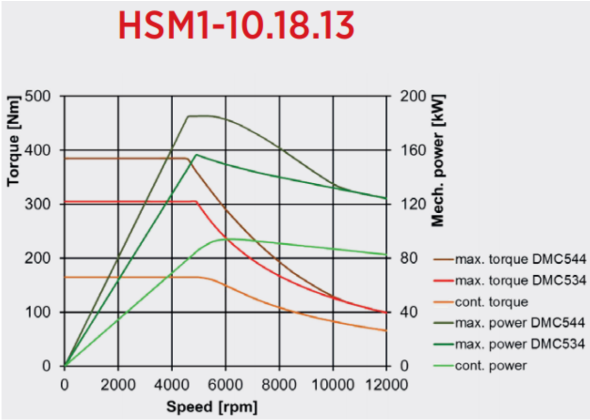


Figure 12 electrical performance of HSM1-10.18.13 electric motor

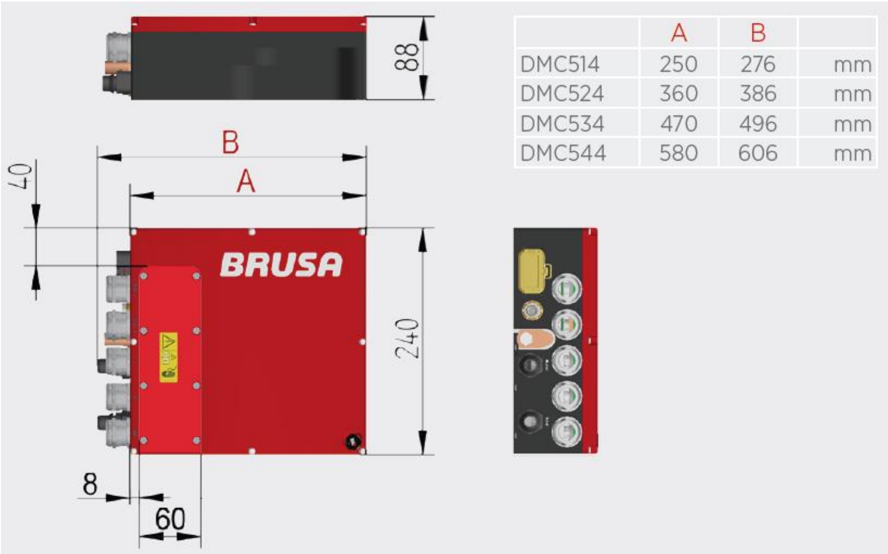
As the tables and figure show upon, the Brusa HSM1 hybrid synchronous motor should be work with the inverter DMC544 or DMC534. When the motor works with inverter in 400V, the maximum torque is almost 400Nm. The maximum speed is over 80kw, at the same time the speed is over 2000rpm. The efficiency of the motor is 95%, that is higher than the Borg Warner one.

In addition, we can get some information about the HSM1 hybrid synchronous motor from the Brusa company website. The motor is a water-cooled 3-phase AC motor. The motor is based on the combination of a permanent synchronous motor and a reluctance motor whereby the advantages of both versions have been coordinated and combined with one another. The HSM works with internal magnets which have an optimum flow direction at low magnetic resistance due to a self-developed alignment to one another. Through this, a remarkably high and consistent power delivery can be achieved while using less energy. The power delivery takes place over a large speed range. In addition, the HSM1 is extremely efficient and is best suitable for use as a traction drive with a constant transmission ratio. With these properties, the HSM1 is a very good choice for drive systems which require constant and high power over a large speed range. To achieve optimum results with this motor, it is paramount that the connected inverter is exactly adjusted to the motor is used.

Now compare the two motors one is the HVH250-115 from Borg Warner another is the HSM1-10.18.13-E01 of Brusa. All of their maximum torque, speed and power satisfy our design targets. What different of them is efficiency. The HSM1-10.18.13-E01 has higher efficiency, which influences the torque and speed output from the motor to the vehicle. Finally, in this project, we decided to use the Brusa's hybrid synchronous motor HSM1-10.18.13-E01.

4.2 inverter

Based on the motor we selected in the project we only consider the DMC534 and DMC544. Now we cannot define which inverter should be defined in the project. In the simulation chapter, we will define it with simulation in order to clarify which one could satisfy the vehicle requires performance. The dimensions of inverter shown below.



	A	B	
DMC514	250	276	mm
DMC524	360	386	mm
DMC534	470	496	mm
DMC544	580	606	mm

Figure 13 dimensions of inverter

4.3 Gearbox

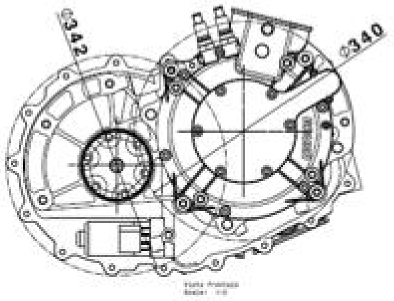
This project is for sports vehicle, the output speed of the electric motor will be very high, the maximum power and maximum torque appear in a certain speed range. In order to achieve the best performance of the motor, a shifting device must be provided to coordinate the motor speed and the actual running speed of the wheel we call the device is the gearbox. According to the utility model, the power is directly transmitted from the motor to the transmission, and the transmission transmits the power directly to the four wheels, thus reducing the power loss, and has the advantages of simple structure, easy manufacture, and low production cost.

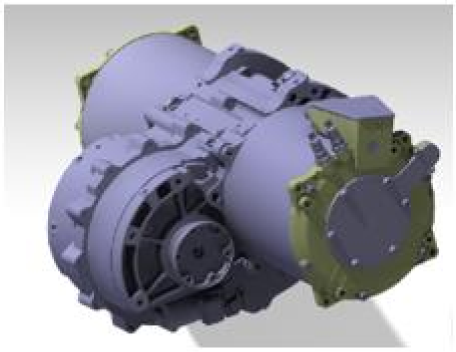
Since the motor torque output is independent of the motor speed, most of the new energy vehicles that rely on the motor for end drive are equipped with single-stage gearboxes or reducers. It is based on the well-known transmission body, bearings and various standard parts, and a motor flange is arranged between the motor and the transmission to connect the motor and the transmission. The motor output shaft is directly inserted into the connecting sleeve in the transmission, and the power is transmitted to one shaft of the transmission through the connecting sleeve. The gear on one shaft meshes with the driven gear on the differential housing to drive the driven gear to drive the differential and the wheel to rotate. complete the power transmission.

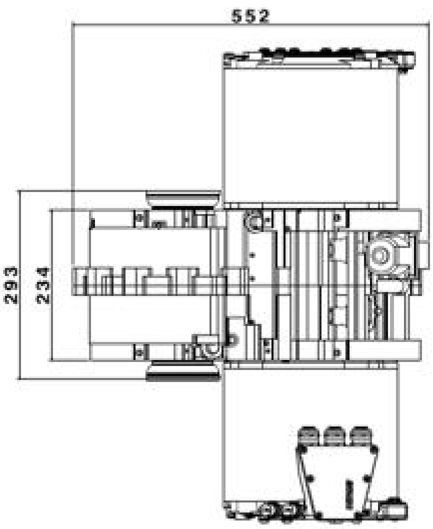
The fixed gear ratio transmission has high transmission efficiency, simple and reliable structure, small size and easy installation, and there is no calibration difficulty, so it is the first choice for the motor drive model.

We don’t equip the ordinary gearbox in the electric vehicle. The main reason is that the volume and weight of the ordinary gearbox are too large compared to the electric car, followed by the poor transmission efficiency, and the installation design and matching are more difficult. If an ordinary gearbox is used in the electric vehicle considering the transmission efficiency, the 100km cruising range can only run at most 80km.

After weighing and cost comparison, this project adopts the fixed gear ratio gearbox, the data of it from the vehicle design company. The architecture and the details performances are showed below.







	Gear ratio
1stratio	24/51
2ndratio	33/39
Final drive	18/69

Figure 14 architecture of gearbox

4.4 Battery pack

For electric vehicles, the battery pack is the only source of energy. The battery life and the entire control system depend on the battery pack's capabilities. As shown in the figure below, the battery pack is composed of thousands of batteries cells. Choosing a suitable battery cell model is critical to electric vehicles.

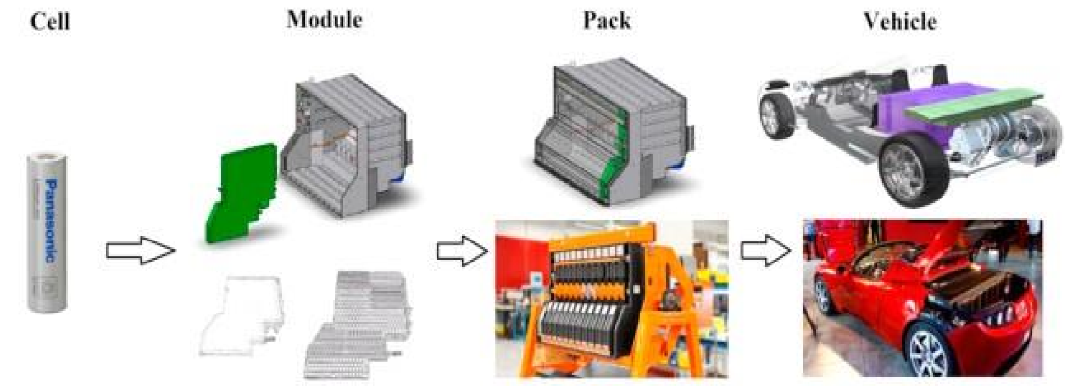


Figure 15 Battery cells to build the battery pack

4.4.1 Battery cells

In order to develop the battery pack, we make a prototype development phase. If we want to build the battery package, choose the best rechargeable cell is necessary. First of all, we decided the battery pack is built based on the 18650 cell which means that we only did research on this model battery. There are LG, Panasonic, Samsung, Sony rechargeable 18650 cells' specific performances which can help us to choose the most fitting one.

Before start to compare the different brands of battery cells, we should clear that 18650-battery cell is based on the Lithium-ion technology, with 65mm heights and 18mm diameter. And the most important thing is the cell should be with the flat top, as the cell has a button on the top PCB protected, it is not suitable for building the battery pack.

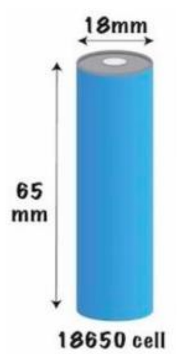


Figure 16 18650 cell data

Firstly, I choose four 18650 cells from LG, LG is a Korea battery brand that is the world's No. 1 automotive battery supplier. The electric vehicle power is provided by a mid-to-large-sized lithium-ion battery pack which is built by the rechargeable batteries. The working principle of lithium battery is that the lithium ions move between positive and negative electrodes to produce electricity. Based on the cutting-edge battery technologies, LG supplies electric vehicle batteries to global automobile manufacturers. It has been the leader of the global battery market.

INR MJ1

INR HG2

INR MH1

INR F1L

Figure 17 batteries of LG

Through table below, it shows that all the cells have the same constant voltage, constant current, end current. More or less the nominal voltage, and maximum charge voltage are similar. I focus on the capacity which means how much energies can be stored in the cell. Obviously, the energy provides power to let the vehicle move. Table 4 shows that the INR18650MJ1 has the best capacity, I peak it up and compare it with other brands' 18650 cells.

Tab 6 compare 5 kinds of LG 18650 cell

model name	Condition/note	LG 18650 INR			
		MJ1	HG2	MH1	F1L
capacity		3500mAh	3000mAh	3200mAh	3350mAh
technology		Li-ion			
Nominal voltage		3.6V	3.6V	3.7V	3.6V
Standard charge	constant current	1700mA	1500mA	1550mA	975mA
	constant voltage	4.2V	4.2V	4.2V	4.2V
	end current	50mA	50mA	50mA	50mA
Max. charge voltage		4.2±0.05V			
Max. charge current		3400mA	6000mA	3100mA	1625mA
standard discharge	constant current	680mA	600mA	620mA	650mA
	end voltage	2.5V	2.0V	2.5V	2.5V
Max. discharge		10A	20A	10A	4.8A
weight		49.0g	47.0g	49.0g	49.0g
temperature range		0℃/45℃	-5℃/50℃	0℃/45℃	0℃/45℃
temperature range		-20℃	-20℃/75℃	-20℃	-20℃
Price		3.75€	3.8€	3.1€	3.95€

Secondly, I compare three kinds of Panasonic 18650 cells. Panasonic is a battery brand from Japan that has made the batteries thinner and lighter for use in devices like notebook computers and mobile phones. Meanwhile, the batteries are also used in electric vehicles to provide the power to the vehicle. Moreover, it is also used to mobile telephones base station and various other industrial uses.

NCR18650 GA

NCR18650 B

NCR18650 PF

NCR18650 A

Figure 18 batteries of Panasonic

Through the table below, we can analysis the detail data of the cells. We should focus on these dates: weight, capacity, price, maximum continuous discharge current, standard charging. While they have many same dates as minimum voltage. Through the price and the capacity, it is obvious that the NCR18650B is stand out of other cells, we define it as the best one of the Panasonic 18650 cells.

Tab 7 four kinds of Panasonic 18650 cells

model name	NCR 18650			
	GA	B	PF	A
capacity	3450mA	3350mAh	2900mAh	3100mAh
technology	Li-ion			
nominal voltage	3.6V	3.6V	3.6V	3.7V
charging voltage	4.2V			
minimum voltage	2.5V			
nominal capacity	3300mAh	3250mAh	2750mAh	2950mAh
typical capacity	3450mAh	3350mAh	2900mAh	3070
standard charging	1475mA	1625mA	1350mA	1475mA
Max. continuous discharge current	10A	6.8A	10A	6.2A
weight	48g	47.5g	45.5g	47.5
temperature range charge	10℃/45℃	0℃/45℃	10℃/45℃	0℃/45℃
temperature range discharge	-20℃/60℃	-20℃	-20℃/60℃	-20℃
price	4.2€	3.75€	2.4€	2.79€

Thirdly, I choose three kinds of Samsung 18650 cells, Samsung is the battery company of Korea. In the electric vehicle battery applications, the battery cell format enables increased driving range in the same external dimensions. So, the vehicle can run over 50km on the electric mode without having to change the current packaging for the next generations.

Samsung 30Q

Samsung 18650 35E

Samsung 18650 30A

Figure 19 batteries of Samsung

By analyzing the table below and neglect the same parameters, we can easily get the best performance of these batteries is INR 18650-35E.

Tab 8 compare three kinds of Samsung 18650 cells

Model name	INR 18650		
	30Q	35E	30A
capacity	3040mAh	3450mAh	3000mAh
technology	Li-ion		
nominal voltage	3.6V	3.6V	3.7V
charging voltage	4.2±0.05V		
minimum voltage	2.5V	2.65V	2.75V
nominal capacity	2700mAh	1500mAh	2250mAh
typical capacity	2983mAh	1700mAh	2900mAh
standard charging	1500mA	1020mA	1500mA
Max. continuous discharge current	15A	8A	6A
weight	45.6g	50g	48g
temperature range charge	0℃/45℃	0℃/45℃	0℃/45℃
temperature range discharge	-20℃/60℃	-10℃/60℃	-20℃/60℃
price	3.3€	3.35€	3.35€

Compare Sony and Sanyo 18650 cells. Sony is a battery supplier from Japan that the battery (has completed the transfer of its battery business to the Murata Manufacturing Group) has excellent performance, suitable for making battery packs. Sanyo is a battery supplier from Japan that is the world's largest 18650 cylindrical battery manufacturer and Performance is recognized as the best.

Sony US VTC6

Sony US VC7

Sanyo NCR GA

Figure 20 batteries of Sony and Sanyo

Through the data analysis in the table below, according to the capacity and price of each battery, the Samsung INR 18650 35E battery cell has better performance, we choose it as the best one.

Tab 9 compare Samsung and Sanyo 18650 cells

Model name	Sony US	Sony US VC7	Sanyo NCR GA
capacity	3120mAh	3500mAh	3500mAh
technology	Li-ion		
nominal voltage	3.6V	3.7V	3.6V
charging voltage	4.2V±0.05V		
minimum voltage	2V	2.5V	2.5V
nominal capacity	2940mAh	1500mAh	2250mAh
typical capacity		1450mAh	
standard charging	650mA	1000mA	1675mA
Max. continuous discharge current	30A	8A	10A
weight	46.5g	45g	44g
temperature range charge	0℃/45℃	0℃/50℃	0℃/45℃
temperature range discharge	-20℃/60℃	-20℃/75℃	-20℃/60℃
price	4.25€	7.75€	3.65€

Finally, I compare the cells that picked from tables shown above, they are the best one in every table. The details comparison is the table shown below. LG INR18650MJ1 has higher capacity and costs less price. In my opinion, the LG INR18650MJ1 cell is the best choice.

Tab 10 compare LG Panasonic and Samsung 18650 cells

model name	LG	Panasonic
	INR18650MJ1	NCR18650B
capacity	3500mAh	3350mAh
nominal voltage	3.635V	3.6V
charging voltage	4.2V	4.2V
minimum voltage	2.5V	2.5V
standard charging	1700mA	1625mA
Max. continuous discharge current	10A	6.8A
weight	49g	47.5g
temperature range charge	0℃/45℃	0℃/45℃
temperature range discharge	-20℃/60℃	-20℃/60℃
price	3.75€	3.75€

4.4.2 Battery module

The module is the elementary part that, replicated several times, composed the battery pack. The main function of the module is the following: Mechanically containing the elementary cells. Connecting the cell from an electric point of view. Allowing temperature and voltage cells sensing.

Because of the mission profile of the battery prototype a passive cooling system has been adopted in order to provide a simple and realizable solution (without liquids flowing within the battery and an external cooling system). The air cooling has been considered not suitable for the application due to the performance expected and also taking into account the large number of cells that composed the battery pack itself. The passive cooling adopts a phase change material matrix where the material spreads the heat evenly throughout the pack, avoiding hot spots and ensuring temperature uniformity. Thermal energy is absorbed by an internal melting process rather than continuing to raise the temperature of the cells.

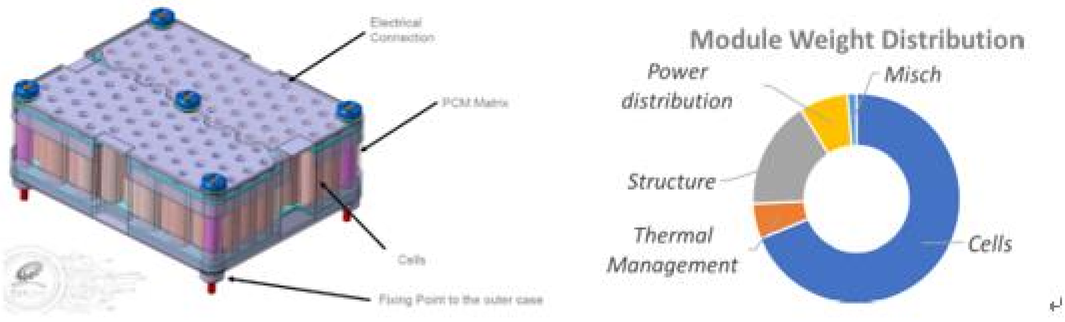


Figure 21 battery module

The overall weight of the concept of the module will consider all the part (cells, electrical connection, thermal management, structural parts).

4.4.3 Battery layout

At this stage, a preliminary volume estimation (in accordance with the vehicle requirement and packaging boundaries) has been provided. Some volume has to be saved for electronic and controls, connectors, contractors and so on.

The main part where the battery pack will be housed is the underbody part (with some exclusion under the rear passenger feet) and the tunnel part. Starting with this layout the overall connection and detailed design will confirm package, volume, and battery to vehicle interfaces. With this finalized packaging some FEA analysis on the outer case has to be performed in order to confirm the overall thickness of the carbon fiber structure.

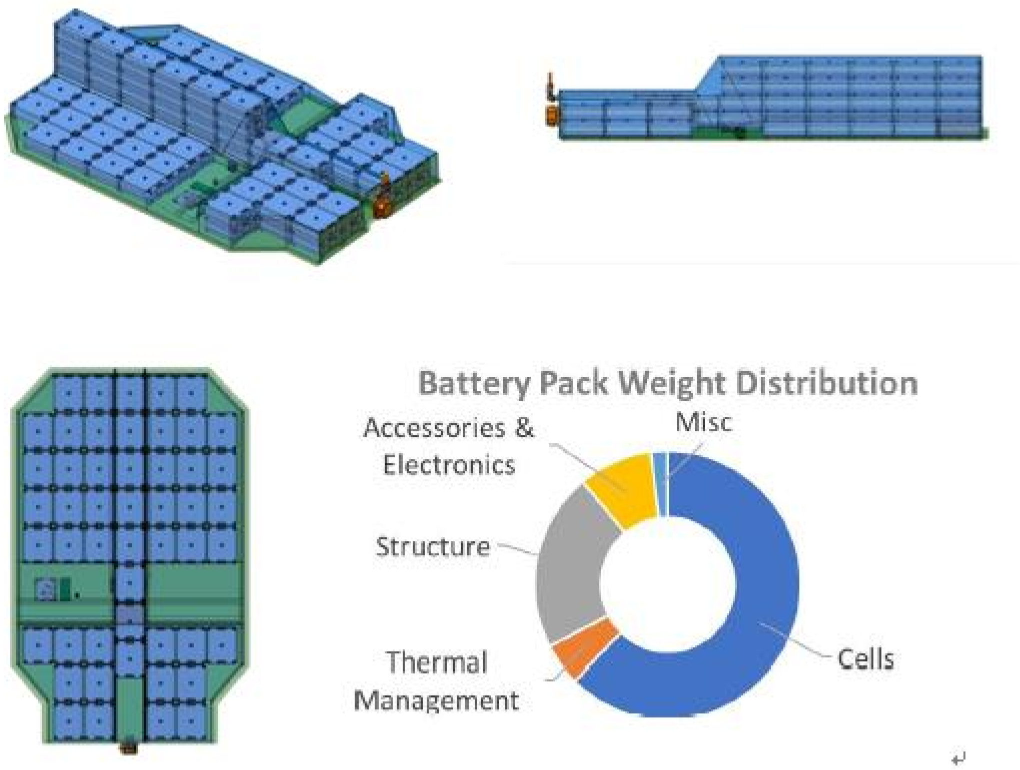


Figure 22 battery pack

A preliminary weight budget split has been considered. Final and detailed design is required in order to confirm the overall weight and the weight distribution of the vehicle itself.

The battery is a prototype system, all the components manufactured and installed are conceived, designed and intended for prototype purpose considering the use for which they are designed and intended the battery pack, its components and accessories, have no the required certification and/or homologation Necessary for the use in many contexts and/or regulation different from which they have been conceived, designed and intended.

Integrated battery management system (BMS), measurement and monitoring of all cells voltages, measurement and monitoring of cells temperatures. The battery pack and the high-voltage systems connected to the DC-Line are protected against short circuits with a single dedicated high-speed fuse. Insulation monitor device. Cooling system is not accepted.

Tab 11 The battery pack technical characteristics

Energy content	106kWh
Capacity (per cell)	3500mAh
Technology	Li-ion
Number of cells	8640
Nominal voltage	400V
Max. voltage	450V
Min. voltage (recommended)	290V
Discharge continuous	800A
Discharge peak (<10s)	1600A
Recommended fast charging current	240A
Control	CAN-Bus (1 Mbit/s)
Weight	Estimated 720kg
BMS power consumption offline (per	12μA
Temperature range charge	0℃/55℃
Temperature range discharge	−20℃/55℃
waterproof	The prototype is not IP-rated, but it is sealed and protected against dust and splashes. The battery pack cannot be (partially) submerged in water.

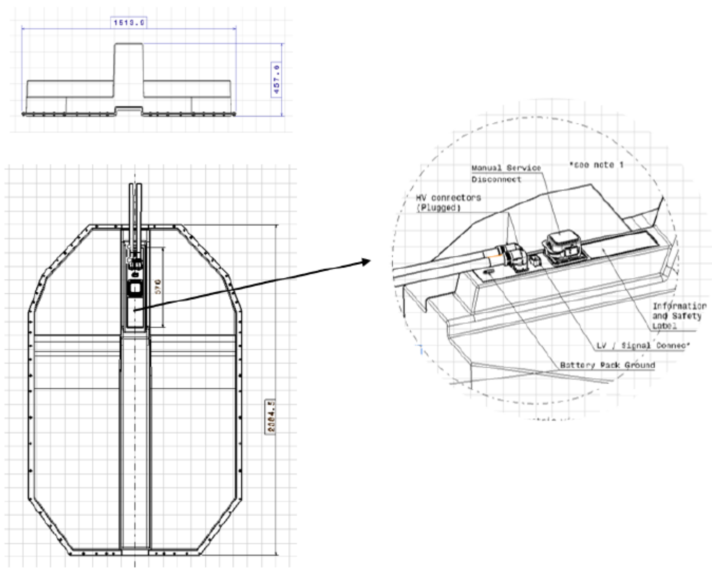


Figure 23 Dimensions and mechanical interfaces

Chapter 5

5 Simulation performances

After all the parameters of the motor, inverter, gearbox and the battery pack are defined, it is time to verify whether they can satisfy the vehicle performance requirements. Now the dynamic performance test simulation is made by using Matlab Simulink model in which all the characteristics and features in the Vehicle and Electric Powertrain are modeled. The main part of the model is the powertrain which includes the gearbox, electric motor, power inverter and battery pack. All the simulation results are based on the available information.

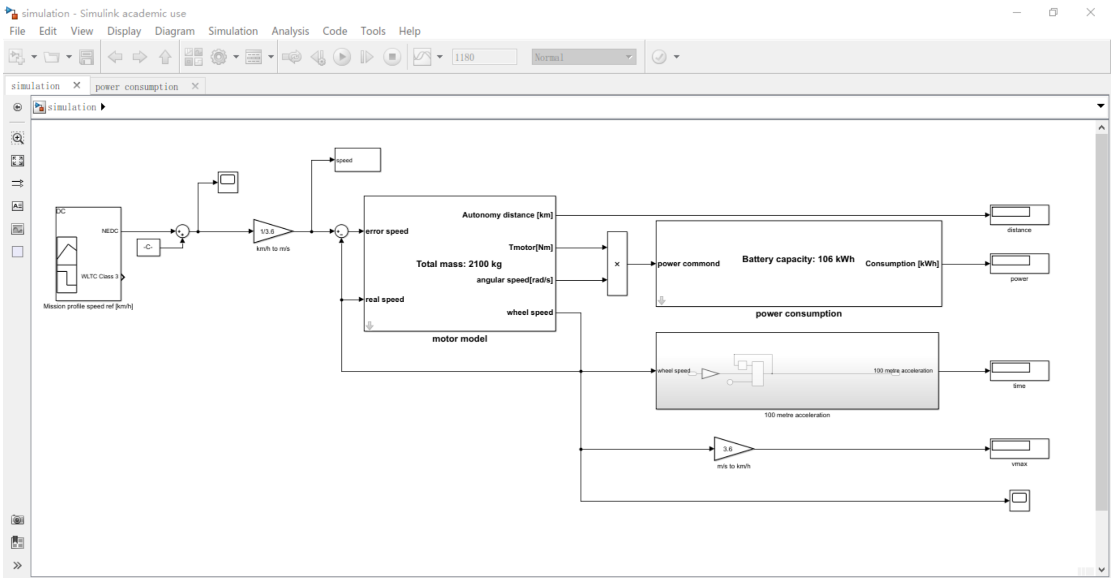


Figure 24 Simulation performances

5.1 Simulation target

In the simulation process, we use the previously selected gearbox, electric motor, inverter and battery pack. By simulating the driving state of the vehicle for the real road, some measured parameters could verify if the vehicle can achieve our intended purpose.

The main purpose of our verification are to confirm if the following purpose can be achieved:

1. The acceleration time for the car from standstill to 100 km/h is less than three seconds.
2. The maximum speed of the vehicle can reach 270 km/h.
3. When the vehicle is driven in NEDC condition, the endurance distance will be more than 600km.

5.2 Simulation prepares

Before we build the simulation model, some data should be considered. All the parameters of vehicle and physical, data of battery pack, motor, inverter and gearbox are shown below.

Tab 12 parameters for vehicle and physical

Parameters of vehicle	Long	5.1	m
	Weight	2100	kg
	Power	700	kW
	endurance	600	km
	Tires specification	265/40 R21	mm& inch
	Exterior body width	2120	mm
	Exterior height	1418	mm
Parameters of dynamics	V_max	270	km/h
	Air density（ρ）	1.161	kg/m^3
Parameters of physical	C_x(C_aero)	0.28	
	A_f	2.34	m^2
	g	9.81	m/s^2
	r_d	349	mm
	Rolling coefficient	0.0109	

Tab 13 parameters for battery pack

Energy content	106kWh
Capacity (per cell)	3500mAh
Technology	Li-ion
Number of cells	8640
Nominal voltage	400V
Max. voltage	450V
Min. voltage (recommended)	290V
Discharge continuous	800A
Discharge peak (<10s)	1600A
Recommended fast charging current	240A

About the gearbox, we have a table with three ratios. Because we decide to use the fixed gear ratio gearbox, we will try these ratios of the simulation model, to find an available one:

Tab 14 Gear ratio

	Gear ratio
1^{st} ratio	24/51
2^{nd} ratio	33/39
Final drive	18/69

About the motor and inverter, we didn't make a final decision in chapter 4. In order to determine which inverter should be used in the project, I get the figures that the electric motor HSM1-10.18.13 works with DMC 534 and 544 inverter, simulation results from the vehicle design company, the figures shown below. Moreover, When the car accelerates from standstill, the vehicle gravity center moves backwards due to inertia, which causes the rear wheels are subjected to greater ground friction than the front. If we apply more pulling force to the rear wheels, the vehicle will have a better acceleration effect. This means that the motors in front of and rear of the vehicle are assigned different powers, when the total power of the vehicle required is constant. In this project we set a relationship between front and rear motors:

$$\frac{P_f}{P_r} = 1:1.7$$

$$P_f + P_r = P_t$$

Where the P_f is the power of front motors, P_r is the power of rear motors. P_t is the total power of the vehicle required.

Option with DMC 534 power inverter (pulling force and speed):

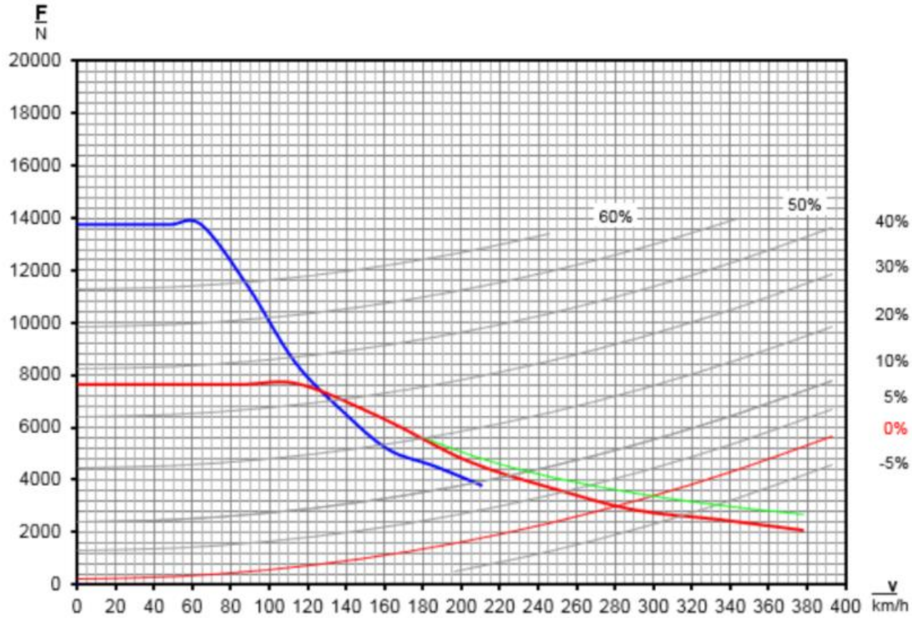


Figure 25 DMC 534power inverter (pulling force and speed)

Figure 25 shows the relationship of pulling force and wheel speed, where motors work with DMC534 inverter. In this graph, the blue curve is the force of rear wheel. When the maximum pulling force is 14000N and meanwhile the wheel speed achieves 60km/h, the maximum pulling force starts to decrease. The red curve is the front wheel pulling force. When the maximum force is 7600N, the maximum pulling force begins to decrease at the wheel speed of 120km/h.

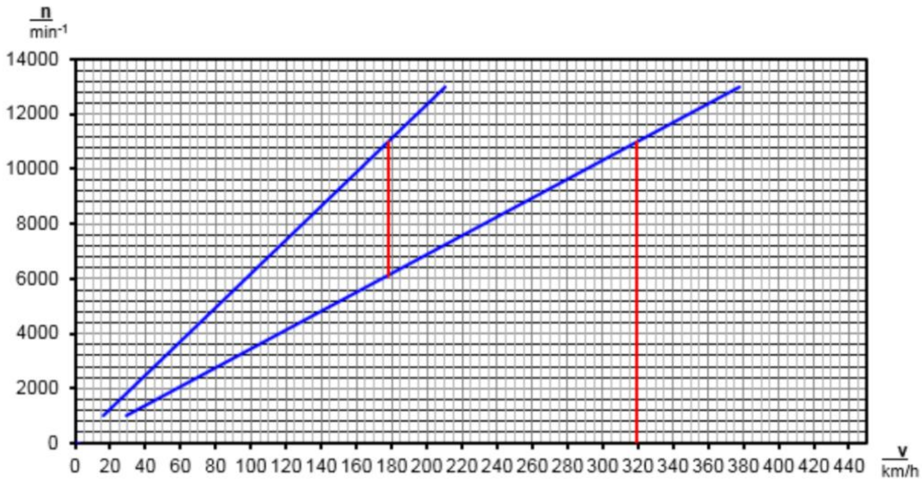


Figure 26 DMC 534 power inverter (motor rotating speed and speed)

Figure 26 shows the speed relationship of electric motor rotating and the wheel. There are two straight lines with different slopes. As the front motors have weaker pulling force than the rear motors, the line of gentle slope is the condition of front wheels. When the wheel speed is 180 km/h, the motor rotating speed reaches up to the rated maximum value. Another straight line for the rear motors' rotating speed. When the wheel speed is 320 km/h, the motor rotating speed at the rated maximum speed of 13000 rpm. With stronger pulling force, the speed rises more quickly than the front motors.

Option with DMC 544 power inverter (pulling force and speed):

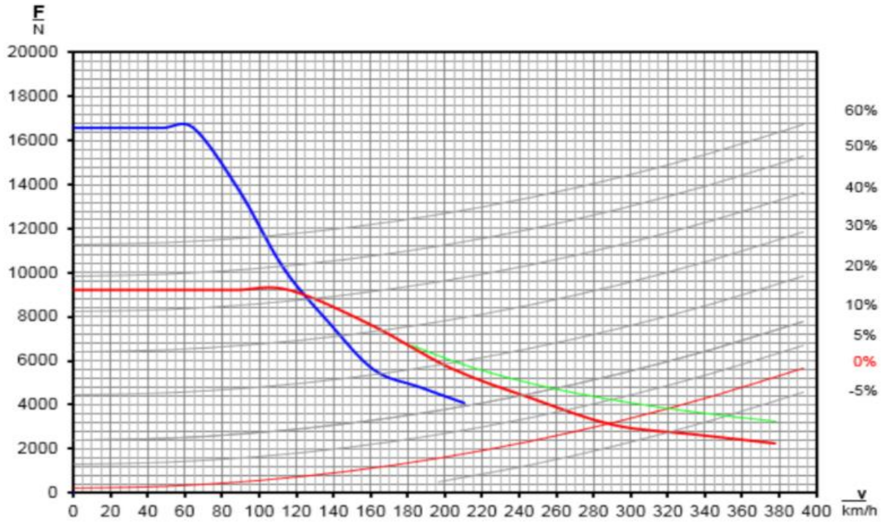


Figure 27 DMC544 power inverter (pulling force and speed)

Figure 27 shows the relationship of pulling force and wheel speed corresponding to the motors working with DMC 544 inverter. The figure is similar with the Figure 25, but the maximum pulling forces are different. In this picture the blue curve is the force of rear wheel. When the maximum pulling force is 16500N and meanwhile the wheel speed achieves 60km/h, the maximum pulling force starts to decrease. The red curve is the front wheel pulling force. When the maximum force is 9200N, the maximum pulling force begins to decrease at the wheel speed of 120km/h.

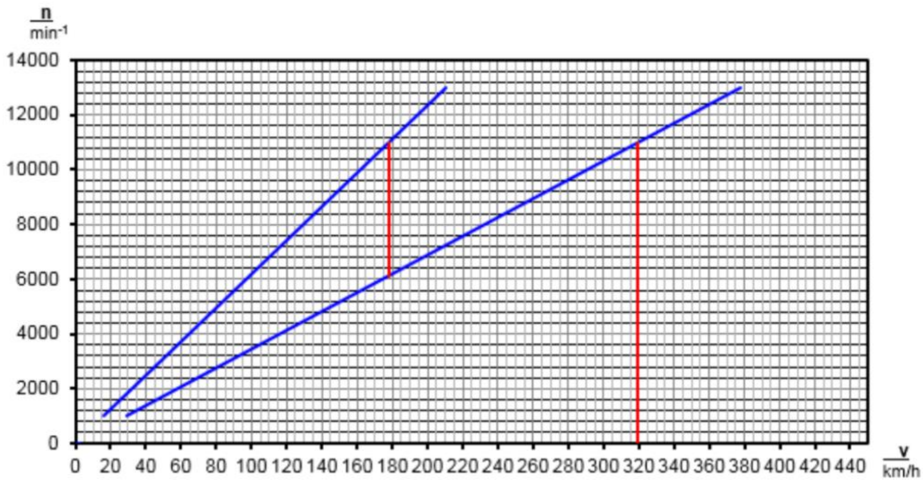


Figure 28 DMC544 power inverter (motor rotating speed and speed)

Figure 28 shows the speed relationship of electric motor rotating and the wheel. There are two conditions expressed as different slopes of straight lines respectively. The line with gentle slope is the condition of front wheels, because the front motors have weaker pulling force than the rear motors. The other straight line for the rear motors' rotating speed. With stronger pulling force the speed rises more quickly than the front motors.

Only through these figure25 to 28 is not enough to decide which inverter is better for this vehicle performance requirement, we need more data in the simulation model. Now, we have to model a more complete simulation of the powertrain. The final decision for inverter will be more preciseness.

5.3 Model build

5.3.1 Motor model

In the motor model we should consider the motor control, the resistance from aerodynamic and rolling friction. In addition, the efficiencies of motor, gearbox cannot be neglected.

Motor controller

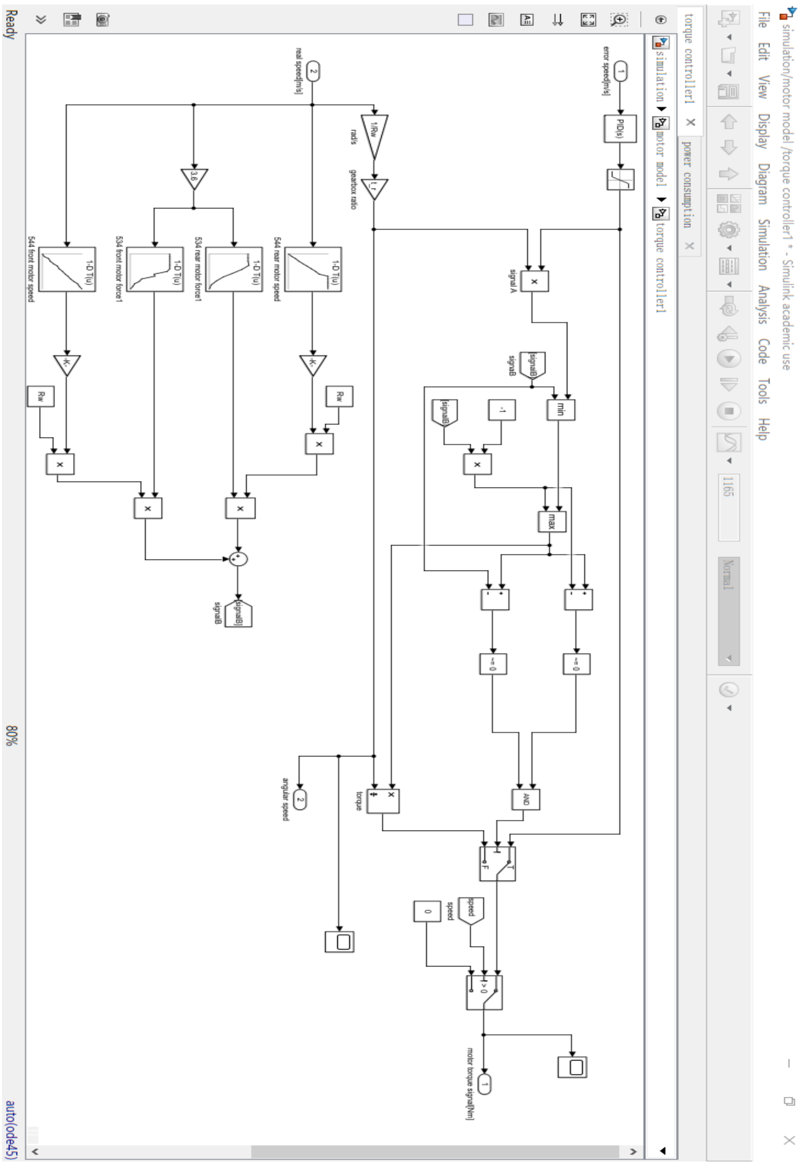


Figure 29 torque controller

This figure shown above is the electric motors torque controller. The motor cannot work when the power over the rated maximum power. Therefore, the aim is to restrict the motors working under the rated maximum power and torque.

The figure shown below is to calculate the power of the vehicle in driving situation. In this project we use the hub motor. There are four motors in the vehicle. In order to have a better accelerating effect, we set the motors have different maximum powers. Also the maximum powers of the motors will change with the varying of motor force, meanwhile the force is changed with the varying of wheel speed, we add the relationship map of the motor force with the wheel speed to calculate the maximum power that the motors can reach, this part is the lower part of the picture, we call it as signal B. The signal B is the sum of rated maximum power of the front and rear motors. In the lower part, the input is real wheel speed, from front to back, including the blocks front motor force, front motor speed, rear motor force, rear motor speed. We have the motors' speed and force in variable wheel speed, according to the $P = F \times v$. We have the power of front motors and power of rear motor, the value of added values are the total power of the vehicle requirement.

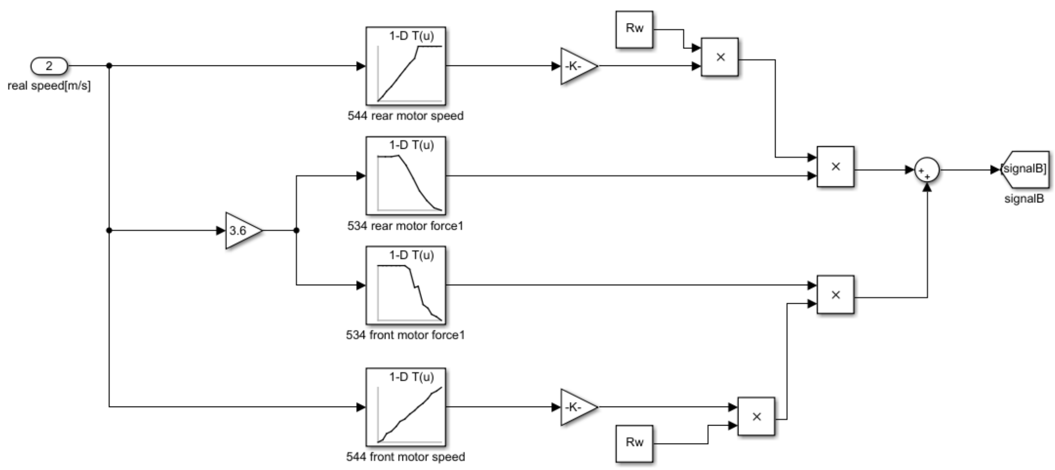


Figure 30 power controller

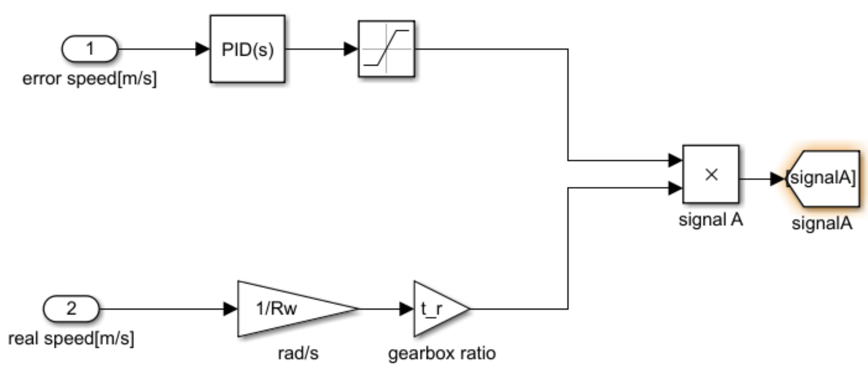


Figure 31 torque controller

The motor cannot work in the values of the torque that higher than the rated maximum torque. The figure shown above shows that the error speed through the PID controller and the torque saturation block to restrict the motors torque under the rated maximum torque and calculate the corresponding power. In the upper part the error speed of input 1 after the PID controller and the torque saturation block we will have the torque. In the lower part, the real speed divided by the vehicle radius then multiply by the gearbox ratio, we will have a corresponding rotate speed of the motor. Through these formulas: $\mathrm{P} = \mathrm{F} \times \mathrm{V}$, $\mathrm{T} = \mathrm{F} \times \mathrm{R}$, we can get $\mathrm{P} = \frac{T \times V}{R}$, so the signal A is the power calculated from the torque part.

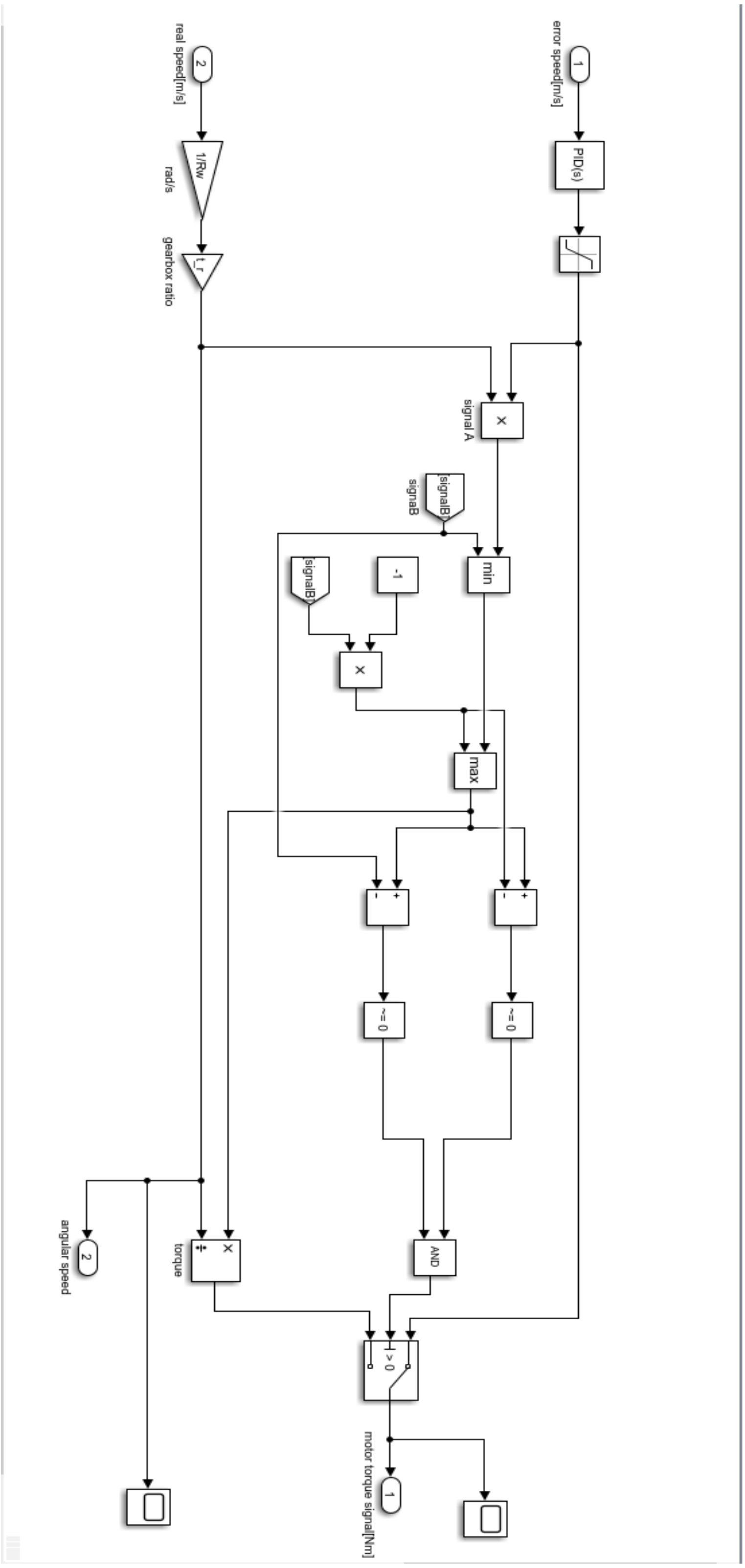


Figure 32 power compare

Comparing the two power values of signal A and signal B, we should choose the smaller one because the motor power cannot higher than both of them. This part done in the min block. We will have different output motor torque signals in different situations.

Situation one, the vehicle is driving in a positive direction. The signal A and signal B are positive values. But signal A is smaller than signal B, after the min block, the output signal is signal A. The output of max block is signal A, in the plus/minus blocks the values are zero. In this condition, the motor torque is the rated maximum torque, the output signal of motor torque is the torque from the saturation block.

Situation two, the vehicle is driving in a positive direction. The signal A and signal B are positive values. Signal A is the higher value. After the min block, the output is signal B. before the max block, the power is multiplied by negative one, the output of max block is signal B, plus/minus block outputs are not zero. In this condition, the motor power is the rated maximum power, the output motor torque is from the power of signal B divide by motor angular speed.

Resistance of the vehicle

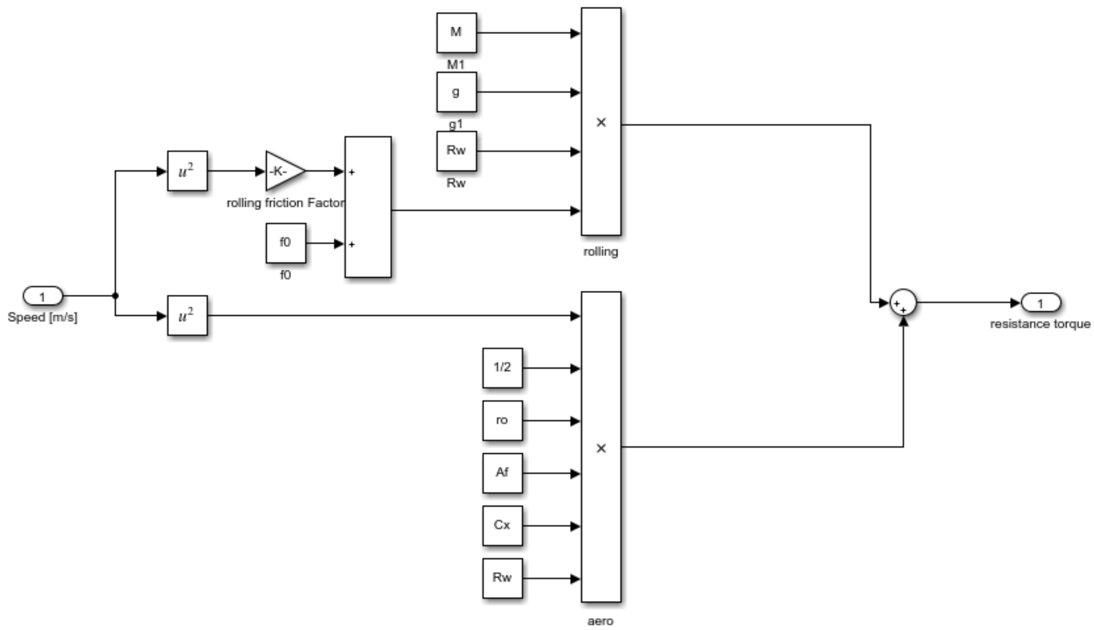


Figure 33 resistive torque

The figure shown above is the resistance of the vehicle, that will influence the accelerate time and endurance distance. When the vehicle is driving at low speed, the resistance contribution is essentially linked to rolling resistance. On the other hand, the aerodynamic resistance is the main source of resistance, when the vehicle is driving at high speeds (> 80 ÷ 90 km / h). When the vehicle is driving on a real road, vehicle resistance is the sum of rolling resistance and the aerodynamic resistance. This figure shows the resistance torque is based on the vehicle velocity. The output is the resistance torque that minus by the motor torque, we will have the real torque that can be sent to the wheels.

Motor model

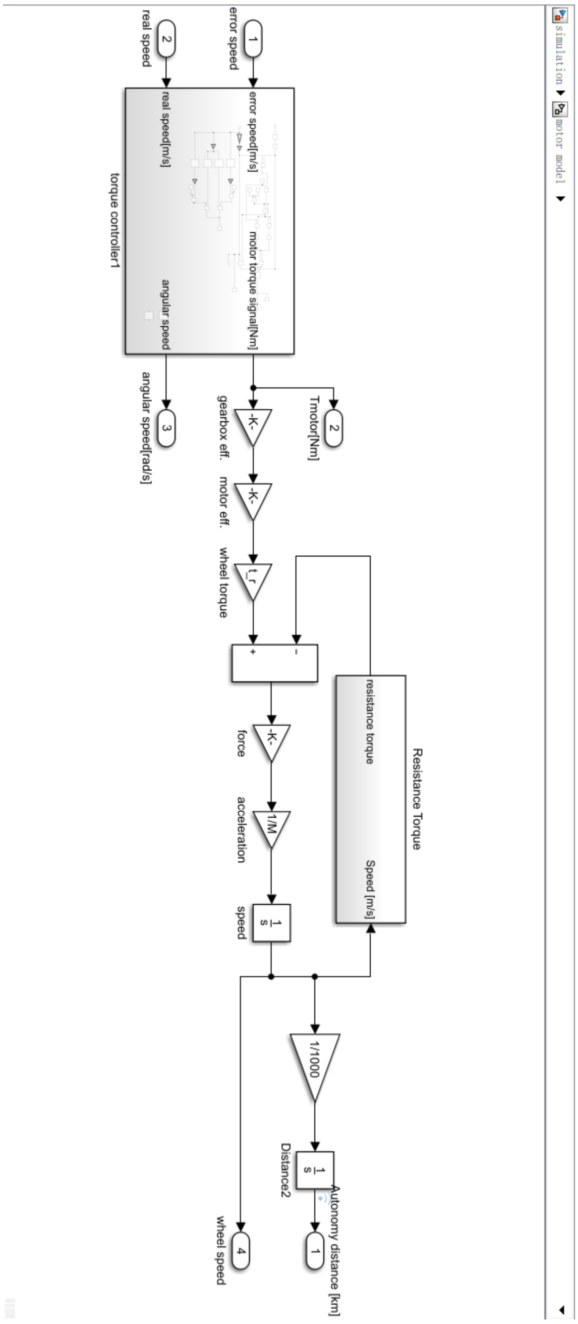


Figure 34 motor controller

Combine the torque controller and the resistive part, we have the motor model. The figure is shown above. In this part, the output 2 is the motor torque. After the motor torque multiply by the efficiency of gearbox and motor, gearbox transmission ratio we have the real torque that the motor transmits to the wheel. The value of motor real torque minus the resistance torque is the torque that the wheels can get. At the same time, the motor torque multiply by the motor angular speed, we will have the command power, sent to the power consumption part. The output 1 is the autonomy distance, output 4 is the real wheel speed, they are shown in the display block.

5.3.2 Power consumption

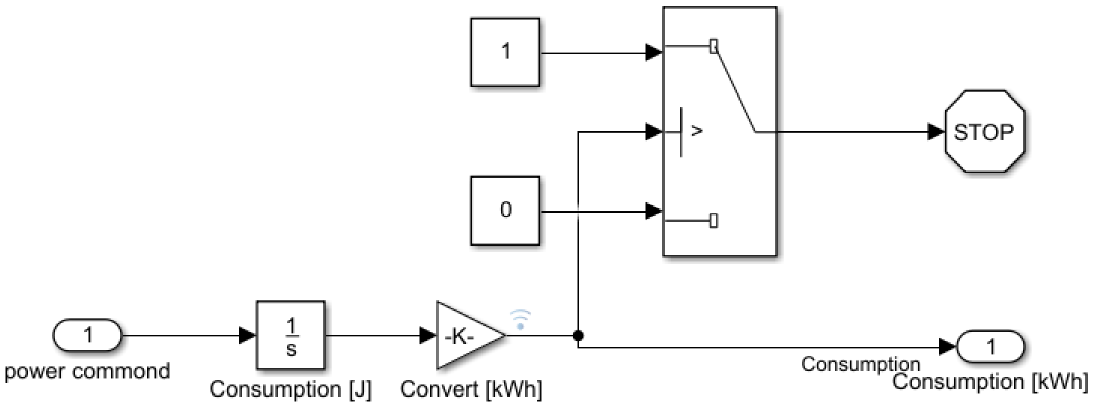


Figure 35 power consumption

For the power consumption part, input 1 is the command power which from the motor model part. We defined the battery pack content is 106kWh. Through the Integral of the command power then convert it, compare the value with the content of battery pack. When the value from the convert block is equal to the battery pack content, the energy is depleted. The vehicle stops running, and the consumption energy shows in the display block of the model.

5.3.3 acceleration time of 100km/h

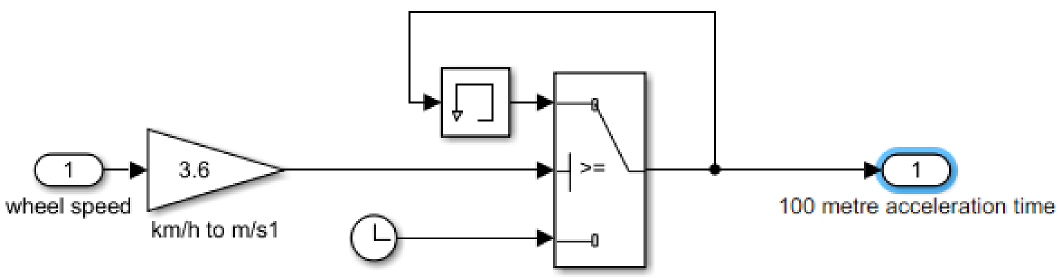


Figure 36 100km/h acceleration time

This part is for the convenience of observing the time that the vehicle accelerates from standstill to 100 km/h. The output 1 is sent to the time display block shows the acceleration time. The input 1 is the wheel speed compare with the speed of 100km/h, if the value smaller than 100km/h, the value of output 1 keeps increasing. When input

1 is equal to 100km/h, the value of output 1 it no more changes.

5.3.4 Speed command is 0

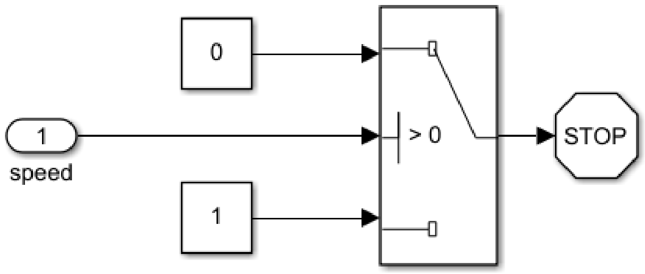


Figure 37 speed command is 0

This part is to ensure that when the speed of the vehicle is zero, the vehicle is in a static state, and the motor's torque and speed are also zero.

So far, we have a complete simulation model. Now it is time to verify whether the selected motor, inverter, gearbox and battery pack could satisfy the vehicle performances requirement.

Firstly, in order to define which inverter can be used in the designed vehicle, we will simulate the motor works with DMC 534 inverter and DMC 544 inverter. To check the acceleration time of the vehicle accelerates from 0km/h to 100km/h. And whether the vehicle maximum velocity of 270km/h can be reached. Whether the vehicle's endurance distance can meet the design requirement when the vehicle driving in NEDC working condition. The figure is shown below, there are four diagrams show the relationship between motor pulling force and vehicle speed, the relationship between motor rotating speed and vehicle speed.

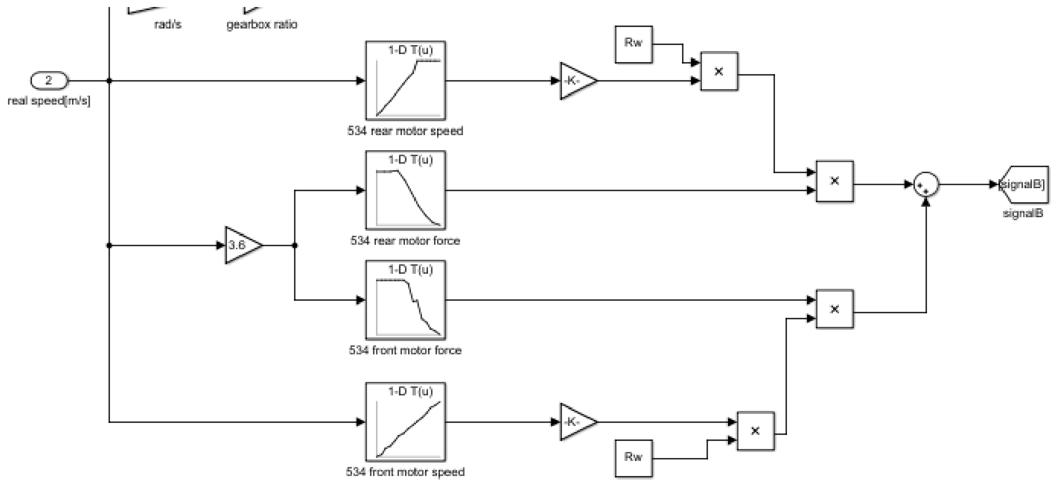


Figure 38 driving with 534 inverter

5.4 Verification of the DMC 534 inverter

Firstly, we check when the command speed is zero, whether the vehicle is at the static condition:

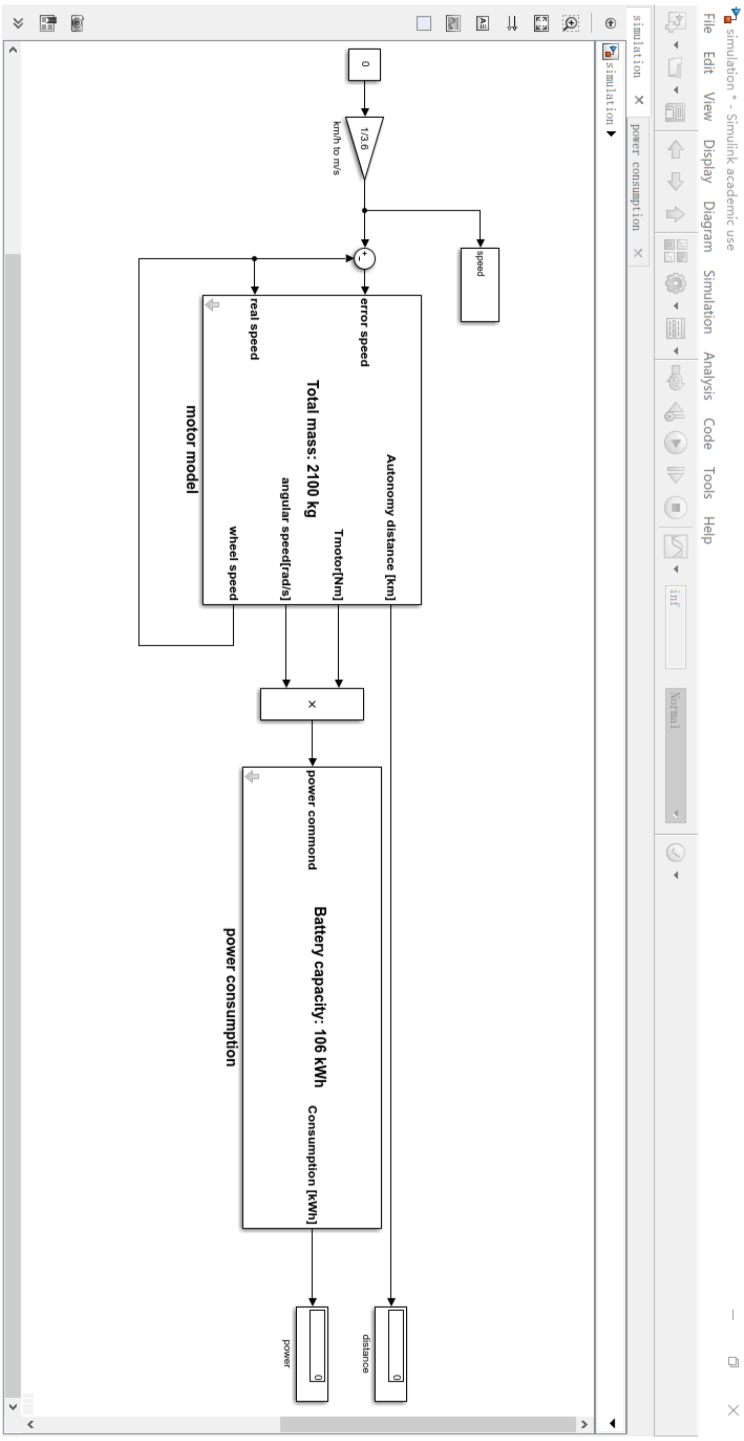


Figure 39 vehicle speed is zero

The figure shows that when the speed command is zero, the driving distance of the vehicle is zero, it means the vehicle is at static condition. And the power consumption is zero, which means in this condition, the vehicle doesn't consume energy.

Next, we need to verify which inverter should be selected in this project. Those lookup tables shown below are the relationship between motor pulling force and vehicle speed, the relationship between motor rotating speed and vehicle speed. As in previous Chapter 4, we define the front motor and rear motor have different maximum rated power and torque.

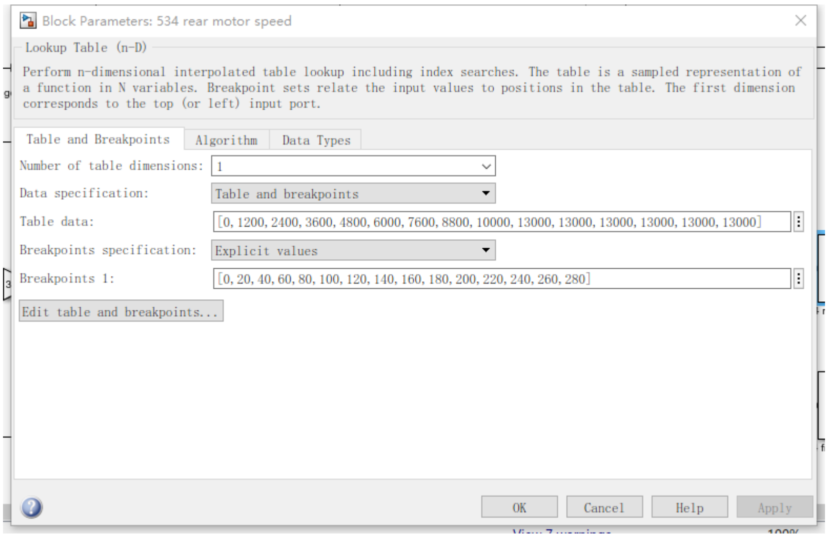


Figure 40 534 inverter, rear motor speed with speed

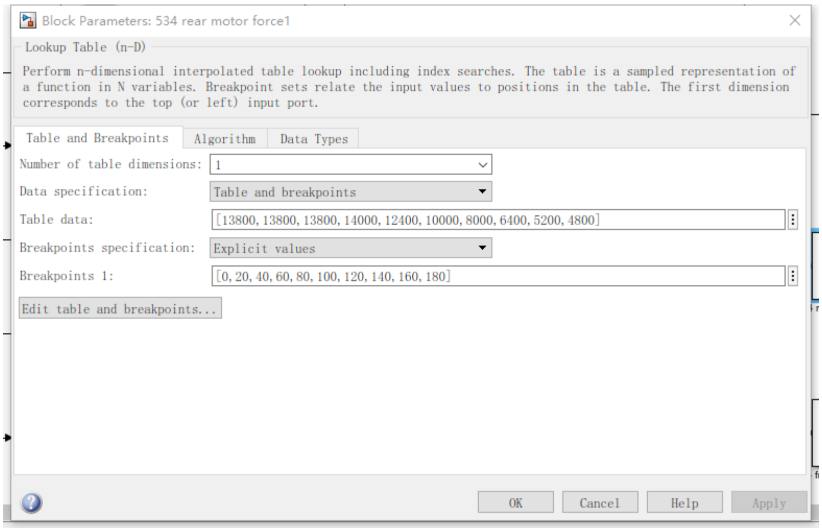


Figure 41 534 inverter, rear motor force with speed

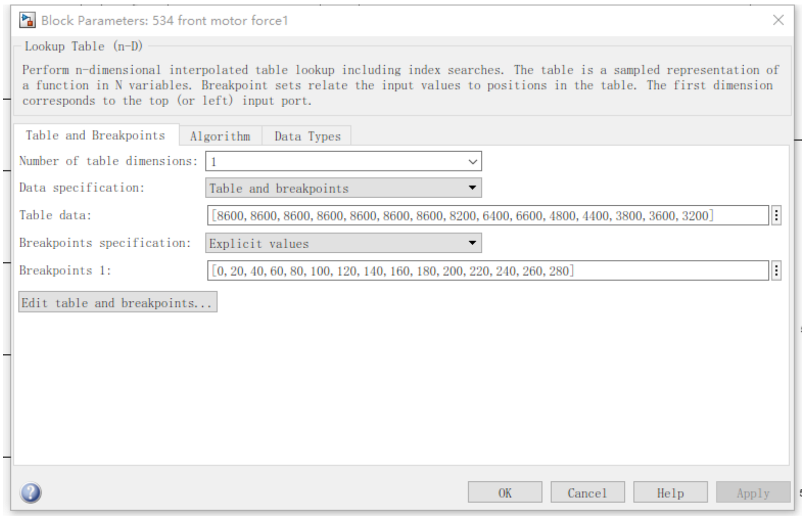


Figure 42 534 inverter, front motor force with speed

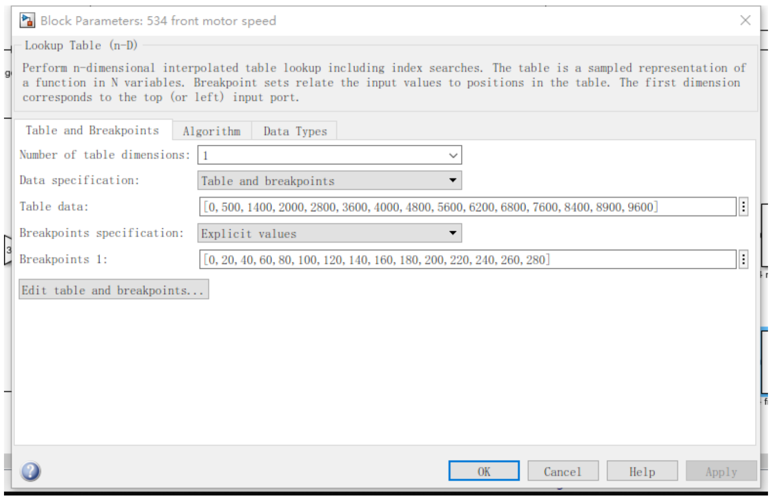


Figure 43 534 inverter, front motor speed with speed

The figures shown below is the result of motor works with DMC 534 inverter. And in the model the fixed gear ratio gearbox ratio is the 1st ratio which is 24/51, the vehicle acceleration time from standstill to 100km/h is 233.5s, it is much higher than 3 seconds, the 1st ratio cannot satisfy the required acceleration time.

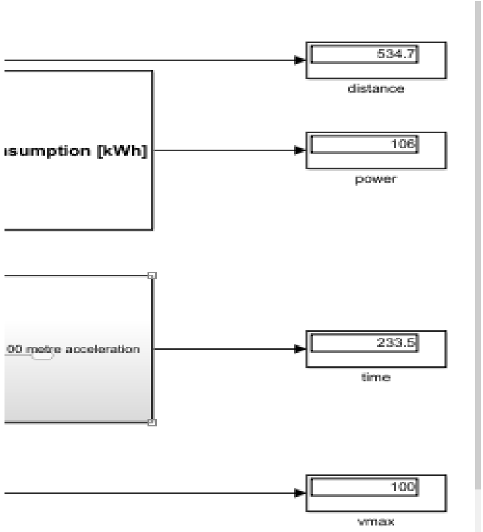


Figure 44 acceleration time with 1st ratio

For the 2nd ratio which is 33/39, the acceleration time shown below, it is slower than 1st ratio, we also cannot use it in the simulation model.

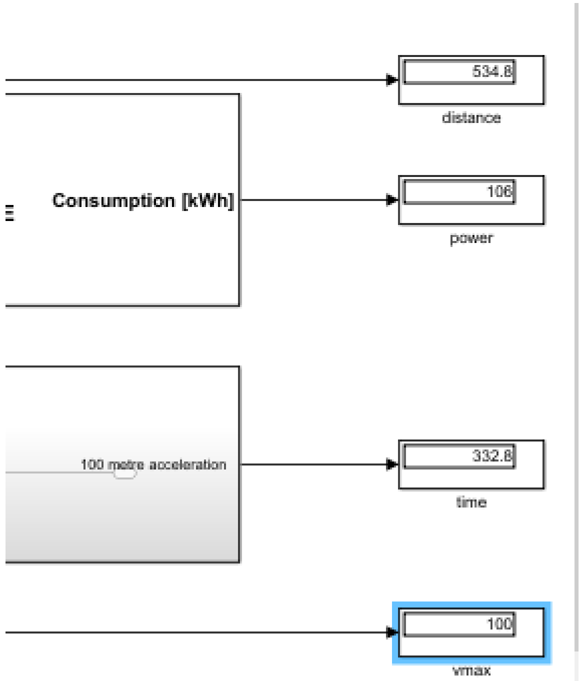


Figure 45 acceleration time with 2nd ratio

For the final driving ratio of 18/69, the acceleration time is 124.1 seconds, it is also cannot satisfy the acceleration time requirement.

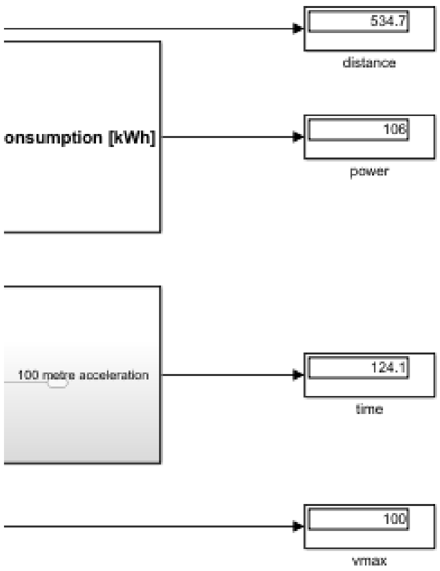
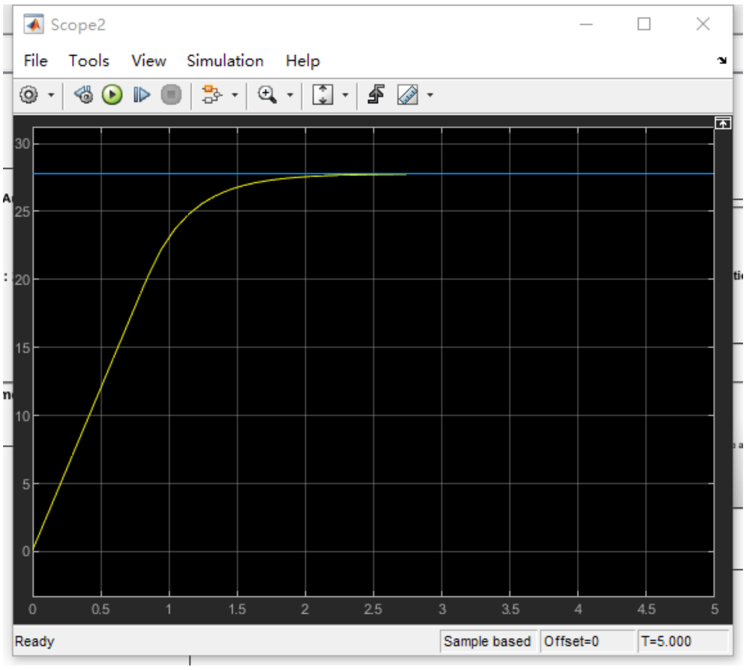


Figure 46 acceleration time with final driving ratio

With the mass of a vehicle cannot change, motors parameters are fixed, and the aerodynamic effect cannot be neglected. We decide to find a gearbox ratio that can satisfy the acceleration time. Finally, we adopt the fixed gear ratio gearbox with the ratio is 12 and run the model again.

In the following scope, the blue line is the command speed, the yellow curve is the vehicle speed, it shows that the vehicle speed can reach 100km/h.



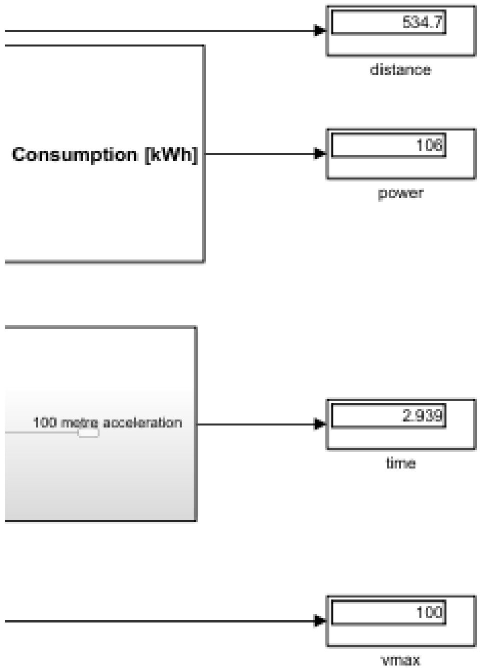


Figure 47 534 inverter accelerate to 100km/h

In the figure below, look up the display block of Vmax, the vehicle speed can reach 100km/h. From the time display block, we can see the vehicle acceleration time from standstill to 100km/h is 2.939 seconds. With the 106kWh energy is depleted and the vehicle driving in a fixed speed of 100km/h, the endurance distance is 534.7km. This result is running with the gearbox ratio of 12, it satisfies the vehicle performance requirement.

Now let's check whether the vehicle maximum speed can reach 270km/h, we set the speed command is 270km/h, the result shows below.

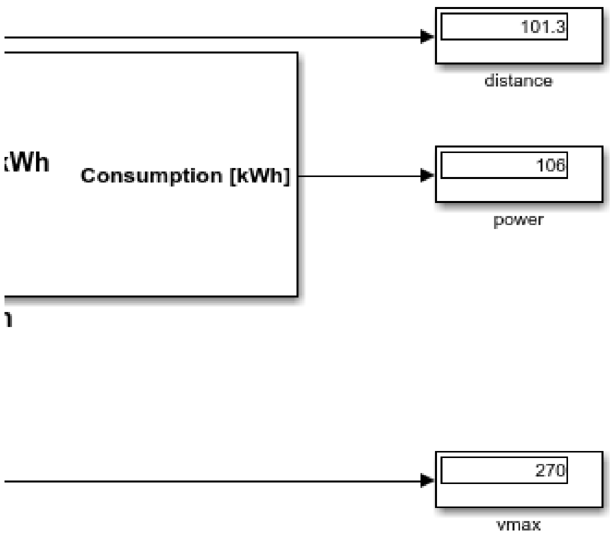


Figure 48 534 inverter accelerate to 270km/h

The above figure shows the expected maximum speed can be reached. With the battery energy runs out, the distance that the vehicle can be driven is 101.3km.

Now let's check the distance for the vehicle driving in NEDC working condition. The NEDC condition is a driving cycle for simulating real road condition. For each cycle, the driving time is 1180 seconds. The figure shown below is the NEDC and WLTC working condition for one cycle.

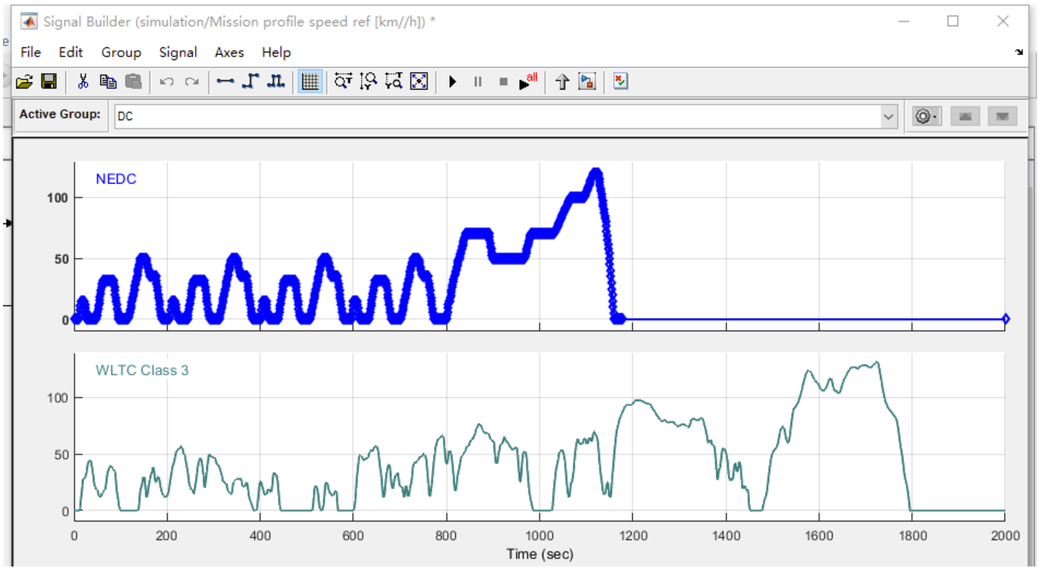


Figure 49 NEDC WLTC working condition

If we want to keep the vehicle driving until the energy of the battery pack is depleted, the simulating process will take a long time. So, we just let the vehicle driving for one cycle, then calculate the distance of the vehicle when it consumes 106kWh energy of the battery pack. The following figure shows the relationship between the vehicle speed and time when the vehicle driving in one cycle of NEDC condition.

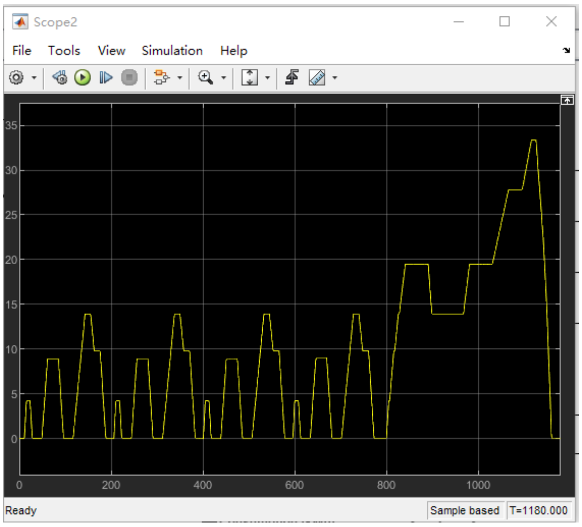


Figure 50 534 inverter relationship between time and velocity

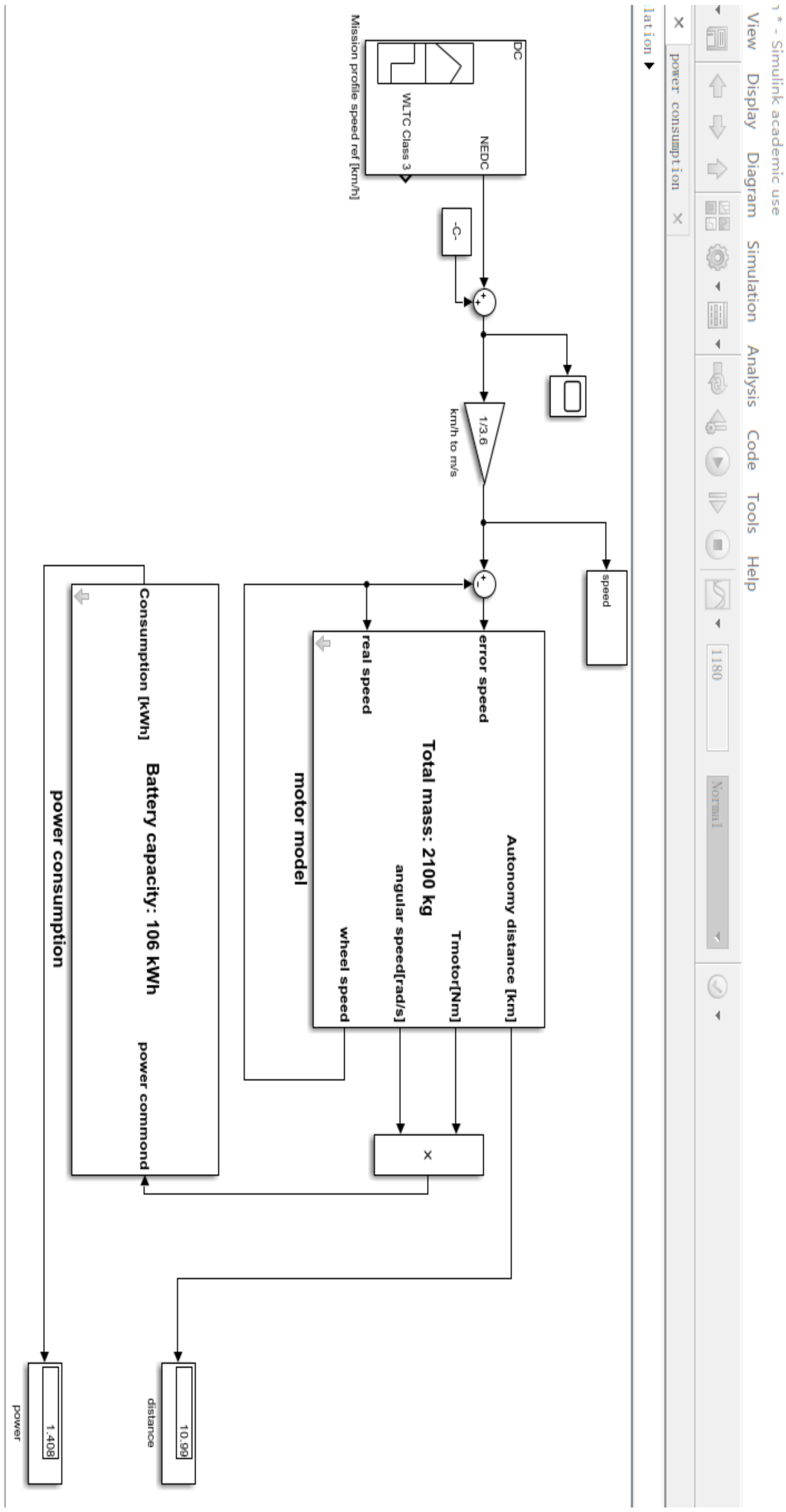


Figure 51 534 inverter driving in NEDC

This figure shows that for one cycle of NEDC condition, the driving distance of the vehicle is 10.99km, and the energy consumption is 1.408kWh. Now we can calculate the endurance distance when the vehicle driving with battery energy runs out:

$$\frac{106}{1.408} \times 10.99 = 827.372km$$

From the calculation, we can know the endurance distance is 827.372km.

End of here, the motor works with the DMC 534 inverter could satisfy the design targets. The vehicle acceleration time from standstill to 100km/h is less 3 seconds. The maximum velocity can reach 270km/h. The distance for vehicle driving in NEDC condition is more than 600km.

5.5 Verification of the DMC 544 inverter

Now let's check the vehicle performance when the motor works with DMC 544 inverter. Relationship between motor rotating speed and vehicle speed shown in the four lookup tables below. Same as the motor works with DMC 534 inverter, we define the front motor and rear motor have different maximum rated power and torque. The data that motors work with DMC 544 inverters shown below:

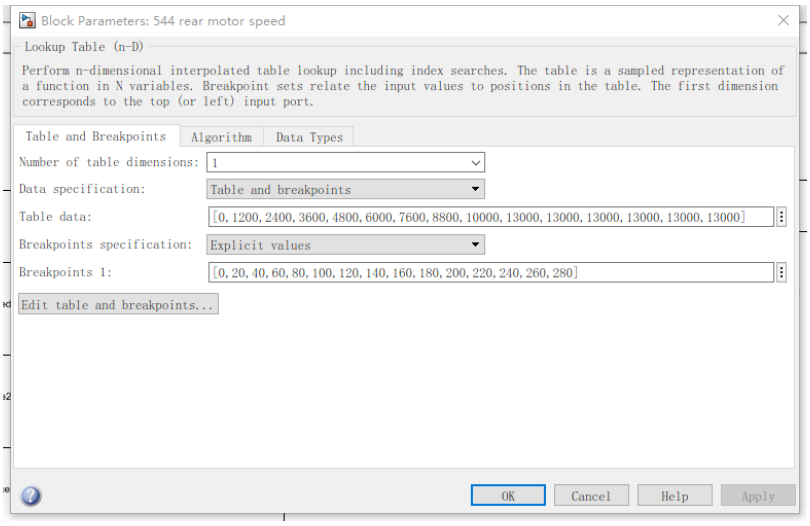


Figure 52 544 inverter, rear motor speed with speed

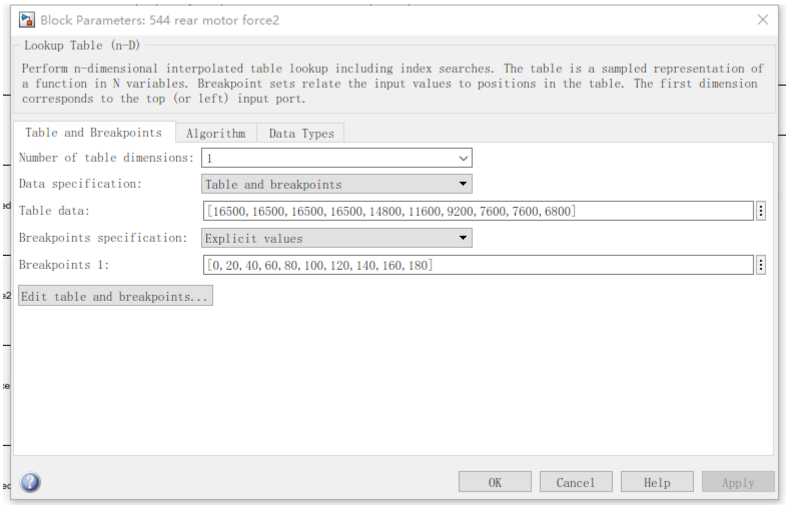


Figure 53 544 inverter, rear motor force with speed

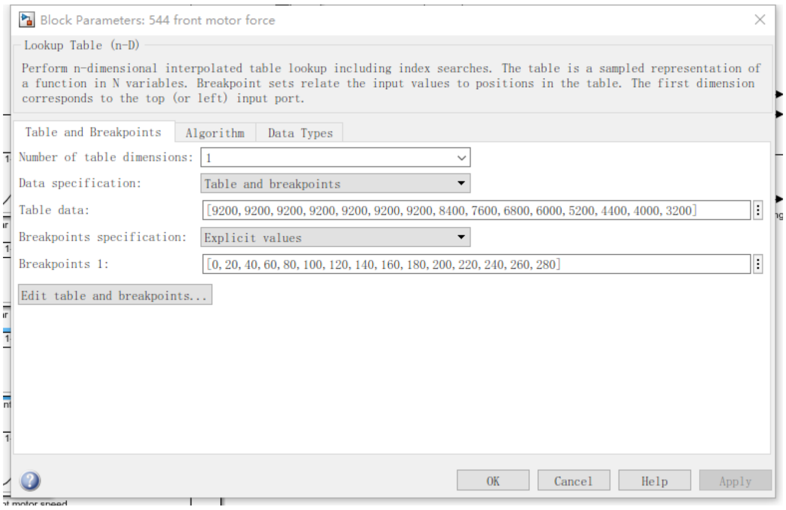


Figure 54 544 inverter, front motor force with speed

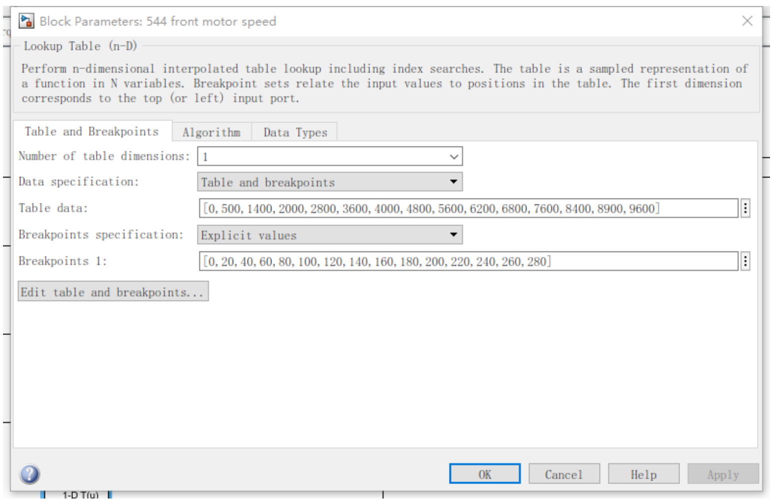


Figure 55 544 inverter, front motor speed with speed

The following scope shows the speed change of the vehicle during acceleration from 0km/h to 100km/h. From the scope, we can see the blue line is the command speed and the yellow curve is the real speed. With the 106kWh energy is depleted and the vehicle driving in a fixed speed of 100km/h, the endurance distance is 534.7km. From the time display block, we can see the vehicle acceleration time from standstill to 100km/h is 2.939 seconds. Look up the display block of Vmax, the vehicle speed can reach 100km/h. This result is the motor works with the gearbox ratio is 12 and the DMC 544 inverter, they can satisfy the acceleration requirement of the vehicle.

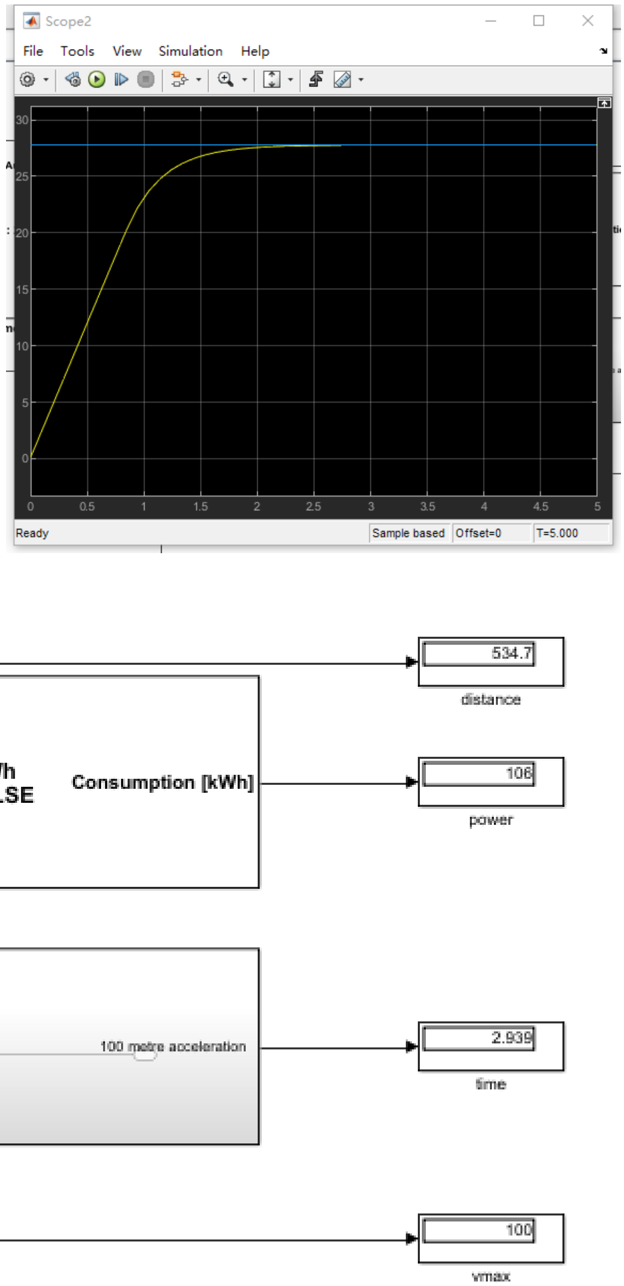


Figure 56 544 inverter accelerate to 100km/h

Now let’s check whether the vehicle can reach the maximum speed of 270km/h.

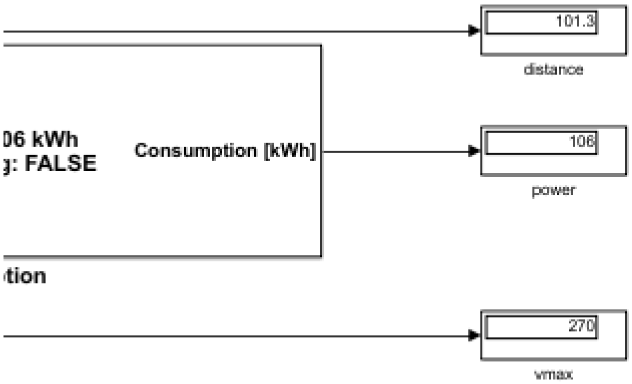


Figure 57 544 inverter accelerate to 270km/h

In the above figure, we can see the vehicle speed can reach 270km/h, motor works with DMC 544 inverter also satisfy the maximum speed requirement. With the 106kWh battery energy runs out, the endurance distance of the vehicle is 101.3km.

When the vehicle driving in NEDC condition, we need to know the maximum endurance distance of the vehicle. Same as works with DMC 534 inverter, we just run one cycle of the NEDC working condition, which is 1180 seconds. For saving simulating time, the value of maximum endurance distance of the vehicle is through calculating.

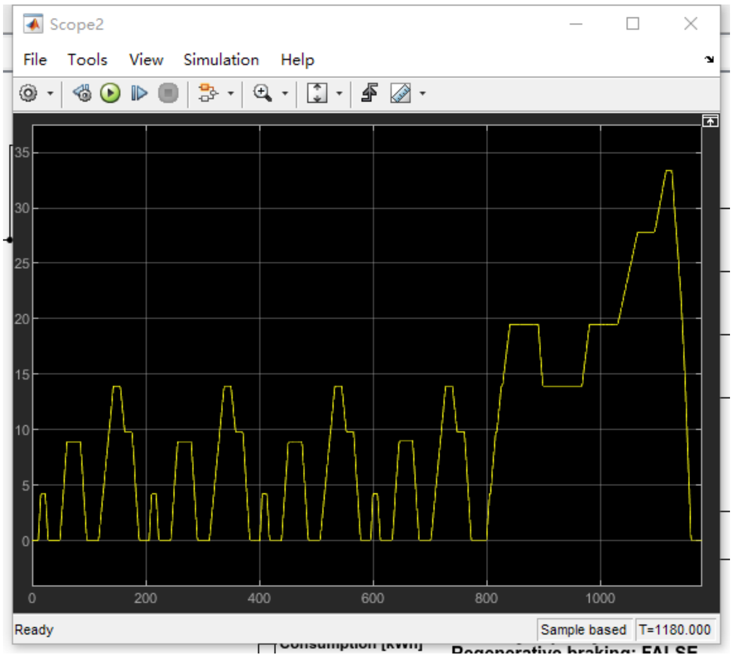


Figure 58 544 inverter relationship between time and velocity

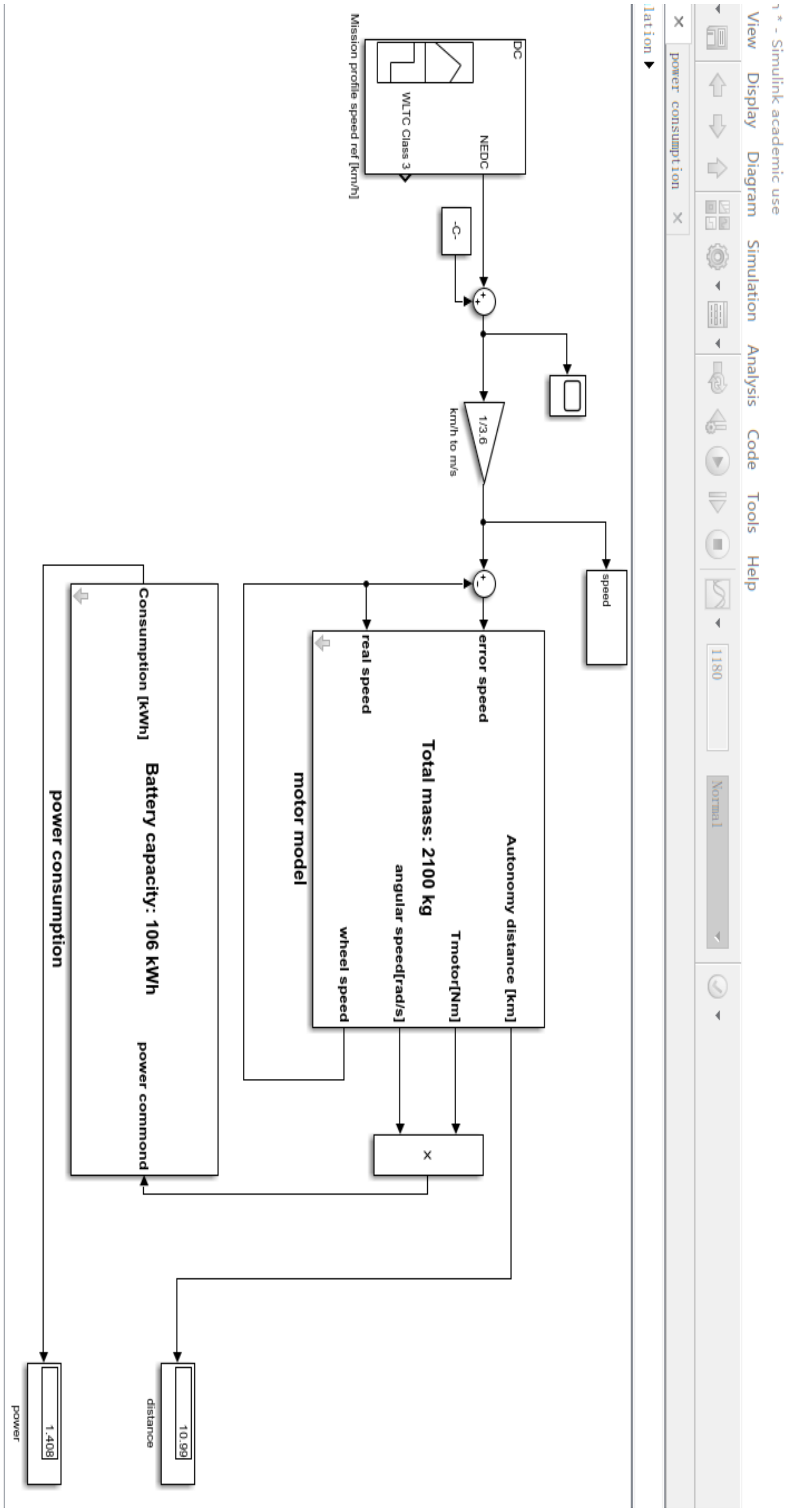


Figure 59 544 inverter driving in NEDC

The figure shows the vehicle driving with one cycle of NEDC condition, the distance is 10.99km and the energy consumption is 1.408kWh. If the vehicle keeps driving until the battery energy is exhausted, the distance can reach:

$$\frac{106}{1.408} \times 10.99 = 827.372km$$

Which means the DMC 544 inverter satisfy the vehicle required performance. Compare the situations that motor works with DMC 534 or DMC 544 inverter, the vehicle shows the same performances. Both of them can satisfy the vehicle performance requirements, we decided to use DMC 544 inverter in this design.

Check the maximum fixed speed that the vehicle can reach when the vehicle driving distance is not less than 600km.

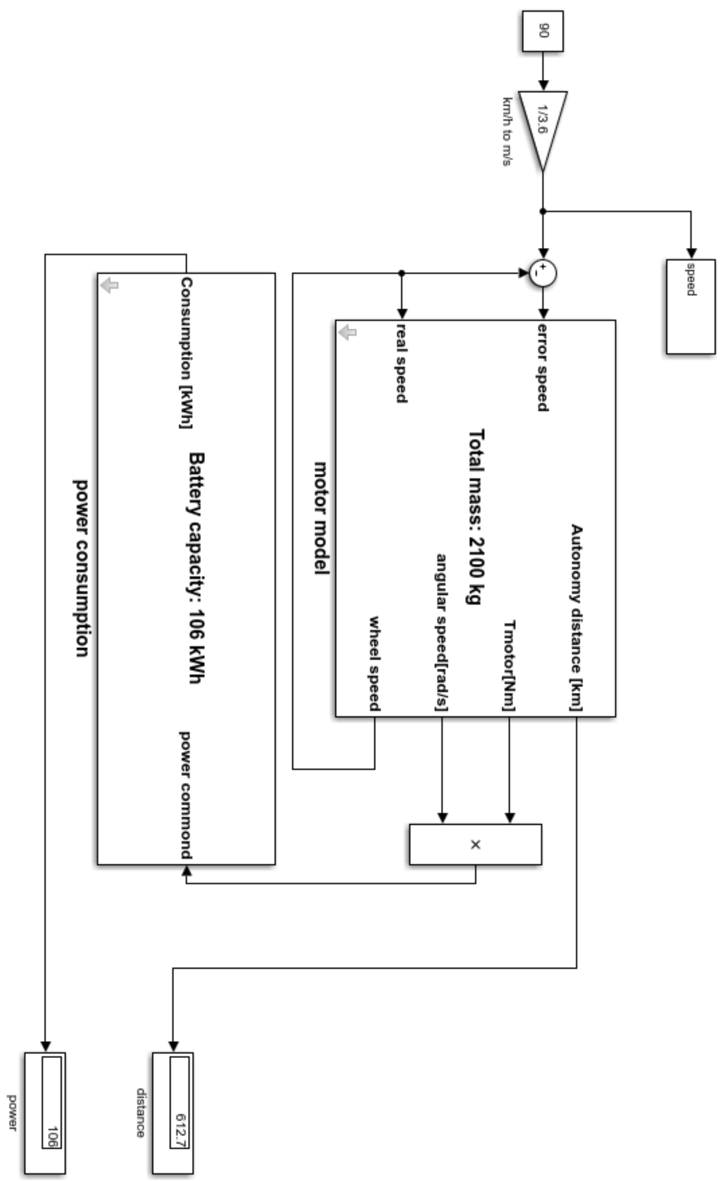


Figure 60 vehicle driving with fixed speed of 90km/h

This figure shows that when the vehicle driving in a fixed speed of 90km/h, with

106kWh energy runs out, the endurance distance is 612.7km.

At the beginning of the project, we know this project is to design a high-performance electric car. Let’s simulate the vehicle driving in the WLTC class 3 working condition and observe the vehicle maximum endurance distance.

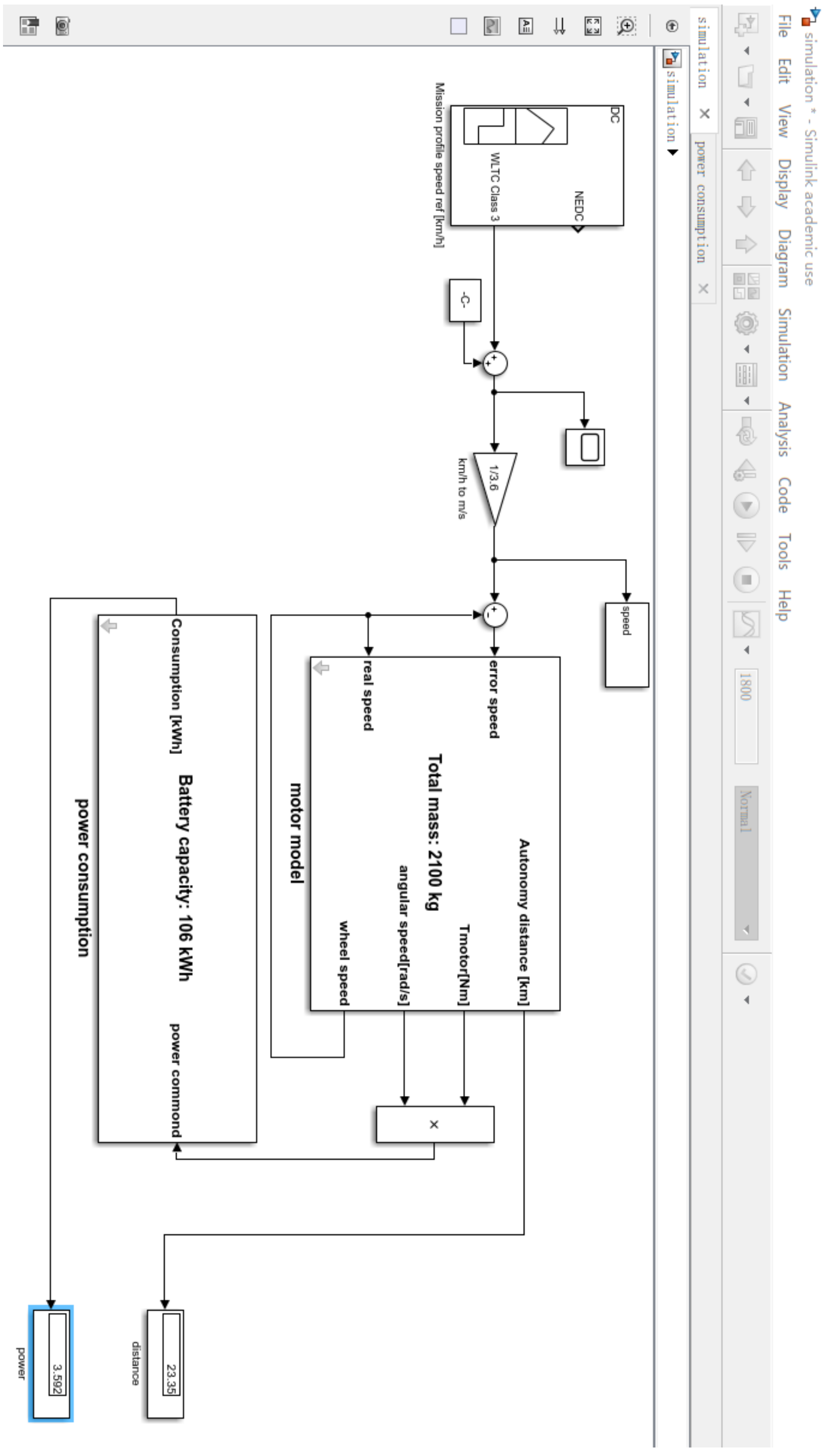


Figure 61 driving in WTLC class 3

Same as driving in the NEDC working condition, if the vehicle driving in WLTC condition until it runs out of battery energy, the simulating process will take a long time.

Similarly, in order to save time, we allow the vehicle driving only one cycle of the WLTC class3 condition as well as the NEDC condition. One cycle of WLTC class 3 condition is 1800 seconds. We calculate that the endurance distance of the vehicle is 689.05km.

$$\frac{106}{3.592} \times 23.35 = 689.05km$$

So far, we have finished the selection of the motor, battery, inverter, and gearbox. The figure shown below is the total parameters we use in this project. With all the part we choose, the vehicle can accelerate for standstill to 100km/h in three second and the acceleration time is 2.939 seconds. The maximum velocity of the vehicle can reach 270km/h. In the NEDC working condition, the endurance distance of the vehicle is 827.372km.

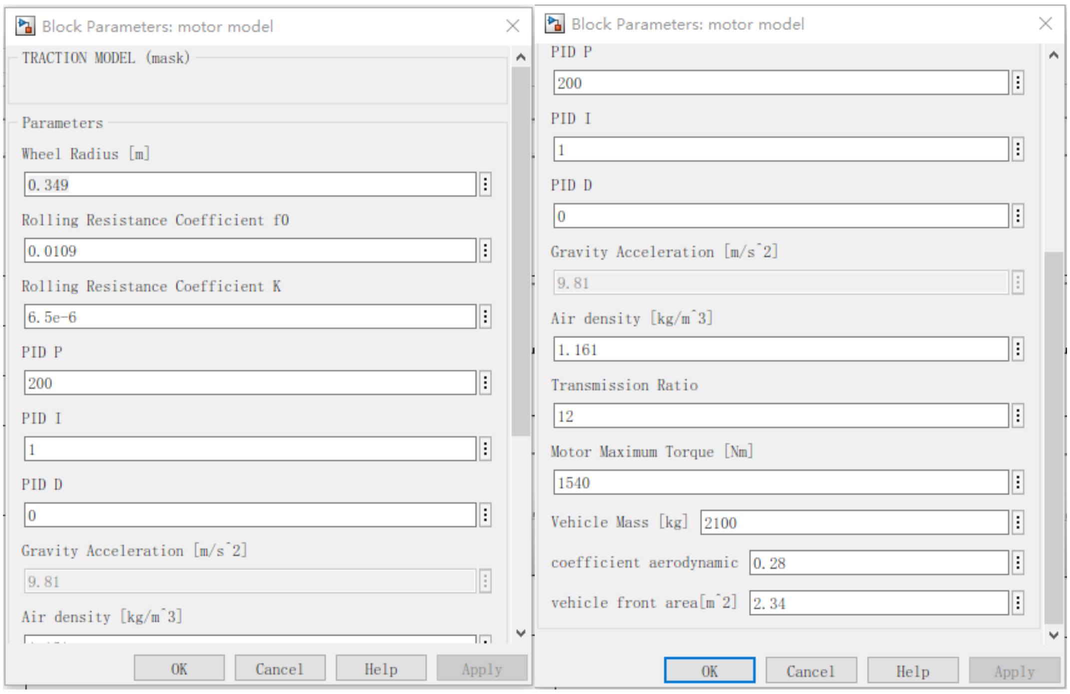


Figure 62 parameters in simulation

Tab 15 vehicle configuration

Vehicle configuration	
Mass (kg)	2100
Aerodynamic	0.28
Maximum speed (km/h)	270
Acceleration (0-100km/h)	2.939
Total power of motors (kW)	740
Total torque of motors (Nm)	1540
Distance (NEDC,km)	827.372
Distance (WTLC km)	689.05
Battery capacity (kWh)	106
Motor arrangement	Front/rear dual motors
Transmission type	Fixed gear ratio gearbox

Conclusion

Generally speaking, the main purpose of this project is to design a high-performance electric vehicle. Firstly, we preset some fixed parameters of the vehicle, such as vehicle height, vehicle weight, the area in front of the vehicle, and so on. Then set some physical parameters of the real situation, such as gravity acceleration, aerodynamic resistance, wheel rolling friction coefficient, etc. After determined the vehicle body parameters and physical parameters, we determined the expected performance of the car. The acceleration time of the vehicle from standstill to 100km/h less than 3 seconds. The maximum speed of the vehicle can reach 270km/h. In the NEDC working condition, the endurance distance of the vehicle is more than 600km.

The designed vehicle is for the Chinese market, we analyzed the current electric vehicle market in China and the preferential policies of the Chinese government for electric vehicles. At the same time, combined with the current development prospects of new energy vehicles, decided to design a pure electric vehicle.

In this project we use the front/rear dual motor in the vehicle, the selected the motor is asynchronous of Brusa HSM1-10.18.13. The inverter also from the Brusa company the type is DMC 544 inverter. The gearbox, we selected the fixed gear ratio gearbox with the ratio is 12. The battery pack is built by the 18650-lithium battery of LG company, the total battery pack has 8640 cells and the energy is 106kWh.

In the simulation part, we built a model to verify the parameters of the motor, inverter, gearbox and battery pack are available. The vehicle acceleration time from standstill to 100 km/h is 2.939 seconds. the maximum speed of the vehicle can reach 270 km/h. When the vehicle driving in NEDC working condition the endurance distance is 827.372 km. When the vehicle driving in the WLTC class 3 working condition, the endurance distance is 689.05 km. And when the vehicle is driven in the fixed speed of 90 km/h, the endurance distance is 612.7 km. All the expected performance are satisfied with our selection, it means the selected motor, inverter, gearbox, and battery are available.

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