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Review Article

Traction Motors and Motor Drivers Used in Electric Vehicles

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Abstract

The production and use of electric vehicles (EVs) are becoming widespread. The negative effect of fossil fuel vehicles to environmental pollution also increases incentives and demand for electric vehicles. One of the most important equipment in electric vehicles is the electric motors. The characteristics of the electric motors (EMs), change according to the usage area and power of the electric vehicles. There are some structural changes to the electric motors used for small powerful electric vehicles and electric motors produced for medium and large powerful vehicles. Depending on the power and structure of electric motors, the characteristics of the drives that control these motors also change. In this study, the structure, types, operating characteristics of the small, medium and large powerful electric motors used in electric vehicles and the motor driver circuits required to running the motors are mentioned.

Keywords: Electric vehicles, Electric traction motors, Electric vehicle motor drivers.

Elektrikli Araçlarda Kullanılan Motorlar ve Motor Sürücüleri

Öz

Elektrikli araçların (EA) üretimi ve kullanımı yaygınlaşmaktadır. Elektrikli araçlarda en önemli donanımlardan birisi, araçları hareket ettiren elektrik motorlarıdır. Elektrik motorlarının (EM) özellikleri, elektrikli araçların kullanım alanına ve gücüne göre değişmektedir. Küçük güçlü elektrikli araçlar için kullanılan elektrik motorlarında ve orta ile büyük güçlü araçlar için üretilen elektrik motorlarında bazı yapısal değişiklikler vardır. Elektrikli motorların güçlerine ve yapılarına göre, bu motorları kontrol eden sürücülerin özellikleri de değişmektedir. Bu çalışmada, elektrikli araçlarda kullanılan küçük, orta ve büyük güçlü elektrik motorların yapısı, çeşitleri, çalışma özellikleriyle motor sürücüleri sunulmaktadır.

Anahtar Kelimeler: Elektrikli araçlar, Elektrik çekiş motoru, Elektrikli araç motor sürücüler.

1. Introduction

Besides the basic vehicle requirement in electric vehicles there are battery pack, e-drive component (power electronics), e-motor, and single speed transmission (fixed Gearbox). Electric vehicles act with electric motors using direct current (DC) electrical energy from the batteries in the vehicle. A very important part of these motors work with DC while others work with the alternative current AC electrical energy obtained at the desired amplitude and frequency with the help of an inverter. These motors are also called electric traction motor (ETM). Required features in motors used in electric vehicles are high energy efficiency, low cost, high-performance, quick acceleration, stopping and starting numbers, durability to extreme temperatures and vibrations, simply construction, regenerative breaking capacity, long lifetime and low maintenance. Tomorrow's electric vehicles must use less energy to meet future challenges with

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accelerating shortage of resources, global warming and climate change. To reduce greenhouse gas (GHG) emissions, the use of Hybrid electric vehicles (HEV) and electric vehicles needs to be increased. In the long term, the use of fossil fuel vehicles should be limited or banned.

The production and sale of electric vehicles or “Electric Mobility”, especially bicycles, scooters and cars, has grown rapidly over the past decade. As of 2018, the rate of active electric vehicles in the world has reached approximately 30% of all vehicles. The countries with the highest number of electric car sales worldwide are China, Europe and the USA, respectively (URL1).

There are many different types of electric motors which are being used in current and upcoming EVs. These are Brushless DC motor (BLDC), AC induction motor (ACIM), Permanent magnet synchronous motor (PMS), and Permanent magnet switched reluctance motor (PMSRM). Although conventional brushed direct current motors were used in the first electric vehicles, they are no longer used today. Because these motors require high maintenance and sparking during their work.

A permanent magnet PM electric motor consists of two main parts. First; it is a stator in which electrical energy creates a rotating magnetic field and carries a series of electric coil windings. The other main part is the rotor on which very strong permanent magnets are placed. The stator is the fixed part and the rotor is the rotating part. The rotor follows and revolves the magnetic field created in the stator. If the rotor is inside the stator (Inner runner), outside of the stator is called (Outer runner) motor.

2. Material and Method

Manufacturers, users and researchers carry out a wide range of study and research to increase the efficiency and lifetime of electric motors, and to reduce losses and prices. High efficiency electric motors and power control units can provide both energy consumption and CO_2 footprint reduction.

The book written by Boldea and Nasar provides a comprehensive, independent and updated reference on single and three-phase induction machines (Boldea, I., & Nasar, S., 2009). The article written by Agamloh et al. determines how to improve the design efficiency of the motors currently being produced (Agamloh et al, 2013). Motors produced by five manufacturers were analyzed to increase design efficiency. Another article written by Groza et al. studies estimating the efficiency of motors by making necessary measurements in working environments and introduces a new concept of “μ and λ matching coefficients” (Groza et al, 2013).

In a study (Trianni et. al., 2019) a comprehensive review of energy efficiency measures (EEMs) for Electric motor systems (EMS) was presented. Various features and manufacturing advantages are specified, and EEMs for EMS are reclassified. EEMs are offered in four main groups: hardware, motor system drives, management of motors in the facility and power quality. In an article written by Ishikawa et al., the relationship between efficiency and source frequency and motor speed is achieved when efficiency is maximized for a given torque and speed. The equations obtained were verified using single phase equivalent circuit considering the iron loss resistance (Ishikawa et al, 2019). In a recent study (Barot et al, 2019), the general difficulties that small and medium motor manufacturers face during the design and development of IE3 class asynchronous motors and the selection of materials and the increase of efficiency by reducing losses have been talked.

In a study (Al-Badri et al, 2019) presents a new simple technique that can significantly reduce the time required for asynchronous machine full load tests. With the proposed technique, the time decreases to 30 minutes. The temperature-speed relationship is an important point and is used to estimate the full load temperature of the machine. Another article written by Adly, A. A., & Huzayyin, A., 2019 analyzed the economic situation of using PM motors instead of asynchronous motors. As a result of the analysis, they have been observed that the life cycle of PM motors is shortened compared to induction motors operating under the same conditions.

In a recent study (Karpe et al, 2019) is based on a 0.5 hp, 2 pole motor. The system is optimized with the help of double revolving theory. The design was verified by Finite Element Analysis. Analysis results was compared with test results and founded to be in good agreement. In this study (Lu, S. M., 2016) a survey was conducted about high efficiency motors, and it was concluded that brushless permanent magnet DC motors are popular motors in the motor industry. In another study Krykowski et al. they mention the characteristics of the drives used for high speed electric motors (Krykowski et al., 2019).

In this study (Omaç et al, 2018) an 18/12 pole in-wheel switched reluctance motor (IW-SRM) was produced with the values obtained as a result of various mathematical equations. The performance tests of the motor produced have been carried out by means of a test device. In their study (Bhatt et al, 2019), (Thattil et al, 2019), they compared various electric motors and determined that the most efficient motors that can be used in electric vehicles are permanent magnet brushless DC motors (BLDC). In addition, they recommended the use of permanent magnet synchronous motors and AC servo motors provided that regular maintenance is carried out.

In this study (Tarımer et al, 2008), were designed and tested a permanent magnet brushless DC motor for use in an ergonomic electric wheelchair. The test results obtained showed that this new design with low speed and high torque may be an alternative in electrical devices and systems.

In general, the inverter is an half or full bridge electronic circuit per phase that converts AC or DC electrical energy into AC energy suitable for the operation of the electric motor. The inverter adjusts the frequency and amplitude of the alternating current with the help of a microcontroller. The microcontroller evaluates all the parameters related to the vehicle and ensures that the necessary tasks are fulfilled. In this way, it can change the rotating speed, power and torque of the electric motor.

The book written by Diab et al, also presents a robust speed controller design for a sensorless vector-controlled induction motor drive system based on H∞ theory, which overcomes the problems of the classical controller (Diab et al, 2020). This paper (Kabir et al, 2019) presents the design characterization, optimization, and experimental validation of a multilayer ac winding that provides a high quality rotating MMF with reduced end-turn length. Multilayer ac winding provides more sinusoidal stator MMF with reduced stator I^2R losses compared to its conventional double layer counterparts.

In this study (Belousov et al, 2017) a solution related to speed adjustment is proposed in a system with two electric motors. A two-channel electric motor driver is used for motors. How to adjust the power and torque is shown. In this article (Zeraoulia et al, 2006), four main electric propulsion systems are examined. After all, the most suitable for hybrid electric vehicle (HEV) is explained by a comparative study. Squirrel-cage Induction Motors are recommended for this task.

This comprehensive review article (Krithika, V., & Subramani, C., 2018) discusses Permanent Magnet synchronous motor drives, Permanent Magnet brushless DC motor drives, and Permanent Magnet hybrid motor drives and their features. This article (Kommuri et al, 2016) discusses the effect of malfunction on a vehicle's speed in a sensor system that controls variable load torque of the permanent magnet synchronous motor (PMSM) driver. In this study (Kumar, A., & Thakura, P. R., 2019), two different controllers are used to start the BLDC motor and an inverter was designed. The designed inverter had been realized on the MATLAB Simulink platform.

3. Utilities of Electric Motors in Daily Vehicles

The most important parts of electric vehicles are electric motors and inverters. In addition, there are battery group(s) and charging system. Electric vehicles are usually manufactured in three sizes. Small size electric vehicles (two or three-wheelers bicycle, scooter, mini golf car, etc., 10 to 250 watts and used brushless in-wheel outer-runner motor usually). The structure of the brushless in-wheel outer runner motor is shown in Figure 1 (URL2).

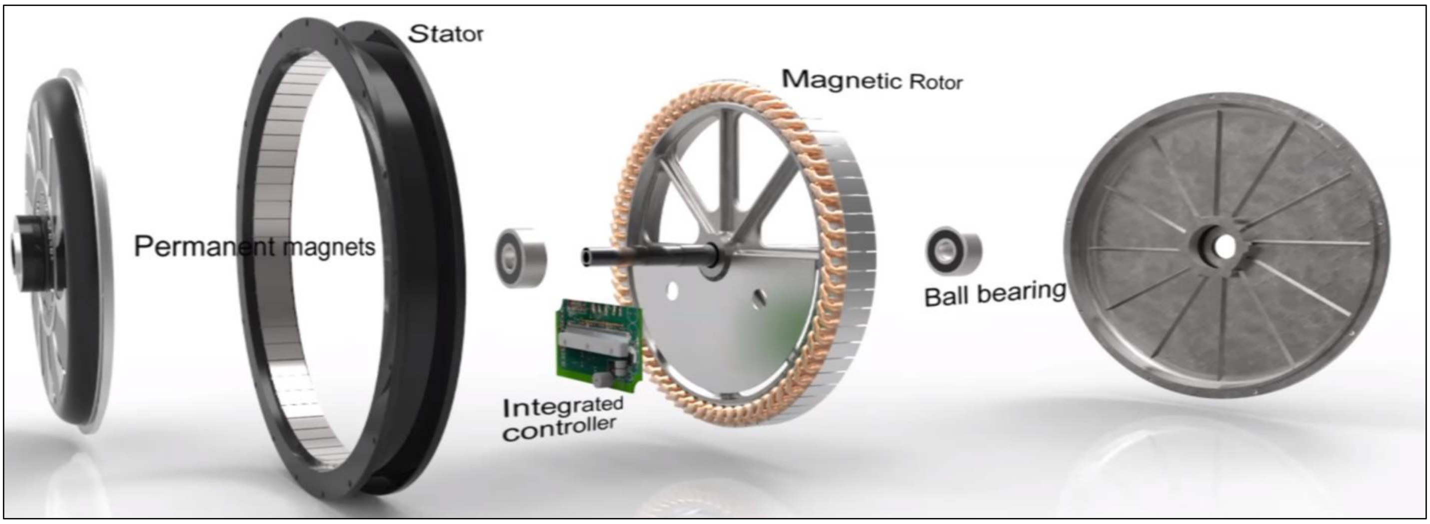

Figure 1: Structure of Brushless In-wheel Outer-runner Motor

Medium-sized electric vehicles are cars, vans, caravans, vans, etc. and their electric motor power is between 500 W. to 280 kW. Large and very large electric vehicles are used for buses, trucks, ships, trains, etc. vehicles and their electric motor power is greater than 280 kW. The inverters to be used for these engines are also produced according to the dimensions of the vehicles.

It has one or two electric motor in motor packaging. Systems with one electric motor are often used in automobiles. On the other hand, two electric motor systems are activated in some special cases when additional power is required (climbing and sudden acceleration). Figure 2 shows one (URL3) and two (URL4) electric motor packages.

Electric car motors have one single speed transmission (fixed gearbox) usually. This gearbox is used to increase motor autput torque. The motor speed change is carried out with the motor driver.

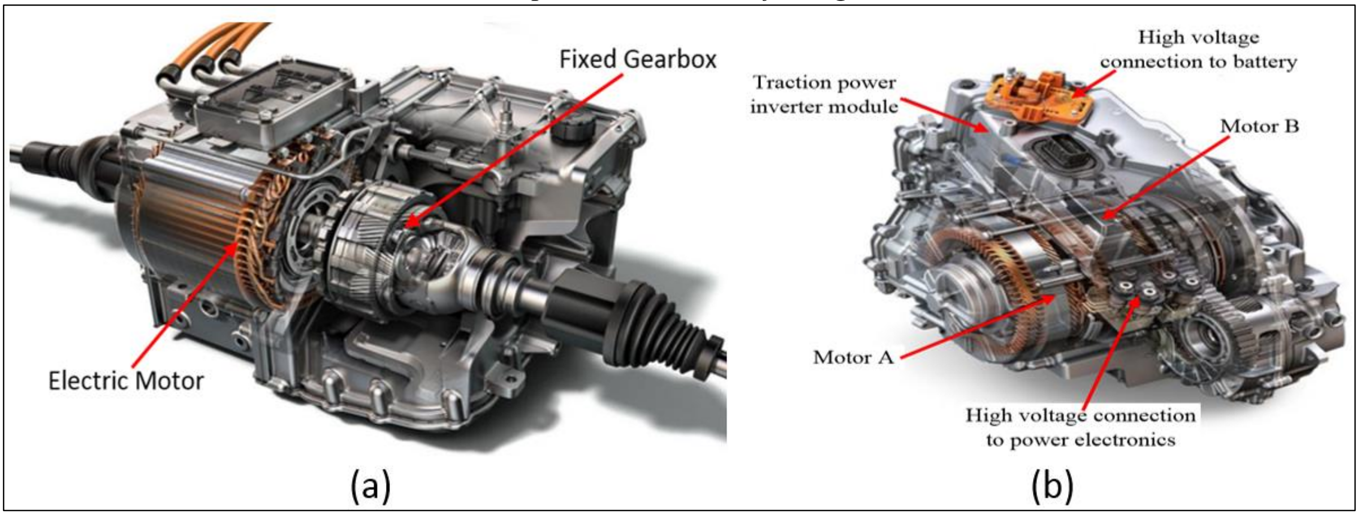

Figure 2: (a) One Electric Motor, (b) Two Electric Motor Tracking System

The most important features of the motors to be used in electric vehicles are high torque at the time of first movement and low power consumption and efficiency at high speeds. Therefore, the motor drivers to be used for EVs must also be capable of providing these requirements (Lazari et al, 2014). While selecting the motor, it is necessary to know the max voltage, current and load values. According to this information, motor torque and power are determined. Figure 3 shows typical power-torque-speed characteristics of electric traction motors (Ehsani et al, 2003).

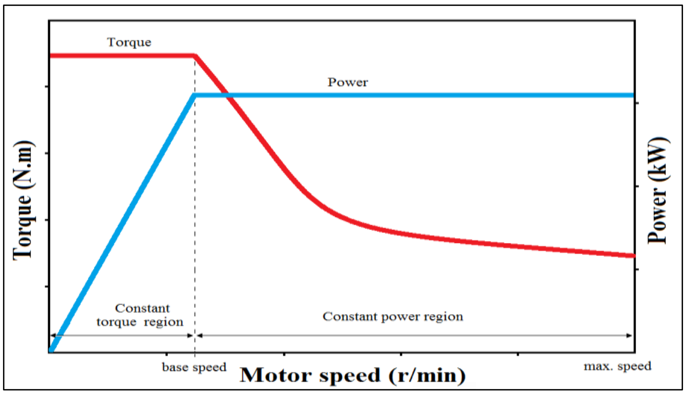

Figure 3. Typical Power-Torque-Speed Characteristics of Electric Traction Motors

Various motors used in electric vehicles are compared in terms of power density, efficiency, reliability, controllability and cost, and are shown in figure 4 (Bhatt et al,2019).

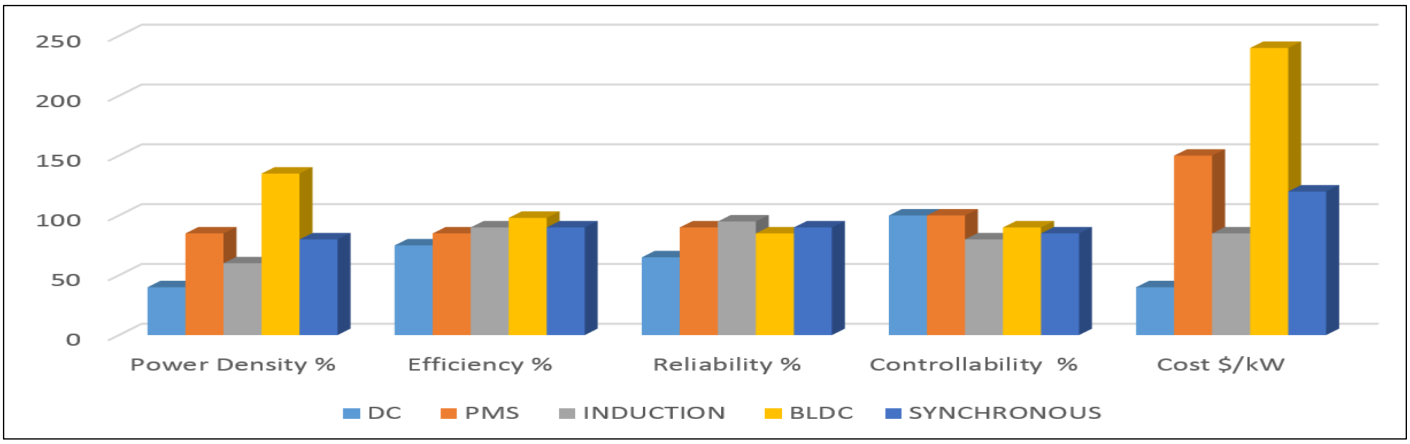

Figure 4: Comparison of Various Electric Motors Used in Electric Vehicles

When Figure 4 is examined, it is seen that BLDC motors are more advantageous in terms of usage compared to other electric motors. But these motors are expensive than others.

BLDC motor is suitable for all of vehicle applications. These electric motors are equipped with hall-effect position and speed sensors usually (Gökozan, H., & Taştan, M., 2019). These sensors support to work properly. The motor at the same time operates like a generator during braking time, generating electricity and charging the batteries. This is called regenerative braking. Principle of an inverter and Traction Motor connecting is seen in figure 5 (URL5).

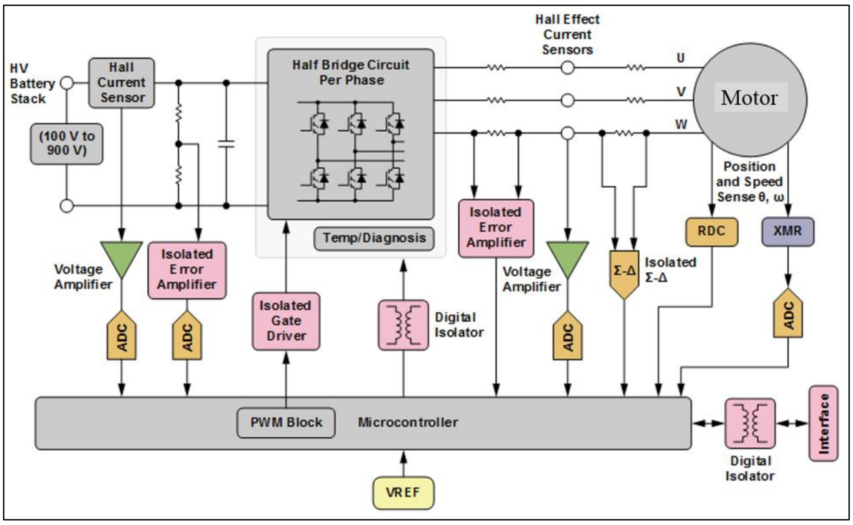

Figure 5. Principle of a Inverter and Traction Motor

Motors and inverters used in large and very large electric vehicles are connected in various ways. With single-axle control, each converter feeds only one motor. Group drive means that one converter feeds several motors, depending on whether car control or bogie control is used. Single-axle control (a), and group drive (b) are shown in figure 6 (URL6).

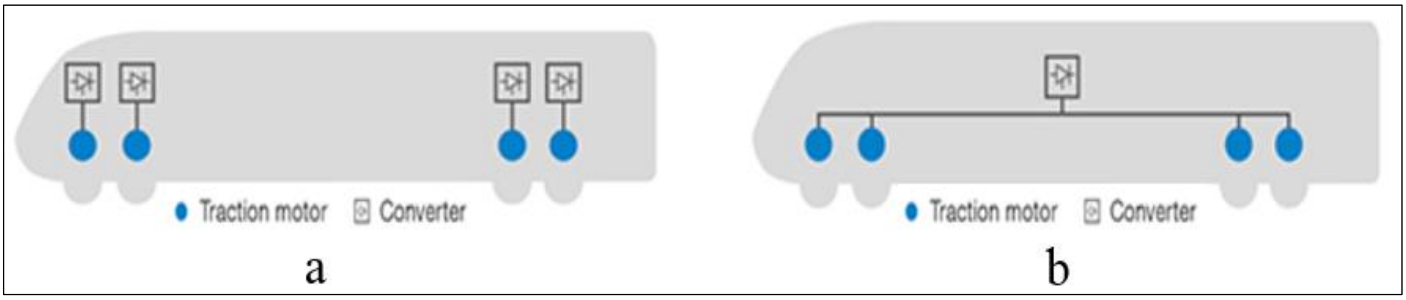

Figure 6: (a) Single-axle Control, (b) Group Drive

The principle of a high-performance double-wheel drive inverter for metro and public transport applications with 2, (a) and 4, (b) motors (URL7) are shown in figure 7. Each Traction Control Unit (TCU) controls two motors.

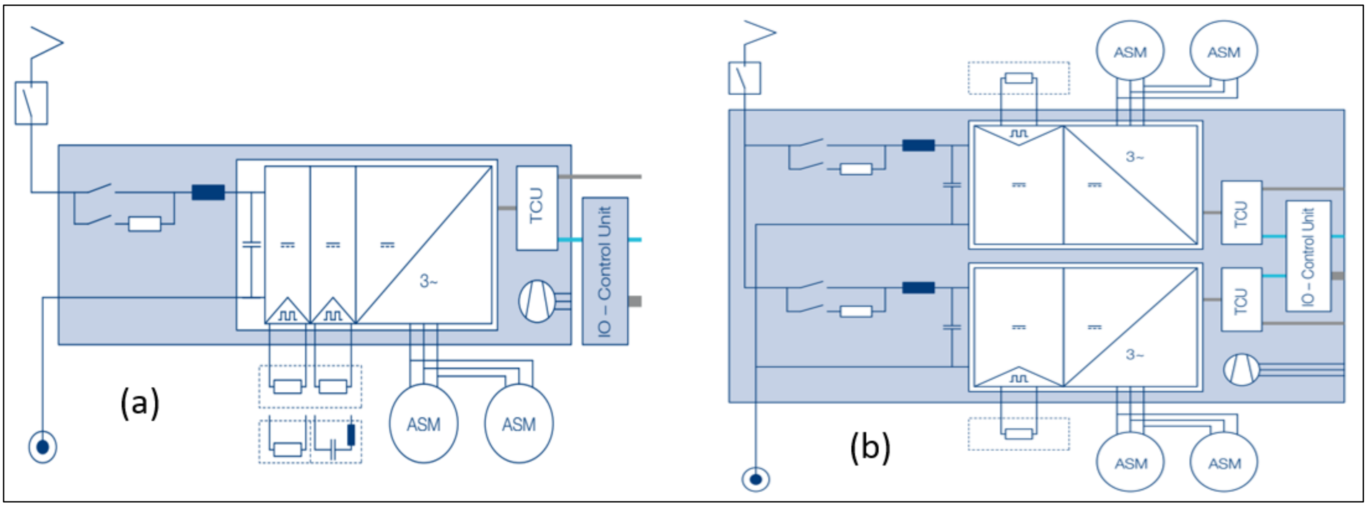

Figure 7: Principle of a High-Performance Double Traction Inverter for Metro Applications

4. Conclusion

The characteristics of the motors used in electric vehicles differ from those used in the industry. The most important features of the motors to be used in electric vehicles are high torque at the time of first movement and low power consumption and efficiency at high speeds. In addition, these motors are commonly used in start and stop cars. Therefore, they may be heat up more. Hence, they need good cooling.

The motors commonly used in electric vehicles are BLDC motors. Thanks to the high magnetic rotor feature, they produce high torque. Specially designed electronic circuits are required to start the motors. These circuits are called motor drives. Motor drivers are control the electric motors by interpreting the accelerator and brake pedal information.

There is currently no Motor Vehicle Tax for electric vehicles. The Special Consumption Tax application is calculated according to the value of the engine power produced by the vehicle in kW. As a result of the widespread use of electric vehicles, the need for fossil fuels will disappear. The price of fuel paid for electric cars is much lower than oil powered cars. Global warming caused by the decrease in city and air pollution will be prevented.

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