# Integrated motor drive for vehicle electrification: a step toward a more sustainable and efficient transportation system

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**ABSTRACT**

The transportation sector is a big source of greenhouse gas (GHG) emissions. It is responsible for about 20% of all carbon dioxide ($CO_2$) emissions in the world, and most of those emissions come from road transportation. The development of greater efficiency vehicles with much reduced fuel consumption and GHG emissions is critical for vehicle electrification and a sustainable transportation system. Electric vehicles (EVs) offer higher energy efficiency than internal combustion engines and emit no $CO_2$ during operation. For future vehicle electrification, cost-effective electric powertrain options are required. The current state of development of two major components of the EV powertrain: motors and drives, is introduced in this editorial.

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## 1. INTRODUCTION

Transport is a critical engine of economic and social growth. Transportation infrastructure connects people to jobs, education, health care, and each other. At the same time, transportation emits pollutants that contribute to air pollution and climate change. A sustainable transportation system necessitates the development of higher efficiency vehicles with much lower fuel consumption and greenhouse gas (GHG) emissions. Electric vehicles (EVs) use less energy than internal combustion engines and produce no $CO_2$. There is a strong push to electrify transportation, which is the process of powering a vehicle with electricity by replacing vehicle components that use a conventional energy source with components that use electricity. In general, vehicle electrification focuses on the powertrain and its auxiliary systems that are powered by electricity. Vehicle electrification also encompasses many other areas of car functionality that are present in a non-electric vehicle [1].

Between 2019 and 2028, the global EV battery industry is estimated to rise from $17 billion to more than $95 billion. Currently, Chinese firms account for 56% of the EV battery market, followed by Korean companies (26%), and Japanese manufacturers (10%). Contemporary Amperex Technology Co. Limited (CATL), the industry leader in batteries, increased its market share from 32% in 2021 to 34% in 2022. The Chinese business produces one-third of the world's EV batteries. CATL supplies lithium-ion batteries to Tesla, Peugeot, Hyundai, Honda, BMW, Toyota, Volkswagen, and Volvo. Despite facing intense scrutiny following EV battery-fire recalls in the United States, LG Energy Solution remains the second-largest battery maker. In

2021, the South Korean supplier agreed to reimburse General Motors $1.9 billion to cover the 143,000 Chevy Bolt EVs recalled owing to fire risks from defective batteries [2].

In addition to the battery, electric motors and drives (powertrains) are key components for EVs. They must be dependable, compact, lightweight, and efficient. A fast reaction, strong speed-to-torque ratio, and tolerance of heat and mechanical stresses are also crucial in terms of performance throughout a wide operating range. The expense of the powertrain is a key barrier to the affordability of EVs. It is critical to develop cost-effective electric powertrain options for future vehicle electrification. This editorial addresses the present state of development of two major components of the EV powertrain: motors and drives.

## 2. WHAT IS THE PROCESS OF VEHICLE ELECTRIFICATION?

The primary goal of vehicle electrification is to replace a gasoline engine with an electric powertrain. The traction battery pack in an electric powertrain uses the energy stored in it to drive the electric motor via a power electronics converter. During braking or when the vehicle's speed is lowered, the electric energy is returned to the battery via a regenerative braking system. The control strategy and architecture of the converter will differ depending on the type of electric motor employed. Electric vehicles (EVs) currently use dc series motors (DCMs), brushless dc motors (BLDCMs), interior permanent magnet synchronous machines (IPMSMs), induction machines (IMs), and switched reluctance machines (SRMs). BMW has recently employed electronically excited synchronous motors (EESMs) to avoid using rare-earth permanent magnets. Each motor type has advantages and disadvantages [1], [3]:

- DCM: The DCM has a strong starting torque, making it appropriate for traction applications; it is simple to use for speed control; it was widely employed for vehicle applications in the early 1900s; and it requires a lot of maintenance due to the brushes and commutators.
- BLDCM: BLDCMs are DCMs that use permanent magnets. The commutation is done electronically; the price of a BLDCM is more than that of a comparable size DCM; and the BLDCM is commonly utilized in electric mopeds.
- IPMSM: The IPMSM is the most frequently used electric motor in modern EVs. It offers a high torque density and better efficiency, particularly at low- and medium-speed ranges. It also requires rare-earth permanent magnets and thermal management to overcome the rare-earth magnets' sensitivity to temperature.
- IM: The industry's workhorse has traditionally been the IM. It runs at a lower power factor with worse efficiency at low speeds; it has a track record of dependability and durability. The main drawback of the IM is the inherent core and copper losses, albeit a correctly constructed IM can provide more torque and high-speed operation. At low speeds and high torque, heat dissipation can be difficult.
- SRM: The SRM is the most affordable machine and has the most straightforward, reliable design. In comparison to IPMSM and IM, SRM is known to have the simplest, most durable, and least expensive construction. The main shortcomings of the SRM are torque ripple and vibration; nonetheless, with advanced design and control methods, the SRM may be an option for EVs.
- EESM: This motor produces electromotive force by using slip rings and brushes to feed electricity to the rotor; high efficiency and lower cost of production of the EESM; It is not necessary to use rare-earth materials, there is no danger of demagnetization, and the motor's long-term dependability has not yet been confirmed.

## 3. TYPES OF VEHICLE ELECTRIFICATION TECHNOLOGIES

The inverter and related controller in an electric powertrain are in charge of managing the electric motor. This is comparable to a classic vehicle's engine management system. Meeting the desired performance levels, reducing switching losses, and maximizing overall efficiency are the shared objectives. The most popular electric machines in modern EVs are IPMSMs and IMs, hence three-phase voltage source inverters are preferred because of their great efficiency, low cost, and straightforward control requirements. Although the Si-insulated gate bipolar transistor was the preferred power device in the 1990s, recent developments in wide-bandgap (WBG) devices using components like silicon carbide and gallium nitride open the door to higher power densities, higher efficiency, and lower operating temperatures in the traction inverter drives. In order to increase the efficiency of e-fuel, the inverter also absorbs energy from regenerative braking [3].

With current battery technology, it is difficult to totally replace a gas-powered motor with an electric one and still satisfy all consumer demands. The maximum energy that can be stored in a battery cell is the main cause. But hybrids, which combine an internal combustion engine and an electric motor, can fill the gap between battery-powered cars and regular cars. The effectiveness of traditional gasoline vehicles can also be increased by hybrids. There are various technologies available for electrifying vehicles, including [3]:

- Hybrid electric cars (HEVs): HEVs combine an electric propulsion technology with an internal combustion engine. The majority of the energy is delivered by ICE, and the electric powertrain technology is simply employed to increase fuel efficiency.
- Plug-in hybrid electric vehicles (PHEVs): ICE and electric powertrain technologies are both combined in PHEVs. An electric power grid or regenerative braking can be used to store energy in a PHEV. The PHEV uses only electric power up to the point where the battery is almost completely exhausted, at which point it switches to using ICE. There are two primary PHEV models. When the battery is fully charged, blended plug-in hybrid electric vehicles (PHEVs) use a combination of gasoline and electricity; however, when the battery is discharged, they only use gasoline. Because peak power demands are not required to be met solely by the electrical system, blended operation has the benefit of allowing for a smaller electrical system. Extended range electric vehicles (EREVs) are plug-in hybrid electric vehicles (PHEVs) that only run-on electricity while the battery is charged and switch to running on gas when the battery is discharged. The car functions as a BEV for distances that are less than the battery's capacity to travel.
- Battery electric vehicles (BEVs): BEVs have bigger battery packs so they can store more energy from the electrical grid and go farther. They lack an additional gasoline engine. Some people also call BEVs "pure-electric vehicles" or "all-electric automobiles" (AEVs).
- Fuel cell electric vehicles (FCEVs): FCEVs employ a fuel cell to generate electricity to power the car while refueling with hydrogen. Fuel-cell vehicles, or FCVs, are another name for FCEVs.

BEV challenges include limited driving range, high pricing, battery difficulties, long charging times, and insufficient charging infrastructure. There are also challenges with various power semiconductors and other devices when it comes to car electrification. The topic of charging is critical to the success of vehicle electrification. The primary technical problem is that the energy density of lithium-ion batteries only allows for a limited driving range of 400 to 500 km (249 to 311 miles), whereas consumers prefer a driving range of 700 km (435 miles) or greater. Furthermore, the size and mass of a battery pack constrain its design. More battery cells equal more vehicle mass. Increased mass necessitates more energy for vehicle movement and has an impact on vehicle agility, including handling, acceleration, and braking. The larger the mass, the more difficult it is to get good performance metrics. Furthermore, all BEV batteries deteriorate (become less efficient). Most automakers guarantee that EV batteries will not degrade below a specific level for at least eight years. As a result, replacing a battery in an EV while the driver owns the car may become necessary. With the correct infrastructure and charging convenience, EVs might compete with ICE automobiles. Long-distance travel is a major issue because charging stations are not always available. More fast-charging stations necessitate significant expenditure. Daily recharging at home or work, or in public or commercial parking places (retail outlets and highway rest areas) would, on the other hand, eliminate the need for drivers to stop at filling stations in the future. Charging comfort in general would help PHEV utilization significantly by ensuring that they are run in electric mode as often as feasible in urban areas, while lowering range anxiety during longer excursions where the availability of (and access to) sufficient charging facilities is questionable [3].

## 4. INTEGRATED MOTOR DRIVE

The integrated motor drive (IMD) is a structural integration of an electric motor and a motor drive as a single unit that increases power density with 10-20% less volume and reduces installation and manufacturing costs by 30-40%. The key driving force behind the cost reduction is the deletion of costly components such as shielded connection cables, a separate housing for the inverter, a centralized controller cabinet, and high-voltage and current bus bars. It also improves electromagnetic interference (EMI) or electromagnetic compatibility behavior since the motor is directly connected to the drive without the use of additional connections [1].

WBG devices enable modular powertrain design due to increased power density, efficiency, and operating temperatures. There is a tendency toward combining a motor, an inverter, and a controller circuit into a single device. The benefits of an integrated motor drive (IMD) include: i) lower cost, ii) simpler layout and loss reduction, iii) lower noise and spikes with better impedance matching, iv) better motor/driver matching and optimization, and v) reduced electromagnetic compatibility difficulties. Despite the appealing advantages, coupling drives and related controls with motors poses issues in terms of temperature management, vibration, and electromagnetic interference. Only sub-10-kW IMD modules are currently available on the market [1].

Vehicle electrification is critical to combating climate change and achieving the goal of net-zero carbon emissions by 2050. The powertrain is the most important component of an EV, aside from the batteries. Although advancements in motor technology, quick increases in power electronics, and innovations in control techniques have established a market for numerous types of EVs, there are obstacles and opportunities to build next-generation EVs with disruptive technologies [1].

## 5. CONCLUSION

A sustainable transportation system necessitates the use of high-efficiency, low-emission vehicles. Electrifying transportation powering a vehicle with electricity by replacing traditional energy sources with electric ones is a big trend. This editorial provided an outlined on the progress of two important components of the EV powertrain: motors and drives. The control technique and architecture of the converter varied depending on the type of electric motor used. Electric vehicles (EVs) currently use dc series motors (DCMs), brushless dc motors (BLDCMs), interior permanent magnet synchronous machines (IPMSMs), induction machines (IMs), and switching reluctance machines (SRMs). Power density, efficiency, and operating temperatures enable modular powertrain design with wide-bandgap (WBG) devices. An integrated motor drive (IMD) offers lower cost, simpler layout and loss reduction, lower noise and spikes with better impedance matching, improved motor/driver matching and optimization, and fewer electromagnetic compatibility issues. Despite the benefits, linking drives and controllers with motors causes temperature, vibration, and electromagnetic interference difficulties.

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