© Infineon Technologies

Drivetrain and Semiconductor Technologies in Future EVs

WRITTEN BY

Dirk Geiger
is Senior Director Automotive Application Marketing and Management, Infineon Technologies at Neubiberg (Germany).

Christoph Bauer
is Global System Architect for Automotive Traction Inverters, Infineon Technologies at Neubiberg (Germany).

The traction inverter determines the power output and directly impacts the vehicle‘s dynamics. It is therefore a key to efficient and sustainable e-mobility. Nevertheless, the complementary subsystems and latest power semiconductors are also crucial to approaching ambitious aims – like Infineon’s vision of “10 kWh for 100 km”.

The drivetrain system of a modern vehicle consists of the On-Board Charger (OBC), the Battery Management System (BMS), inverters and the traction motor, **FIGURE 1**. These applications complement each other in order to optimize vehicle efficiency: Battery capacity and electrical efficiency, for example, are critical to range. However, for the best possible driving performance, all aspects of the electric drivetrain and vehicle must be optimized, including weight, aerodynamic drag, rolling resistance, and recuperation efficiency. In the overall concept, the integration of the vehicle into smart charging infrastructures and the selection and sizing of the EV for its application are also important. To achieve a sustainable life cycle, the vehicle‘s production processes and recycling options must also be considered.

Range might not be the decisive factor when OEMs discuss efficiency. Improved vehicle efficiency leads directly to less vehicle weight. This in turn means that production requires fewer raw materials and rare earths, and lower energy consumption for a given distance. Efficiency is therefore the key to producing more vehicles at affordable prices.

THE TRACTION INVERTER – MORE THAN A CONVERTER

The traction motor is controlled by an inverter. It converts the direct current (DC)

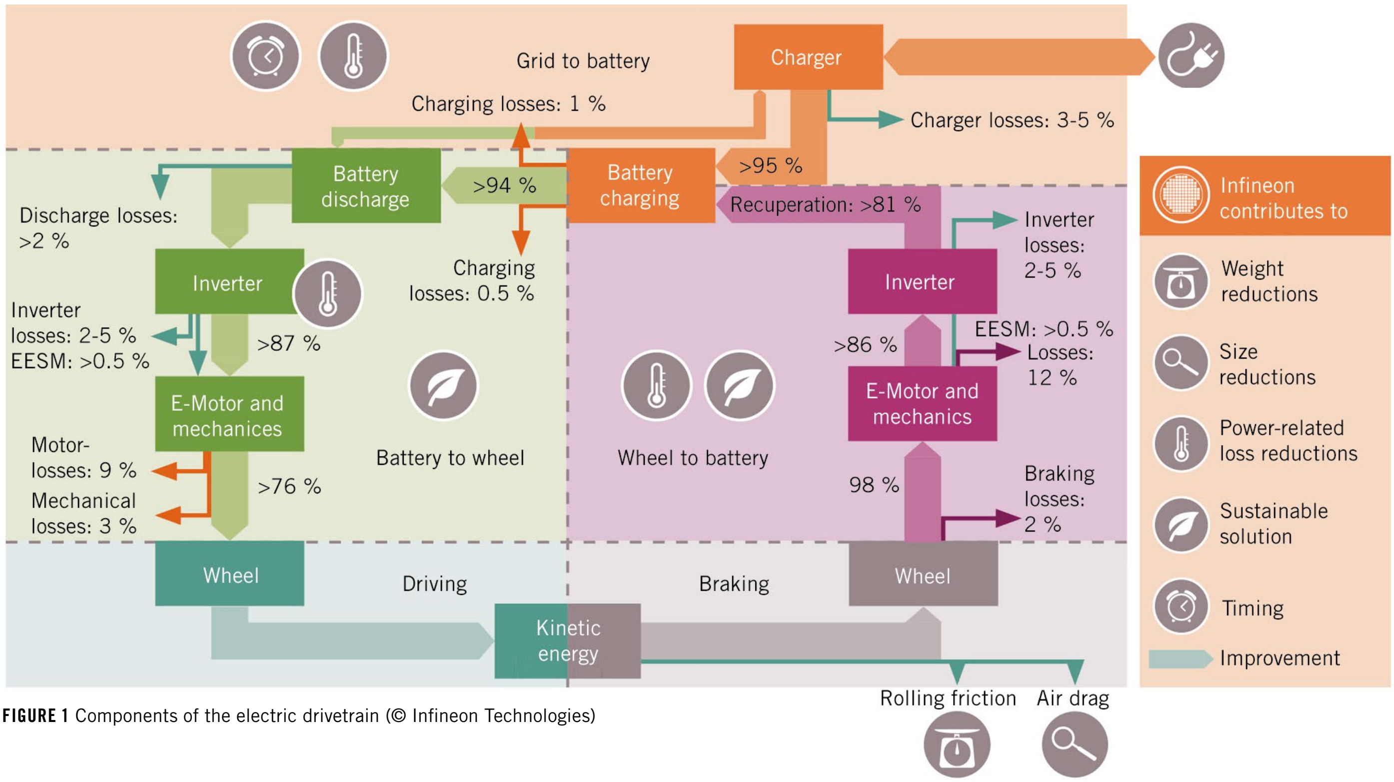


FIGURE 1 Components of the electric drivetrain (© Infineon Technologies)

into the alternating current (AC) required to power the engine. It also changes the speed of the motor by adjusting the AC frequency. Furthermore, in generator mode, it acts as a brake allowing the vehicle's dynamic energy to be harvested. This closes the energy loop, **FIGURE 2**, whereby the more efficient the recuperation, the more energy can be retained in the system. Therefore, power semiconductors based on silicon carbide (SiC) are advantageous because they allow for bi-directional currents within the switch. On the other hand, since less energy is converted to heat via the mechanical brakes, more energy can be recuperated. This inevitably leads to a reduction in brake dust – a desirable side effect, especially in congested urban areas.

The introduction of the all-electric drivetrain also brings new challenges: More and more applications are connected to the drivetrain and depend on each other. These interdependencies require OEMs to think more holistically, which in turn offers new optimization opportunities. For instance, using the traction inverter as a braking system can eliminate the need for a fully mechanical brake. Unlike the latter, the traction inverter generates more precise and efficient torque, which supports hill hold, braking, and ABS. A four-motor system with torque management could replace a standard Electronic Stability Control (ESC). Thus, the traction inverter is much more than just a motor drive for the vehicle, **FIGURE 3**.

HOW WBG SEMICONDUCTORS BOOST PERFORMANCE

Wide-bandgap (WBG) semiconductor devices enhance power efficiency in electric vehicles – among others, for example, in traction inverters, onboard chargers and High-Voltage DC-DC (HV-DCDC) converters. In the context of efficiency, it is important to consider the entire application, from a complementary and optimized chipset of microcontroller, sensors, gate driver, and power switch to vehicle integration and peripheral functions. The efficiency of today's traction inverters is already well above 98 %. Further efficiency-improving drive innovations will therefore primarily affect motors, gearboxes, and cooling systems.

Optimizing efficiency is at the forefront of current developments, with new power switching technologies and advanced microcontroller functions enabling the next generation of traction inverters. The focus is on cost, but performance, manufacturability and integration are also important aspects, **FIGURE 4**. In terms of defining and improving the efficiency of traction inverters, switching devices, such as Mosfets and IGBTs – and their associated diodes – have the greatest impact. To improve these devices, two materials provide the necessary performance: silicon carbide and gallium nitride (GaN). Both WBG compound semiconductors are characterized by their high electron mobility. Many engineers see them as key to the performance of future power systems in harsh environments – for example, in drive inverters. SiC-based semiconductor switches help increase efficiency by addressing the two main causes of losses in power designs:

- Conduction losses, where the lower on-resistance between drain and source $R_{DS(ON)}$ reduces losses and thus heat generation. Since in SiC and GaN switches the current passes through the channel rather than through the diode during motoring and generator mode, this is a crucial parameter.
- Switching losses, which are of similar magnitude to conduction losses and are therefore equally important.

As the trend is toward higher switching frequencies, targeting up to 40 kHz,

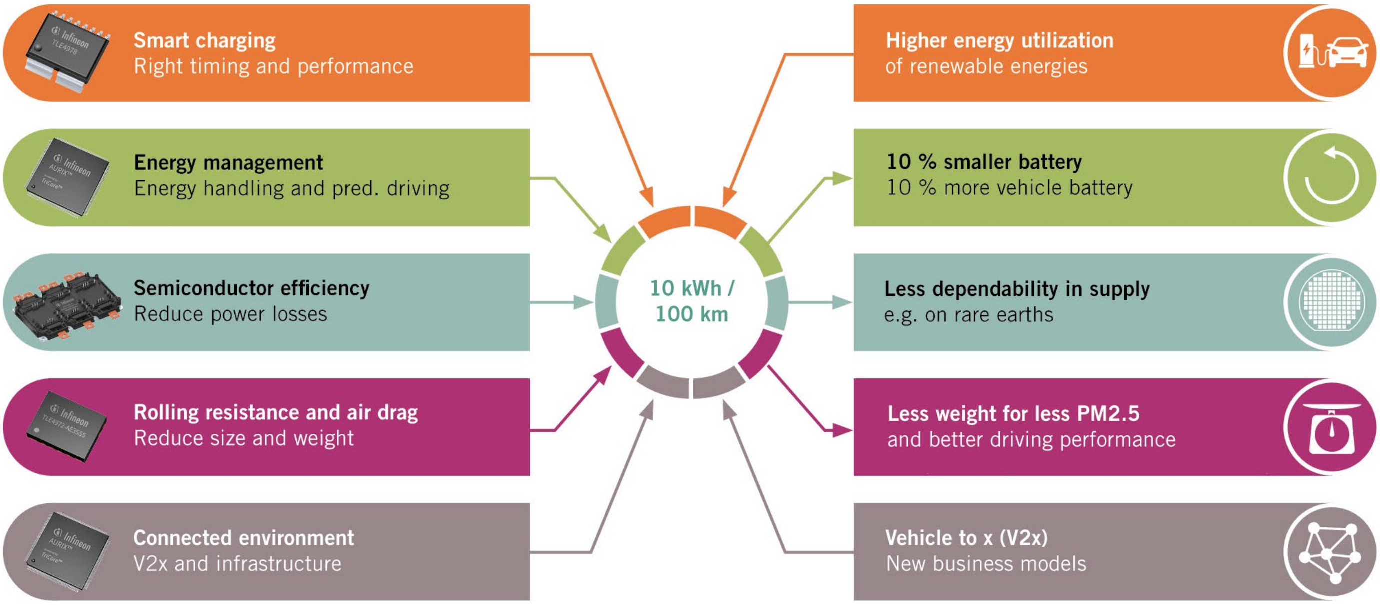


FIGURE 2 For a greener future, it is critical to consider all aspects of the vehicle's architecture to achieve the best efficiency (© Infineon Technologies)

losses during a single switching event have to be reduced. Using SiC or GaN technology, switching speeds can be increased up to 40 V/ns, which reduces losses – the current state of the art is about 10 V/ns. Further improvements are possible, particularly with GaN. However, the application itself, most likely limited by the insulation strength of the traction motors and EMC constraints, requires compromises.

GaN and SiC offer different strengths. However, their advantages depend on the specific application. The benefits of SiC are due to its band gap. In addition to its electron mobility, the critical breakdown voltage is also high compared to silicon. As a result, SiC devices can be made smaller and with a shorter channel, resulting in lower on-resistance at a given nominal voltage. Smaller chip

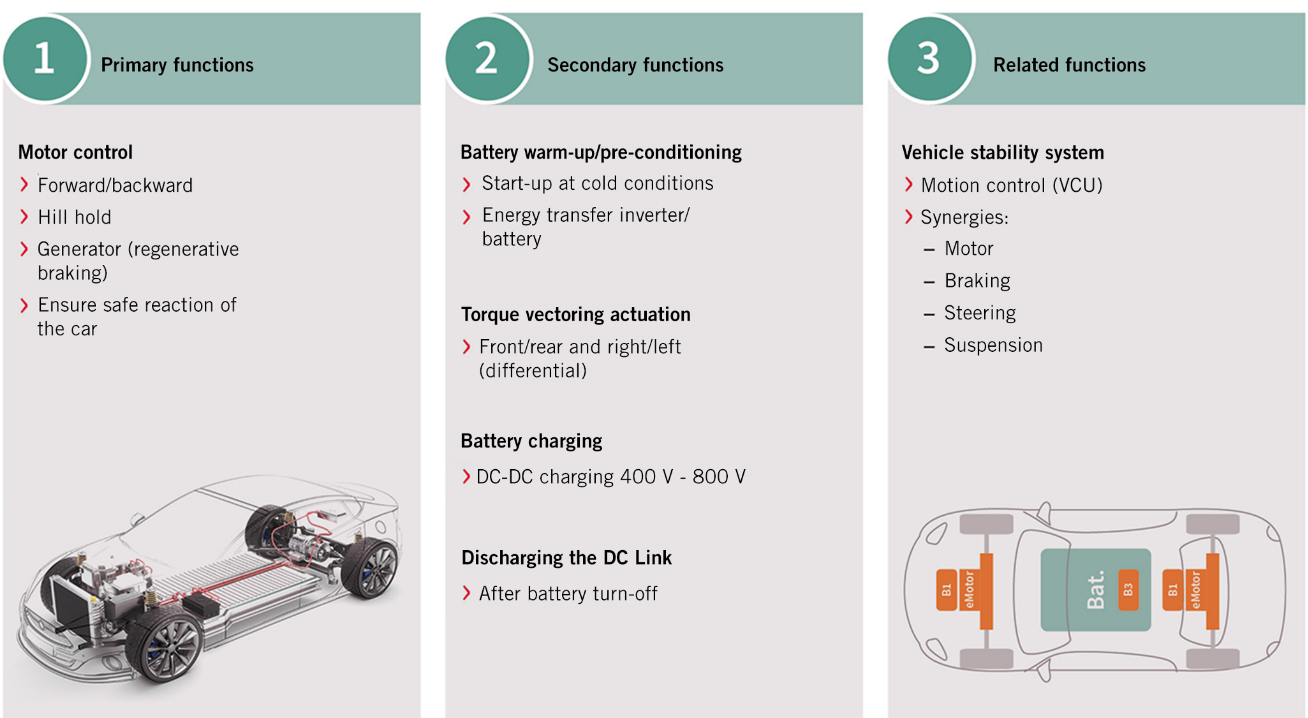


FIGURE 3 The many different functions of a modern traction converter/motor in an electric vehicle (© Infineon Technologies)

size also reduces the capacitance of the device, which in turn reduces switching losses since the capacitance has to be recharged and discharged with each cycle.

GaN has an even larger band gap and much higher electron mobility. The gate charge is one-tenth that of silicon devices, and the so called Reverse Recovery Charge Q_{RR} is negligible, allowing GaN to switch with significantly lower losses. This enables solutions for extremely high frequencies – up to about 10 MHz – and makes GaN a popular choice for resonant topologies.

DESIGNS THAT SAVE RAW MATERIALS AND RARE EARTHS

The introduction of electric vehicles offers scope for a variety of drivetrain configurations. Depending on an OEM's performance and functional goals, multiple motors are used in various locations. With the market for all-electric vehicles now growing rapidly, the focus is shifting to further optimization of drivetrain architectures, **FIGURE 5**, to increase efficiency, but also to make better use of the limited supply of raw materials and rare earths.

Since the electrical components already work very efficiently, integration is evolving as a mandatory next step. Microcontrollers, for one, are now powerful enough to handle more than one dedicated task, allowing for further integration of functions.

Electric motors are moving to the center of innovation, including the associated transmissions and cooling systems. They are another factor in reducing the amount of raw materials required in the vehicle and making production sustainable. In addition, there is the economic aspect: less expensive and more readily available materials are the prerequisite for affordable electric vehicles with shorter production times.

One example: Externally Excited Synchronous Machines (EESMs) can be used as traction motors and are already known from other industries. Magnets, as used today in a typical drive motor (Permanent Magnet Synchronous Motor, PMSM), are expensive. Additionally, rare materials are needed to achieve the best performance. The main advantage of the EESM is the design of the rotor with electrically fed field windings instead of magnets. The magnetic field in the rotor is generated by an additional field exciter circuit. This results in entire control over the behavior of the stator and rotor. The electric motor can now be optimized for a wider range of applications with higher efficiency. In the automotive industry, three-phase synchronous machines (multi-phase are possible) are a typical configuration for traction applications.

Depending on the application, there is a preferred choice of motor design. It is even possible to combine different motors in one vehicle. For example, the main axis can be driven efficiently and powerfully by an EESM motor, while the optional second axis is driven by a cost-optimized PMSM or an asynchronous machine.

In the context of EESM and PMSM, recycling is also an important issue.

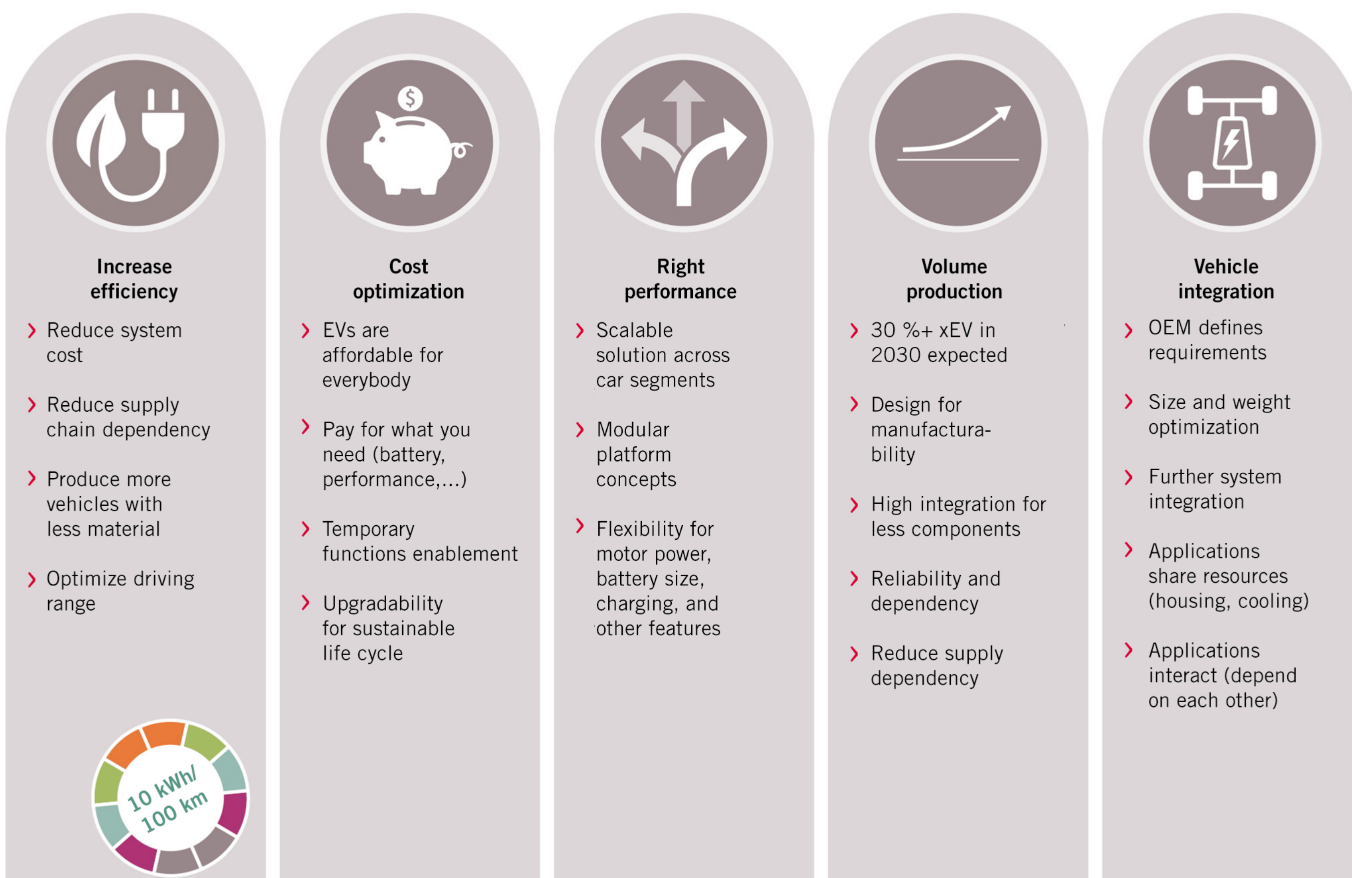
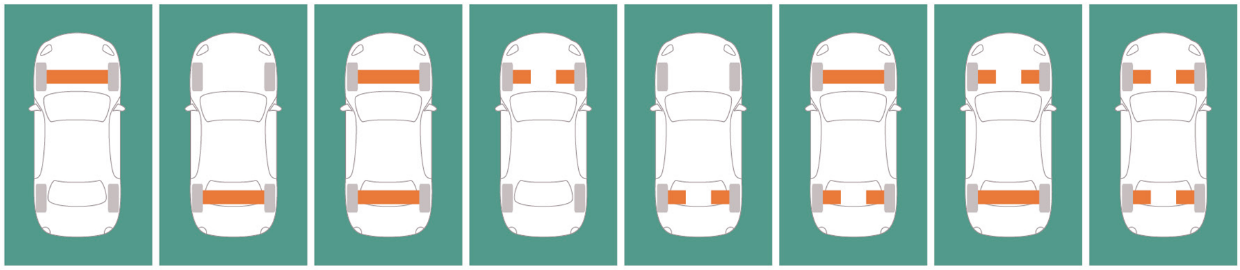


FIGURE 4 The most important market drivers for traction inverter applications (© Infineon Technologies)

FIGURE 5 Freedom of design: different engine configurations in the car (© Infineon Technologies)



MFL	MFA		MFA	MFL		MFA	MFL	MFL
MFR				MFR			MFR	MFR
MRL		MRA	MRA		MRL	MRL	MRA	MRL
MRR					MRR	MRR		MRR
# Motor	1	1	2	2	2	3	3	4

Acronym definition:
1st character: M # motor
2nd character: F # front, R # rear
3rd character: L # left, R # right, A # Axle (w/differential)

Since the magnets inside a PMSM are buried and glued into metal sheets, it is not common today to recycle these magnets. In an EESM, where only copper wires are wound around the rotor, the recovery of the materials is much more efficient.

MORE COMPLEXITY AND EFFORT FOR SAFETY

It is unlikely everything will work smoothly at once during implementation, and some challenges will need to be overcome. For example, the ASIL-D torque path requires additional hardware and software functions. Also, with the additional circuits and control loops, the complexity of the system increases. Since torque is controlled not only by stator currents but also by those of the field windings, more current sensors are needed. In terms of safety, various safe states require different actions, leading to revisions of vehicle functional safety concepts. Furthermore, some EESM-related impacts need to be investigated, such as R_{oss} (series resistance) coupling effects between rotor and stator.

With current technical solutions, the maximum efficiency of an EESM is lower than that of a PMSM. Yet, since the EESM has higher efficiencies at the more frequently used operating points according to the WLPT (Worldwide Harmonized Light Vehicles Test Procedure), the effective efficiency of an EESM is somewhat higher or at least equal to that of a PMSM. When evaluating efficiency, the power consumption of the EESM excitation is also taken into account. The current is drawn from the high-voltage side, and a partially wired H-bridge is used to generate an excitation current of about 30 A_{rms}.

CONCLUSION

10 kWh for 100 km – the electrification of vehicles is an important contribution to improving energy efficiency as well as to reducing NO_x, CO_2, and particle emissions. Power semiconductors such as GaN and SiC can play to their strengths here, depending on the application. High switching frequencies in on-board chargers and HV-DCDC make them the wide-bandgap materials of choice.

The performance and efficiency of the traction inverter, together with the motor technology, directly impact vehicle dynamics and range. SiC semiconductor components are the preferred solutions here – in conjunction with optimized chipsets comprising gate drivers and sensors as well as microcontrollers. To optimize an electric vehicle in terms of efficiency, however, a holistic, integral view of the drivetrain and the entire life cycle is required.