



Stray Inductance of Power Semiconductors in Electric Mobility

Power electronics are playing an important role for electric mobility, as they handle the efficient power transmission from the battery to the motor. Silicon carbide as a new semiconductor base material offers advantages for that, such as lower conduction losses and higher switching frequencies. According to ABB, it is important for the system as a whole that the interfaces and internal structure of the power electronics are optimized for low stray inductances for maximum pay-off.



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DOMINANT PERFORMANCE CHARACTERISTIC FOR ELECTRIC MOBILITY

With electric mobility, the converter and the power semiconductor device contained therein appear to be emerging as a new central differentiating feature between the automotive manufacturers and between low- and high-power automobiles. Over the past 20 years, silicon IGBT, paired with free-wheeling diodes, have become the preferred semiconductor technology in most sectors such as traction drives, industrial voltage inverters and power transmission applications.

In addition to silicon-based semiconductors, the use of Silicon Carbide (SiC) in power semiconductors has been the subject of fundamental research, leading to several very advantageous material characteristics. SiC is one of the so-called Wide Bandgap Materials (WBG) and as a result permits a typically ten times thinner layer thickness compared to Silicon (Si). In addition, higher temperatures are possible and the electrical resistance is linear, while the very low switching losses allow for very high frequencies. Despite these excellent features, wide-scale use has been limited to a few applications only resulting in a low volume compared to silicon semiconductors. The main reason for the low take-up is the very high price of SiC which is due to the complex wafer production.

However, with the advent of electric mobility and the large volumes of SiC

required, the long awaited excuse to exploit the technology at a competitive price has arrived.

STRONG ADVANTAGES FOR PART-LOAD OPERATION

So what are the specific advantages of SiC for vehicle operation? The construction of converters basically always includes the requirement of maximizing the efficiency so that motors can be operated at full load. However, automobiles are different as they are overpowered to meet the few “full throttle” situations. Combustion engines are notoriously inefficient because they are rarely operated at full throttle. The higher the power of the automobiles, the greater this inefficiency is. It is one of the big advantages of electric drives over combustion engines that this part-load efficiency is much bigger. And within the electric drives, SiC-based power electronics show even higher efficiency.

While SiC has clear advantages at high switching frequencies, there are additional benefits associated with conduction losses. The linear losses are advantageous if the electric motors are operated with less than 50 % of their maximum power. In this area the conduction losses of SiC are always significantly lower than the conduction losses of silicon semiconductors which, even at the lowest power, have high conduction losses, **FIGURE 1**.

AUTHORS



Tobias Keller
is Vice President
Global Product Management
at ABB Power Grids Switzerland
in Lenzburg (Switzerland).



Dr. Daniel Schneider
is Senior Principal Engineer BiMOS
at ABB Power Grids Switzerland
in Lenzburg (Switzerland).

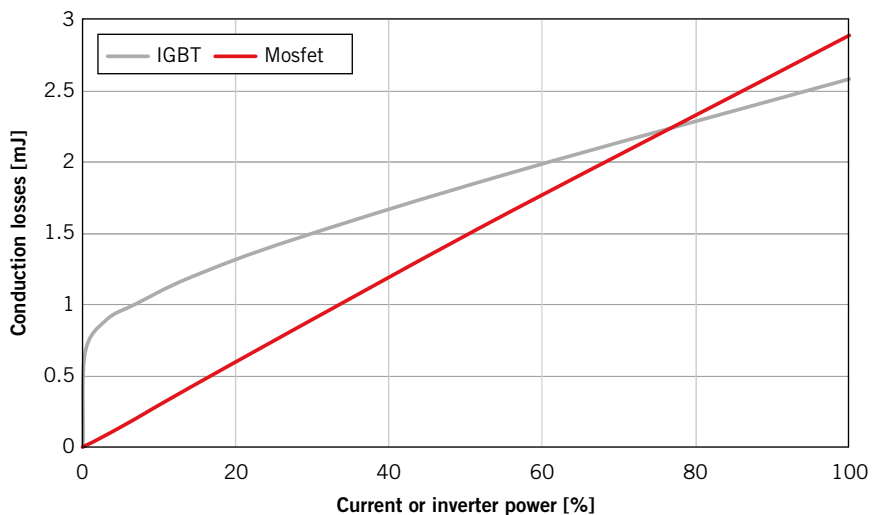


FIGURE 1 Comparison of conduction losses between Si-IGBT and SiC-Mosfet (© ABB)

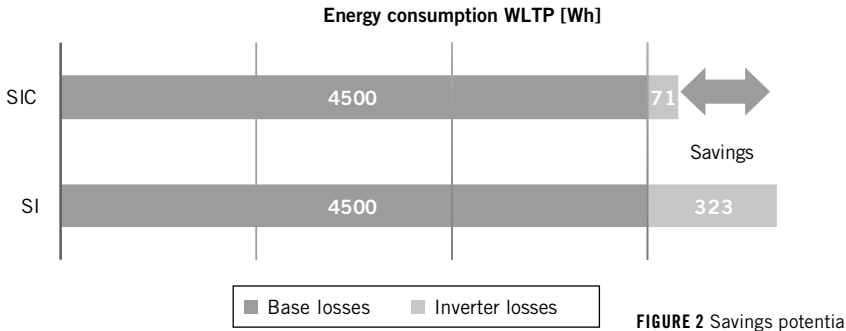


FIGURE 2 Savings potential in the overall energy balance of an e-vehicle (© ABB)

SIMULATION OF POWER CONSUMPTION

When the power consumption of inverter modules with a silicon base and an SiC base is mathematically simulated, a significant difference is observed. Even with a relatively low switching frequency of 10 kHz, a dramatic 75-% reduction in semiconductor losses can be anticipated. If these losses are placed in relation to the overall energy consumption during one trip in Worldwide Harmonised Light Vehicle Test Procedure (WLTP), the savings in the overall energy balance can be seen. If a consumption of 20 kWh/100 km is assumed, savings of approximately 5 % would result. This in turn results in either 5 % lower battery costs and weight or 5 % greater range, **FIGURE 2**.

Similar calculations were conducted by many manufacturers at all levels of production (chip manufacturer to automobile manufacturer). Depending on the assumptions, values between 3 and 11 % [1, 2] resulted. If the higher costs of the inverters are now considered in relation to the savings and additional advantages, the preferred version is determined.

Even though SiC is still a new technology in this application, it continues to gain ground in the medium to upper power segment, particularly with large batteries with higher voltages in the range of 800 V. The most famous example for the application of SiC is Tesla’s Model 3. Additional advantages could result if the low switching losses in SiC are used in order to increase the switching frequency.

BASIC STRUCTURE OF CONVERTER CRUCIAL

However, in doing so the basic structure of the converter becomes an important topic. Typically, the main propulsion converter is a two-level converter and equipped with six SiC-Mosfets, **FIGURE 3**.

As it is known from electrical engineering, contact resistances, existing inductances and structure-related capacities lead to parasitic low-pass arrangements. This limits, for example, the transmission of the quick control pulse for the Mosfets since the power slew rate is limited. As a result, an important advantage of the SiC

semiconductor is at risk of being lost. The same behavior applies to parasitic inductances which lead to a delay in the power slew rates in the main current path with source and drain. This leads directly to a limitation in performance. Furthermore, overvoltages can result from the inductances which during switching-off can stress the entire converter. This influences the design of the converter and other connected components with regard to overvoltages and significantly increases the cost.

DESIGN OF CURRENT PATHS IMPORTANT

The limitation of these inductances is, therefore, a central goal and can be achieved using various measures. A well-established option is the paralleling of the load current paths to the direct current side. By guiding the wide and flat conductors close together and in parallel, a strong magnetic coupling results which is tantamount to a low stray inductance. This is due to the fact that nearly the entire magnetic field from one conductor also penetrates the other conductor of the load current path. As a result, with a corresponding switch of the semiconductor which is synonymous with a switch from DC+ to DC-, only a minimal change to the magnetic field needs to take place. Of course, the power semiconductor modules must be designed accordingly in such a way that a close and parallel guidance is even possible, **FIGURE 4**.

With an appropriately implemented copper-bar package, the DC- connections can be easily connected and isolated from where the DC+ connections are attached. Since the DC-link or battery nominal voltages are limited to 1200 V in automotive technology at

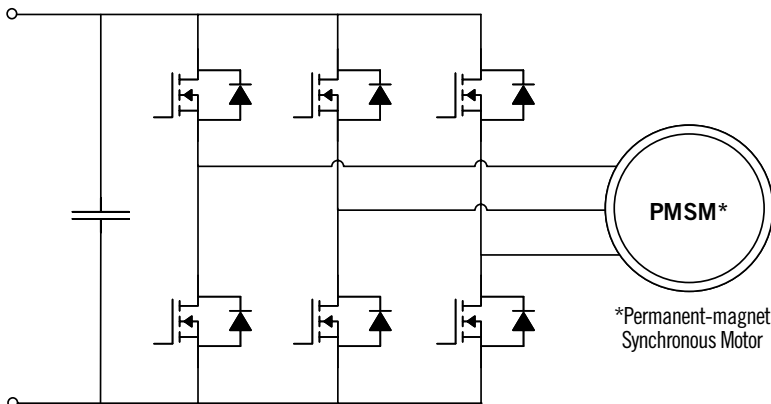


FIGURE 3 Schematic structure of a two-level converter (© ABB)

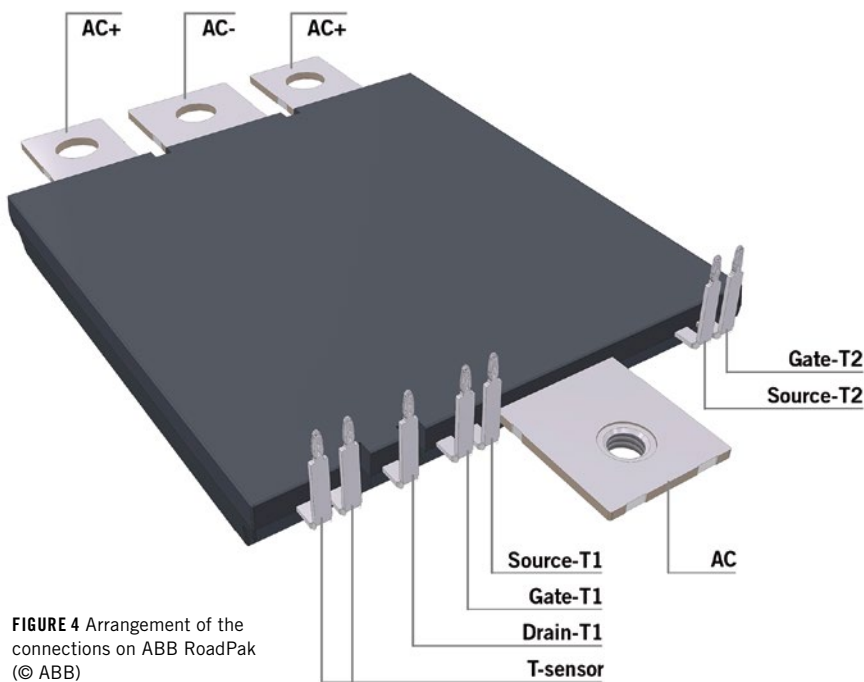


FIGURE 4 Arrangement of the connections on ABB RoadPak (© ABB)

the moment, a thin insulation between both load current paths is relatively simple. The experience from current modules used in automotive applications shows that stray inductances of below 10 nH can be realized as a result.

REDUCING PARASITIC LOSSES

Going one step further in the setup of the semiconductor shows that here too, parasitic inductances inside the module can lead to an unequal distribution of the currents. Because power semiconductors consist of multiple, parallel Mosfet chips in the medium and high power range, it is possible that parasitic inductances or coupling inductances will lead to an unequal distribution of the chip currents. This limits the performance of the whole module. If similar principles are used in the set-up of the Mosfet chips, and individual wire bonds are guided across long distances in parallel and close together, stray inductances of below 6 nH can be realized. In summary, this results in stray inductances which lie below 20 nH per active switching path. This greatly limits the negative effects, such as the aforementioned overvoltages and the limitation of the switching speed. The stated advantages of SiC come into full effect. The analysis can now be continued and expanded to the engine side (AC side). The corresponding stray inductances should be reduced as much as possible and the cable paths kept short.

USE OF HIGH SWITCHING FREQUENCIES

The higher switching frequencies that can be used with SiC components allow to reduce inductances, which are used in the switches for filter applications or in the actual traction motor. This is more cost-effective and allows for smaller and lighter vehicles. These circuits should also be taken into consideration and, of course, optimized accordingly during the design phase. In addition, the coupling capacities should also be addressed, which enable new current paths for high frequency currents and, depending on the structure of the switch, trigger an earth current which in turn can lead to bearing damage or trigger monitoring equipment.

CONCLUSION

In summary, the performance of a switch or an inverter for xEV vehicles can be increased with an optimized design of the load current paths. This means that the advantages of SiC can be fully utilized for greater efficiency, either resulting in greater range or a more compact design for the electric drivetrain.

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