Solving the Current Sensor Footprint Problem when Designing Compact EV Traction Inverters

Electric vehicles (EVs) are said to be the future of transport as the trend for electric mobility moves forward. This article is focused on the challenges of current sensing in high-power integrated traction inverters and highlights the benefits of using compact magnetic core-based sensors. **Sofiane Serbouh, Product Manager of Large Drives, LEM, Switzerland**

Globally, according to the International Energy Agency's Global EV Outlook 2022 report, the number of electric cars on roads by the end of 2021 was around 16.5 million and EV sales around the world in just the first five months of 2022 are reported to have exceeded 3.2 million.

Challenges of current sensing in high-power integrated traction inverters

Of course, with this increased popularity of EVs comes greater demand on their reliability, most notably their ability to be driven longer distances between charges. To achieve this, components such as high-power integrated traction inverters – which are essential to the vehicle's battery range and the whole driving experience – have needed to become as compact and efficient as possible. A traction inverter converts DC current from the EV's battery into AC current which powers the vehicle's propulsion system. Another of the inverter's functions is to capture energy from regenerative braking and send it back to the battery.

The solution to the requirement for high-power integrated traction inverters has been to develop reliable power module packages and take advantage of the ability to slash the footprint of such components as capacitors, inductors, transformers and filters using the benefit of Silicon Carbide MOSFETs to switch faster and increase battery voltage.

Engineers involved in the design of EV traction inverters understand that a key component is the current sensor and for it to meet the requirements of the e-mobility market it must offer a combination of high accuracy, affordability, high integration and the ability to operate in a demanding and rugged environment.

Integration of coreless current sensors in EV not yet mature

Coreless current sensors represent a promising solution for the future, because they will enable smaller and lower cost components to be used, but there are still many challenges with this technology before it can be widely adopted by the market.

For example, the strong variation of the magnetic field in space makes it necessary to place the coreless sensors on the busbar with high accuracy and with no option to move them following assembly and calibration. A tenth of a millimetre variation can quickly lead to a degree of error that is not acceptable in high-power traction inverters. Tolerances on assembly, mechanical handling, vibrations and thermal expansion are all potential causes of displacement. Together with the need to overcome skin effect to achieve high bandwidth, these factors mean that significant efforts in mechanical design need to be carried out in order to achieve reliable current measurement.

Furthermore, with traction inverters getting more compact, conductors are getting closer with a complex magnetic field distribution. Coreless sensors with their differential measurement are immune to homogeneous external fields but not to field gradient, which can introduce an extra degree of error in the measurements. Overall, significant constraints on the mechanical design to achieve the desired accuracy, combined with time-consuming calibration steps at the inverter level, reduce the attractiveness of the coreless sensor solution - for the moment.

Meeting the challenges with magnetic core current sensors

Until these technical barriers are overcome, fully calibrated current sensors with a magnetic core will remain the preferred means of achieving highly accurate current measurements in EV traction inverters. Not only does this technology have many years ahead of it but there is still massive potential for development and innovation in this area.

In operation, the magnetic core concentrates and amplifies the magnetic field to sense with a reduced output noise, while also shielding the measurement from external disturbing fields. As a result, there is a high signal-to-noise ratio (SNR) over a wide bandwidth. Also, reliable and stable measurement is made possible even under tough vibration scenarios due to the tightly controlled assembly and calibration of the magnetic core, the Hall-effect based ASIC and the busbar.

The problem is that open loop core-based sensors tend to be bulky and present challenges in terms of integration at inverter level. That's why LEM has focused on developing compact and affordable current sensors with magnetic cores, to offer reliable current

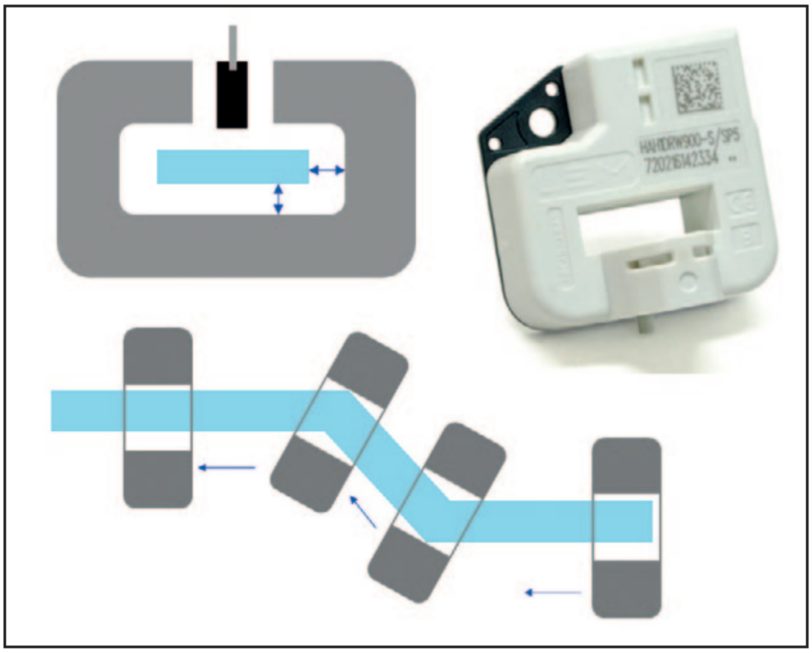


Figure 1: **HSTDR single-phase current sensor with integrated busbar**

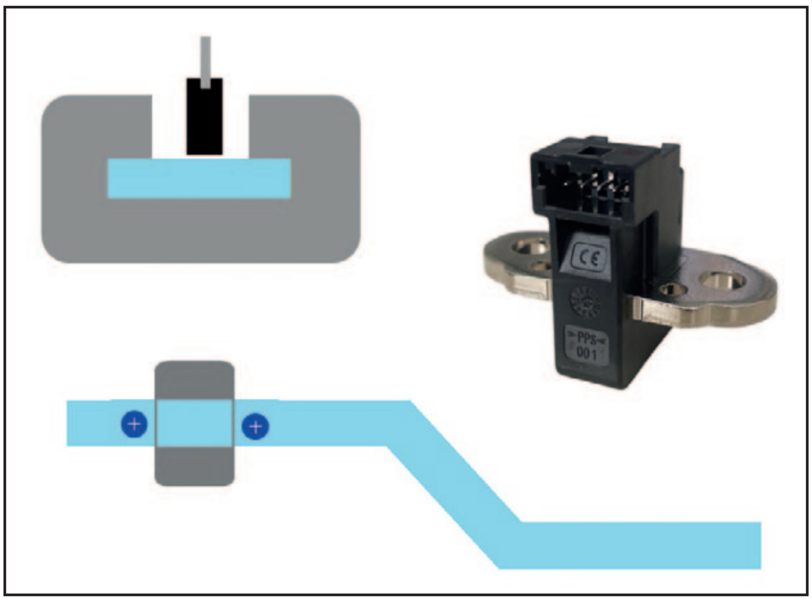


Figure 2: **HSTDR single-phase current sensor for 1500 A that incorporates core, busbar and sensing element in a single package**

measurement over the widest range of applications. The sensors are part of the company's portfolio that are designed specifically for use with EV traction inverters. This allows customers to select highly reliable off-the-shelf products for their inverter requirements which enables EV component manufacturers to achieve a rapid time-to-market turnaround.

When looking at solving customers' problems that existing current sensors could not tackle, the R&D department at LEM came up with a solution in the form of the HSTDR single-phase current sensor with integrated busbar, that is considerably smaller than any traditional current sensor with an opening hole. Designed for DC-Link voltage measurement and 3-phase current measurement, but also for DC/DC converters, the HSTDR's small footprint offers a greater flexibility to designers working within the constrained space availability of a traction inverter box. The HSTDR also offers protection against external fields and high SNR thanks to its magnetic core with a small air gap (Figures 1 and 2).

Busbars tend to be isolated from the magnetic core in traditional designs but LEM's approach of having the core located directly on the busbar, which has a restriction, means the core can be much more compact. Typical current sensors with an opening hole tend to require a large aperture for sliding on to busbars that can be of a complicated design (resulting in a large sensor), whereas there are no limitations on where to fit sensors with integrated busbars. This makes it possible to minimize the aperture of the magnetic core – and therefore reduce the overall size of the core by up to 40 % – while increasing the current measuring range by 60 % compared to the previous generation HSNDR. This again offers superior flexibility to EV component designers because the sensor is capable of being

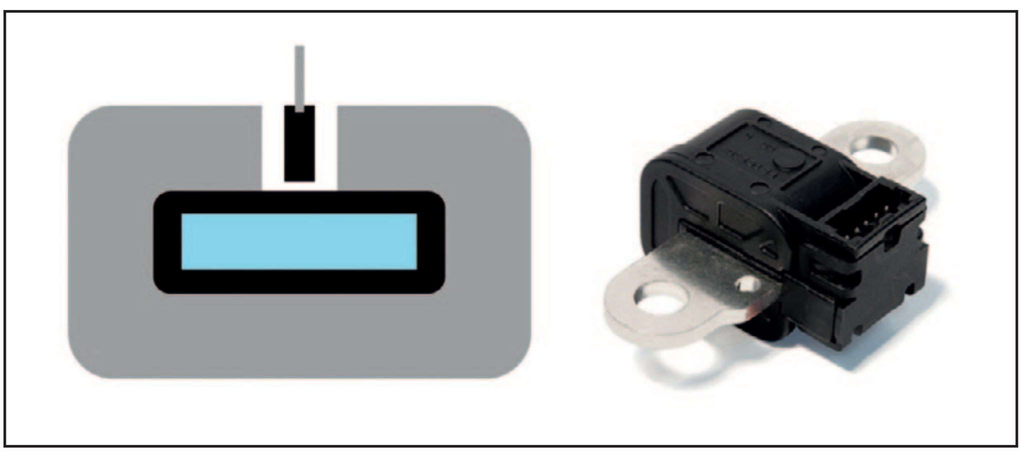


Figure 3: **HSTDR 1000 A single-phase current sensor**

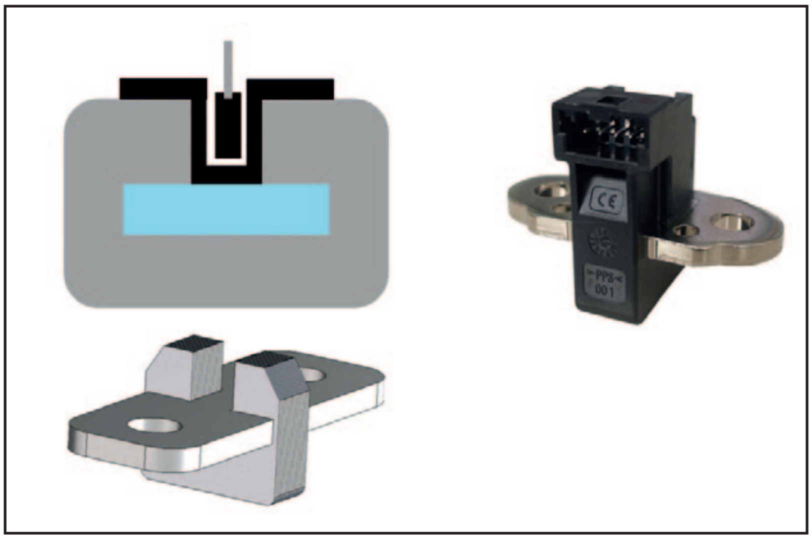


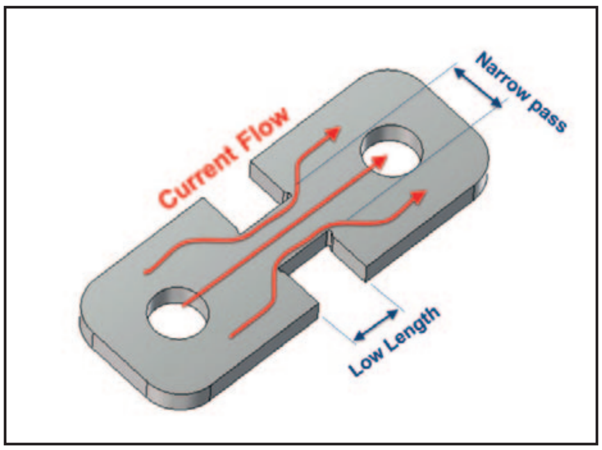
Figure 4: **HSTDR 1500 A single-phase current sensor including restrictions**

placed anywhere in the traction inverter.

Of course, a smaller magnetic core also means that the overall weight of the sensor can be reduced by around 50 %. As a consequence, the sensor can handle vibrations of up to 10 g, which is now a standard requirement in automotive environments. Another benefit of a smaller magnetic core is that it reduces the amount of raw materials required in the sensor build, keeping costs down. Also, there are considerable time-saving and productivity advantages associated with having a fully calibrated sensor that incorporates core, busbar and sensing element in a single package (see Figure 3 and 4).

Key design considerations for the new sensor

When LEM's engineers designed the HSTDR single-phase current sensor with the EV traction inverter market firmly in mind, they had three key considerations.



LEFT Figure 5: **HSTDR busbar restrictions**

Firstly, the restriction mentioned earlier on the integrated busbar should be large enough to ensure mechanical stability while preventing additional power loss and heat dissipation in an already extremely hot environment. As a result, resistance introduced by the restriction on the busbar is negligible at no more than 20 μΩ (see Figure 5). Secondly, with the magnetic core directly mounted on the busbar, it was important to design an isolation barrier between the electronic and the magnetic core, to ensure enough clearance and creepage distance for 800V battery systems. Finally, it was important that – because the sensor would be operating in harsh and noisy environments – its output would remain immune to high switching speeds (dV/dt) – see Figure 6.

One other point of note is that, in terms of accuracy, the HSTDR current sensor delivers a global error over temperature and lifetime of less than 3.5 % over a dynamic range up to 1500 A. Also, because the unit offers consistent performance over a range of frequency levels with minimal part-to-part phase shift dispersion, it is capable of ensuring accurate torque control which is an essential factor in EV motor drive applications.

Conclusions

Having produced its first current sensor for battery monitoring systems over 20 years ago, LEM is no newcomer to the automotive market and the company is continually developing innovative new products for this demanding sector. LEM has built up an extensive portfolio of such products as sensors for use in traction inverters, DC/DC converters and on-board chargers, with the aim always to go smaller and smarter wherever possible. The company focuses on solving customers' problems by exploring today's technologies to take them further as well as developing tomorrow's solutions by foreseeing future challenges and working to address them.

RIGHT Figure 6: **HSTDR immunity to high switching speeds (dV/dt)**