Addressing High-voltage Current-sensing Design Challenges in HEV/EVs

DHarmon

Electrification has created a new paradigm in automotive power systems; whether the design is a hybrid electric vehicle (HEV) or fully electric vehicle (EV), there are new design challenges to address. In this technical article, I'd like to highlight some of the primary challenges in high-voltage current sensing and share additional resources to aid and simplify your design process.

For an introduction to current sensing, see our e-book, "Simplifying current sensing."

High voltage, high current (>200 A or, more commonly, 1,000 A)

High voltage (≥400 V) fully electric systems aim to lower the current consumption for the traction system that moves the vehicle. This requires isolating the solution so that the "hot," high-voltage side can provide current measurement to the "cold" side (attached to low-voltage ≤5-V microcontrollers or other circuitry). The high current presents an issue when trying to measure with a shunt resistor due to the I^2R power dissipation.

To use a shunt in these conditions means that you must select a sub-100-µΩ shunt resistor, but these resistors tend to be larger and costlier than more common milliohm resistors. One alternative is to use magnetic-based solutions, but these are less accurate and have higher temperature drift than shunt-based solutions. Overcoming these performance drawbacks will dramatically increase the cost and complexity of a magnetic solution as well.

Learn more with these design resources:

- "Design Considerations for Dual DRV425 Bus Bar Application."
- "Bus Bar Theory of Operation."

High voltage, low currents (>400 V and <500 A)

Again, high voltages require an isolated solution. From a current perspective, anything below 100 A tends to be a shunt-based solution. Between 100 A and 500 A, choosing between a shunt or magnetic solution requires trade-offs between cost, performance and solution size. This white paper explains:

- "Comparing shunt- and Hall-based current-sensing solutions in onboard chargers and DC/DC converters."

Precision measurements on the 48-V rail, low current (<100 A)

The main design challenge with a 48-V rail is the survivability voltage necessary to meet your requirements, which may be as high as 120 V. In some 48-V motor systems, precision current measurement is required to enable peak motor efficiency. These motor systems may include a traction inverter, electronic power steering or a belt-start generator. In-line measurement provides the most precise representation of actual motor current but is also very challenging due to the presence of high-speed pulse-width modulation (PWM) signals, as explained in:

- "Low-Drift, Precision, In-Line Motor Current Measurements with Enhanced PWM Rejection."

For non-motor 48-V systems, such as DC/DC converters or battery management systems (BMSs), implementing bidirectional DC current measurement is more critical than switching performance, as explained in:

- "High-side, bidirectional current-sensing circuit with transient protection."

Remove high voltage common-mode voltage requirements with low-side sensing

Low-side current sensing reduces some of the amplifier requirements: the inputs do not need to survive a high voltage, as the common mode for low-side sensing is ground – 0 V.

The amplifier's common-mode voltage range must include 0 V in order to measure on the low side. If the application is motor low-side phase-current measurement, the amplifier must have a high slew rate to adjust for the switches turning on and off, as explained in:

- "Low-Drift, Low-Side Current Measurements for Three-Phase Systems."

For non-motor applications, the choice of what you use is based on the implementation's accuracy requirements. See:

- "Low-Side Current Sense Circuit Integration."
- "External current sense amplifiers versus integrated onboard amplifiers for current sensing."

Measuring multidecade current in BMSs

High-precision, multidecade current measurement (from milliamperes to 1 kA) is a significant challenge to address in a single solution. Magnetic solutions do not measure low currents well due to their high offset levels and significant drift. Shunt-based measurements require very low offset to be able to measure low currents on a sub-100-μΩ shunt resistor due to the very low differential input voltage level.

For example, a BMS may want to measure ±1,500 A. In a bidirectional measurement with a ±2.5-V output swing relative to the 0-A output voltage and a gain of 20, the maximum input voltage is ±125 mV. This results in a shunt resistor value of ≤ 83 μΩ. The voltage drop across this shunt at 100 mA is only 8.3 μV, which means that you'll need an amplifier system with very low offset to be able to measure this level. If the system has 1 μV of offset, your error at this level is ~16%.

To learn more, read:

- "Shunt-based current-sensing solutions for BMS applications in HEVs and EVs."

Current sensing in solenoids for a smoother drive

Many automotive applications use proportional solenoids, but when it comes to high-voltage current sensing, proportional solenoids are mainly used in automatic transmissions. Proportional solenoids provide a smooth driving experience when shifting the clutch and gears or operating hydraulic fluid pumps. The drivability of a solenoid mainly depends on two factors: solenoid drive and solenoid position sense.

High-accuracy current measurement enables precise closed loop-control of the solenoid plunger position.

Current sensors in solenoid applications follow a shunt-based principle. Pulse width-modulation signals are made to flow on the solenoid through milliohm shunts. Depending on the current range, this milliohm shunt is integrated or external to the current-sense amplifier.

For more details about solenoid current sensors, check out:

- "Current sensing dynamics in automotive solenoids."
- "Automotive Proportional Solenoid Drive with Highly Accurate Current Sensor Reference Design."
- "Reference Design for Automotive, Proportional-Solenoid Current Sensor."

Current sensing is a foundational element for the increased electrification in automotive design, particularly in high-voltage systems. Modern cars are requiring more from sensors than ever before, but the resources I've linked to in this article can help you design a powertrain that's equipped for strong performance and safe power delivery.

Thanks to my colleague Sandeep Tallada for contributing his expertise to the solenoid portion of this article.