ElectronicDesign

WEBINAR SUMMARY

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Electrification: In-Line vs. Isolated (Non-Contact) Current Sensors

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KEY TAKEAWAYS

- Electrification has the potential to slow global warming.
- Electric vehicles (EVs) will play a central role in achieving climate goals.
- Current sensors used in vehicles maintain battery system safety, control motors, and detect faults.
- Sensor characteristics are determined by the underlying current sensing technology.
- Honeywell offers open loop, closed loop, and flux gate current sensors.
- When selecting a current sensor, designers must consider accuracy, range, robustness, and temperature rise.
- Current sensors used in battery management systems must be accurate over the sensing range and immune to stray magnetic fields.
- For motion control, current sensors must provide a fast response and accuracy over the sensing range.

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OVERVIEW

Electrification will have a profound impact on a wide range of industries, including transportation, construction, and energy storage. As platforms become electrified, current sensing will be required in applications like current flow monitoring, battery health and charge estimation for electric vehicles, and heavy industrial and battery energy storage systems. Honeywell offers a variety of sensing methods to deliver the best combination of performance and value.

CONTEXT

The presenters compared different current sensing methods and discussed tradeoffs related to performance, cost, and implementation.

KEY TAKEAWAYS

Electrification has the potential to slow global warming.

Electrification replaces technologies that use fossil fuels with technologies that use electricity as a source of energy. Depending on the resources used to generate electricity, electrification can potentially reduce carbon dioxide emissions from the transportation, building, and industrial sectors, which account for 65% of all U.S. greenhouse gas emissions.

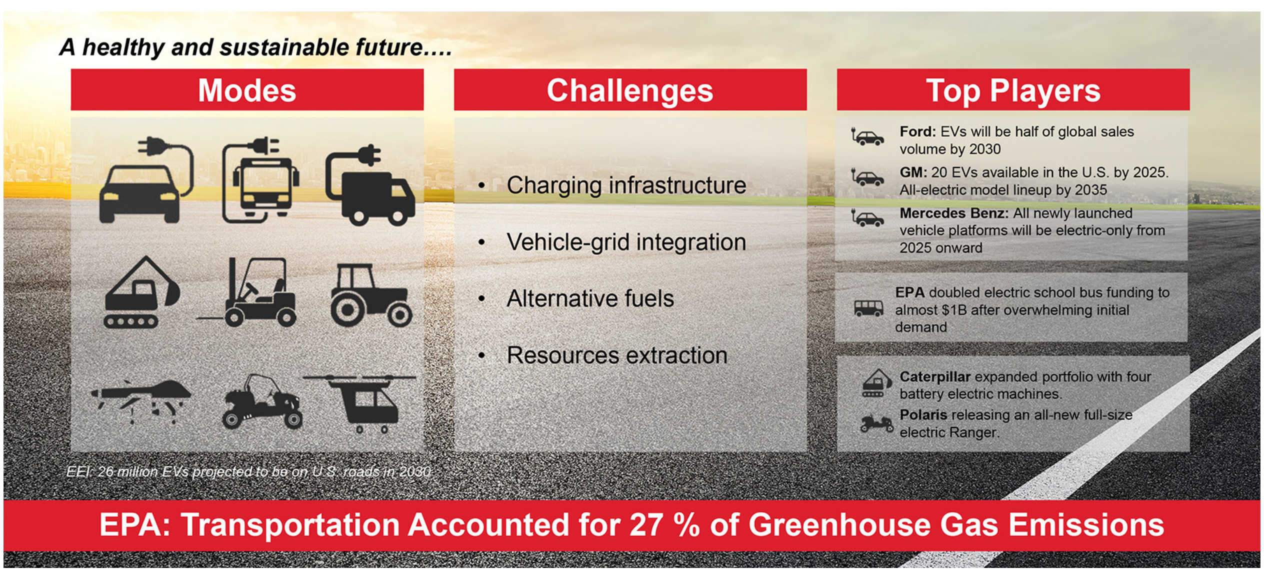
To slow global warming, governments and companies worldwide have committed to cutting greenhouse gas emissions, with a goal of reaching carbon neutrality by 2050. To attain these goals, organizations and individuals must transition away from fossil fuels, toward renewable energy sources like solar, wind, hydro, and geothermal. Cutting greenhouse gas emissions will also involve a shift to power by electricity.

Electric vehicles (EVs) will play a central role in achieving climate goals.

Electrification goes beyond electric cars to vehicles like buses, vans, trucks, and aircraft, as well as construction, agricultural, and recreational equipment. Many companies such as Ford, GM, Mercedes Benz, and Caterpillar have committed to electrification. By 2030, 26 million EVs are projected in the United States.

However, this transition will only be successful if several challenges are overcome. These include the charging infrastructure, vehicle-grid integration, alternative fuels, and resources extraction.

Figure 1: The Need for Electrification



Current sensors used in vehicles maintain battery system safety, control motors, and detect faults.

Current sensors measure the electrical current running through a wire by using the magnetic field to detect the current and generate a proportional output. They are used with both AC and DC current. When these sensors are placed around the conductor or wired carrying the current load, they can measure current passively without interrupting the circuit.

When current flows through a conductor, it creates a proportional magnetic field around the conductor. Honeywell current sensors use Hall-effect sensing and stable amplification circuitry for improved accuracy over the full operating temperature range.

Vehicle designers utilize current sensors for two primary reasons:

1. **Battery management.** Today's vehicle battery systems incorporate a battery management system (BMS). A BMS must be capable of monitoring state of charge (SOC) and state of health (SOH). A BMS accurately monitors an electric vehicle's power consumption and estimates the remaining charge in the battery. This aids in estimating the EV's range.

2. **Motor control and fault detection.** Current is measured in motor control circuitry as an input for motor control algorithms and for fault protection. Current sensors enable open-loop control at the motor controller and fault detection where fast response time is critical. Current measurement can also be used to determine the speed at which a motor is turning. The current measurement is directly proportional to the motor torque.

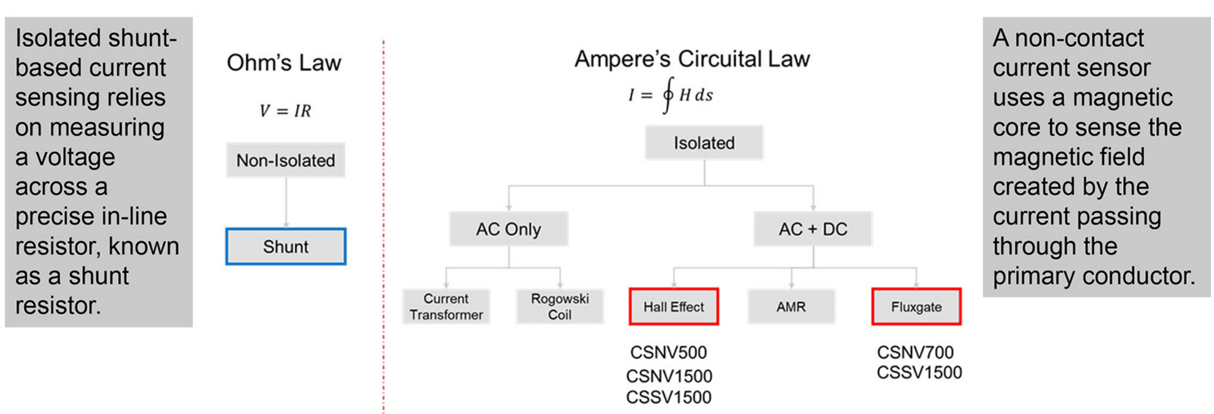
Sensor characteristics are determined by the underlying current sensing technology.

There are two current sensing principles:

1. **Isolated, shunt-based current sensing.** Shunt sensors are simple to use and integrate into systems. Historically, designers have preferred shunt-based solutions for load current applications.

2. **Non-contact current sensing.** Due to increasing current measurement range and accuracy requirements, EV suppliers are migrating to magnetic-based current sensing methods. This is particularly true in high-current environments, from 500 to 1500 amps and beyond.

Figure 2: Current Sensing Principles



Non-contact current sensors fall into three categories:

1. Open-loop Hall effect
2. Close-loop Hall effect
3. Flux gate

When selecting current sensors, designers must consider factors like accuracy, affordability, response, flexibility, robustness, isolation from the primary busbar, and more. The pros and cons of the different types of non-contact sensors, as well as shunt sensors, are outlined in the table in Figure 3.

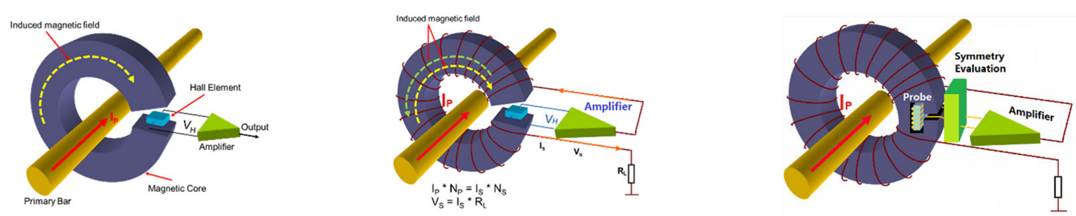
Figure 3: The Pros and Cons of Different Current Sensing Technologies

Technology	Pros	Cons
Open-loop Hall-effect	**Isolated:** Electrical isolated from primary busbar **Affordable:** Lower cost due to simple structure **Response:** Fast response time (microseconds) **Flexibility:** Wide operating temperature range	**Robustness:** May be affected by external magnetic field. Magnetic simulation is required **Accuracy:** Low accuracy in small current scenario such as <2 A
Close-loop Hall-effect	**Isolated:** Electrical isolated from primary busbar **Accuracy:** Highest accuracy **Current draw:** Low power consumption	**Robustness:** May be affected by external magnetic field. Magnetic simulation is required **Heating:** Heat is generated due to high power consumption, especially in large current scenario **Cost:** Higher cost to manufacture
Flux gate	**Isolated:** Electrical isolated from primary busbar **Accuracy:** Higher accuracy and compact structure compared to close-loop Hall technology **Current draw:** Lowest power consumption	**Robustness**: May be affected by external magnetic field. Magnetic simulation is required **Heating:** Heat is generated at higher sensing current range due to high power consumption **Cost:** High cost to manufacture
Shunt	**Robustness:** Immune to external magnetic field **Affordable:** Lowest cost due to simple structure **Implementation:** Easily installs in line with conductor	**Heating:** More heat is generated due to high power consumption, especially in large current scenario **Power Loss:** Generates the largest power loss in the current conducting path **Zero off-set:** Lowest accuracy when capturing small current (<10 A)

Honeywell offers open loop, closed loop, and flux gate current sensors.

When determining the best current sensor to use in an application, designers must understand the end users' needs. The goal is to select a component that is accurate, reliable, and cost effective. Honeywell's portfolio of current sensors is suitable for a range of use cases, such as hybrid EVs, battery electric vehicles and energy storage systems, and battery management systems in electrified vehicles.

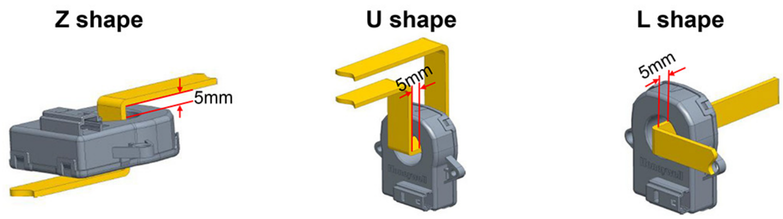
Figure 4: Honeywell's Current Sensor Portfolio



Sensing Type	Open Loop	Closed Loop	Flux Gate
Operating Principle	Open Loop current sensors consist of a Hall sensor mounted in the air gap of a magnetic core. A conductor produces a magnetic field comparable to the current.	The magnetic flux created by the primary current Ip is balanced by the complementary flux produced by driving a current through the secondary winding. A hall effect device is used to generate the secondary.	Advanced flux gate current sensor uses a secondary winding to counteract the field generated in magnetic circuit by the primary conductor.
Benefits	• Simple design • Higher measuring range • Lower cost • Wide operating temperature range	• Higher full temperature accuracy • Stronger magnetic interference resistance • Better di/dt performance • Low power consumption	• Higher accuracy • Low zero offset • High reliability • Lowest power consumption
Drawbacks	• Lower accuracy • Prone to saturation & temperature drift	• Prone to saturation & temperature drift • Slower response time due to CAN • Slightly higher cost	• Higher cost • Limited operating temperature range • Slower response time due to CAN
Use Case	Current measurement for open-loop operation of EV drives such as hybrid electric vehicles	Current measurement in battery electric vehicles and energy storage systems	Current measurement for battery management systems in electrified vehicles (EV, HEV, PHEV or BEV)
Honeywell	CSHV:100 A to 1500 A	CSNV500, CSNV1500	CSNV700, CSSV1500*

To provide greater design flexibility, Honeywell current sensors have been engineered for varying busbar layouts which minimize magnetic interference.

Figure 5: Honeywell Current Sensor Busbar Options*



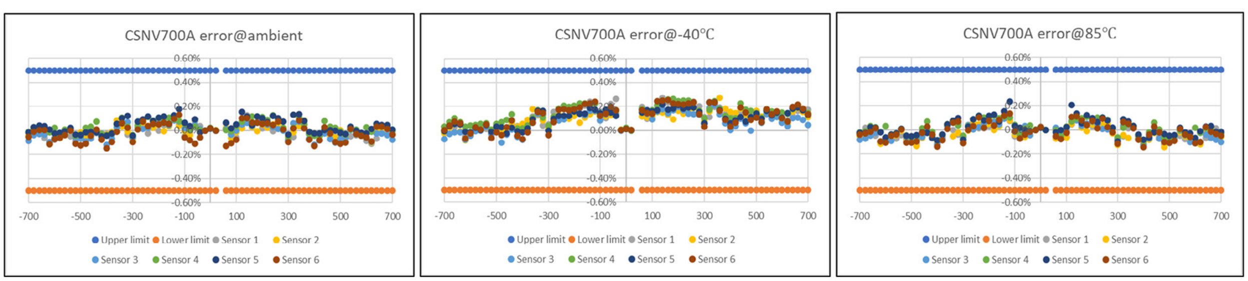
* CSNV700A sensor used as example

When selecting a current sensor, designers must consider accuracy, range, robustness, and temperature rise.

Four important criteria when selecting a current sensor are:

Accuracy	Current sensors in a BMS require very high accuracy for state-of-charge monitoring and cruising range estimation. For Automotive Safety Integrity Level D (ASIL-D), two current sensors may be used in the BMS—the main current sensor is high accuracy and the second, lower-accuracy sensor is used as a backup for safety.
Range	Current sensors must be selected based on the highest current consumption in the application. For example, vehicle rapid acceleration and heating may be considered in EVs.
Robustness	Electromagnetic interference (EMI) tends to be harsh inside battery disconnect units (BDUs). As a result, sensors with immunity to EMI are required. Mechanical robustness is also important if the environment has high vibration or if there are sealing or mounting considerations.
Temperature rise	Temperature increases in the BMS may trigger thermal runaway risks. Rises in temperature are usually affected by sensor power consumption. Honeywell current sensors utilize a patented temperature compensation algorithm that supports high-accuracy performance throughout the operating temperature range. In addition, Honeywell's patented technology offers very low power consumption which translates into minimal heating concerns. For instance, power consumption of the CSSV1500N sensor, when measuring current over 1000 A, is still lower than 50 mA.

Figure 6: Honeywell Sensors—Accuracy Measurement at Different Operating Temperatures



Honeywell offers three series of current sensors:

1. **CSHV Series.** These are the lowest-cost options with microsecond-level fast response times to suit motion control applications with analog output. These sensors have a measurement range from 100 A to 1500 A. They can also be used as backup in the BMS for current sensing.

2. **CSNV Series.** This "middle of the line" option is specifically engineered for BMS applications with a controller area network (CAN) interface and strong immunity to EMI. These sensors have a measurement range of 500 A, 700A, and 1500 A. They offer a full range of accuracy of ± 0.5% and ± 1% of readings. They also have low power consumption (50 mA<@Ip=1500 A).

3. **CSSV Series.** This is the top-of-the-line option which is designed to meet ASIL-C. The sensors are specifically engineered for BMS applications with a CAN interface and strong immunity to EMI. Their measurement range extends up to ± 1500 A and they have a full range of accuracy of ± 0.5% of readings. They also have low power consumption (50 mA<@Ip=1500 A).

Current sensors used in battery management systems must be accurate over the sensing range and immune to stray magnetic fields.

A current sensor in a BDU can be used for:

Overcurrent protection	The sensor continuously monitors the current passing through the BDU and can trigger the disconnection of the battery, if the current exceeds a predetermined threshold. This prevents damage to the battery, wiring, and other components due to overheating and overcurrent situations.
Battery health monitoring	By monitoring the current in the BDU, the sensor can provide valuable information about the battery cells and their performance. It monitors the charging and discharging current which helps assess the battery's state of charge, capability, and overall condition. This data is critical for optimizing battery usage.
System control and safety	Current sensors can be integrated into the BDU's system control logic to detect abnormal condition levels or faults, triggering actions such as system shutdown, fault notification, or activation of a backup power system.
Energy efficiency	By monitoring current, sensors can detect wasted energy, inefficient power consumption, or abnormal energy patterns. With this information, system operation can be optimized.

For motion control, current sensors must provide a fast response and accuracy over the sensing range.

A current sensor in motor control can be used for:

Monitoring motor current	Current sensors provide feedback about motor operation conditions and performance. This data ensures motor operator safety limits are not exceeded and it offers insights into abnormalities or faults.
Overload protection	Current sensors can protect motors from excessive currents that lead to overheating and damage. By continuously monitoring the current, a sensor can trigger protective measures, such as shutting down the motor or activating an alarm if the current exceeds a predetermined threshold.
Closed-loop control	In closed loop control systems, current sensors are used for precise motor control. The control system can compare current level to the desired level and adjust the motor's voltage or speed accordingly.
Energy efficiency	By analyzing the current profile, it is possible to identify inefficient operating conditions or energy wastage. This information can be used to optimize a motor control strategy, adjust load requirements, or detect potential energy-saving opportunities.

Figure 7: Current Sensing in a Battery Management System

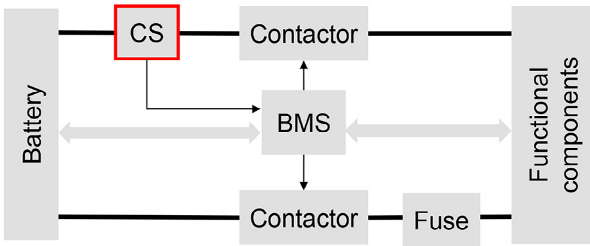
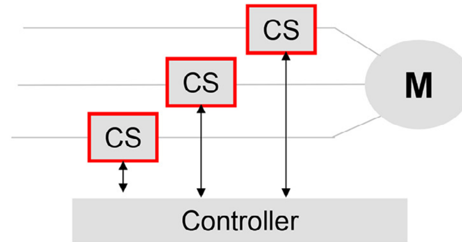
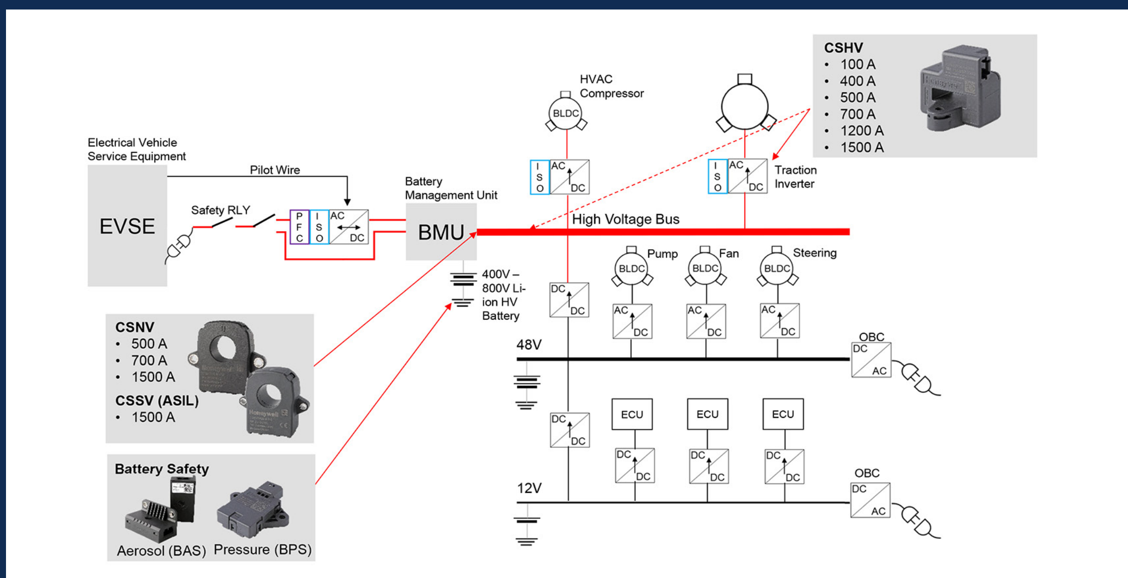


Figure 8: Current Sensing for Motion Control



Case Study: Current Sensors in a Typical EV Application Scenario

Most EVs have a high busbar that powers everything in the vehicle. Current sensors are installed with the busbar running through the center of the sensors to measure current in a non-contact way.



Battery management unit (BMU)

- The BMU is a sensor-based electronic device that measures, monitors, and evaluates key parameters like temperature, voltage charge, and discharge current to maintain operational safety and increased battery longevity.
- Honeywell CSNV and CSSV sensors are integral parts of the BMU system.

Power distribution unit

- This helps regulate and control power to traction motors and other vehicle systems.
- Honeywell's CSHV analog sensor offers very fast response. It is the lowest-cost option in the Honeywell portfolio and is rated for elevated temperatures commonly used in traction control systems. Accuracy is less important in this type of application.

Battery safety

- Honeywell BAS and BPS sensors monitor the possibility of a thermal runaway event.
- The BAS sensor measures and reports aerosol concentrations from 1 to 10,000 micrograms. It detects anomalies inside the battery pack and alerts the BMU to take the appropriate action.
- The BPS automotive-grade pressure sensor is designed to detect and report any thermal runaway events in a lithium-ion battery pack. If a thermal event occurs due to cell damage, cells will typically vent gas out at a rapid rate. The BPS sensor detects the pressure and alerts the BMU to take appropriate action.

BIOGRAPHIES

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John Fontes is a Global Applications Engineer at Honeywell Sensing and Safety Technologies, supporting sensor needs for electric vehicles. John has over 30 years of experience working on sensors used in Transportation vehicles.

Edward Woollard

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Edward Woollard is a Product Marketing Specialist at Honeywell supporting sensors used in Transportation vehicles. Prior to joining the Transportation team, Edward managed multiple product lines that support both medical and industrial applications.