

Hall-Effect Current Sensing in Hybrid Electric Vehicle (HEV) Applications

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Allegro™ MicroSystems is a world leader in developing, manufacturing, and marketing high-performance Hall-effect sensor integrated circuits. This note provides an understanding of hybrid electric vehicle (HEV) power systems and the contribution Hall-effect sensing technology can provide to improving the performance and cost-effectiveness of these systems.

Introduction

Consumers are embracing environmentally friendly “green cars” as a result of the rising cost of fossil fuels and a growing concern for the health of the environment. Sales forecasts predict that green car sales will comprise 20%–25% of all vehicle sales by the year 2015.[1] The hybrid electric vehicle (HEV) is quickly becoming the most popular green car and by 2015 is expected to comprise approximately 12% of global vehicle sales.[1] Hybrid electric vehicles employ complex power electronic circuitry to control the flow of

electric energy through the vehicle. In a single motor HEV (see figure 1) the motor acts as a drive motor in parallel with the internal combustion engine, or as a generator to charge the battery during regenerative braking.

A typical HEV contains various systems that require electrical current sensors for maximally efficient operation; including AC motor and DC–DC converter applications. This article focuses on recent advances in Hall-effect current sensor technology and the use of unique, high bandwidth, enhanced resolution current sensors in HEV applications.

The HEV Power Cycle

In the HEV power cycle the main battery voltage is inverted as shown in figure 1, and the resulting AC voltage is applied to the motor which in turn drives the wheels. During regenerative braking the AC motor also serves as a generator. When the regeneration system is active, the output of the motor-generator is rectified and converted to a DC voltage

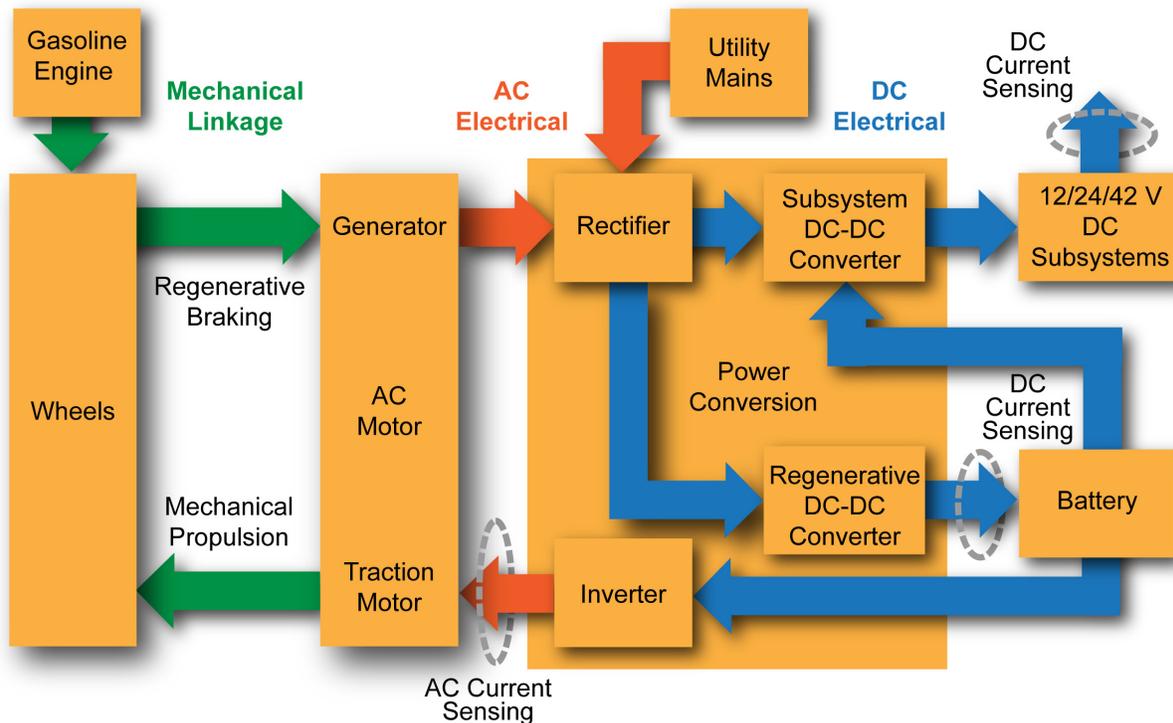


Figure 1. Typical HEV System Block Diagram

necessary to charge the HEV battery cells, completing the power cycle. If the HEV is a plug-in vehicle, then also line voltage can be rectified and used to charge the battery.

The regenerative braking process is a primary contributor to the improved fuel efficiency of an HEV, since braking energy, which is normally wasted in the form of heat, is partially recovered and used to charge the main battery. To power the low voltage infotainment and body control subsystems in the car, a DC-DC converter is typically used to reduce the hybrid battery voltage (from typically 300 to 500 V) to a lower-level DC voltage.

A Revolution in Hall Effect Current Sensing

One drawback of conventional Hall-effect sensors, when used in current sensing applications, has been a general limitation in both accuracy and output signal bandwidth. However, Allegro has developed a broad family of Hall-effect current sensor integrated

circuits (ICs) that are ideally suited for HEV applications. The features and benefits of these industry-leading Allegro current sensor ICs include:

- Signal processing and package design innovations enable > 120 kHz output bandwidth
- The highest current resolution, lowest noise spectral density Hall sensor ICs in the marketplace
- Proprietary, small footprint sensor IC packages, with galvanic isolation
- Reduced power loss: through-hole compliant and low-resistance integrated conductor packages
- Precise factory programming of sensor IC gain and offset

Figure 2 depicts the wide range of proprietary package configurations in the Allegro current sensor IC family and displays the current magnitude that can be sensed using each package type.

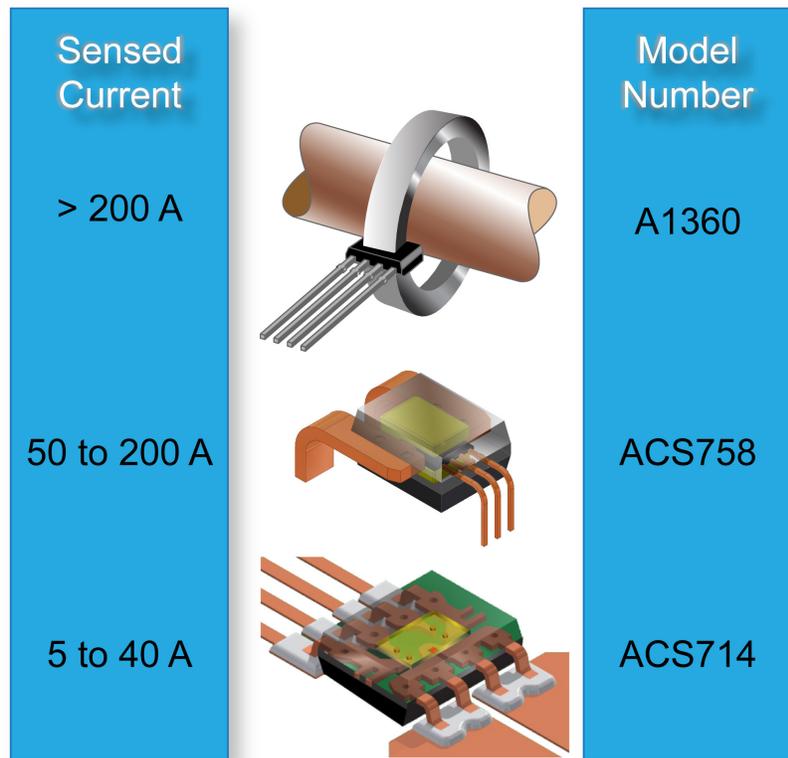


Figure 2. Allegro Current Sensor Packages

Current Sensing in Inverter Applications

The 3-phase, full bridge driver in a typical inverter converts DC battery voltage to a 3-phase AC voltage that is required for efficient operation of the system motor (see figure 3). The inverter phase currents are measured and the resulting information is typically used to control the pulse-width modulated (PWM) inverter switches (typically IGBTs). The inverter control loop requires high bandwidth current sensors to improve accuracy, and to maximize motor torque and overall motor efficiency. High-side current sensors with fast response times also enable overcurrent protection during a short circuit condition from a motor phase to the system ground node. The Allegro A1360 Hall linear device is tailor-made to meet the voltage isolation, > 200 ampere (A) load

current, and high bandwidth demands of HEV inverter applications.

The A1360 linear Hall-effect sensor is typically placed in the gap of a ferromagnetic toroid which surrounds each inverter phase conductor in the motor (figure 2). As current flows in the conductor the toroid concentrates the resulting magnetic field through the standard single-in line package (SIP). The A1360 Hall transducer provides an output voltage proportional to this current. The device is available in a proprietary, 1-mm thick package that reduces eddy current losses to improve sensor IC output bandwidth when compared to more conventional IC packages. Allegro SIP-based current sensor ICs have a typical output bandwidth as high as 120 kHz and offer high resolution, high accuracy per-

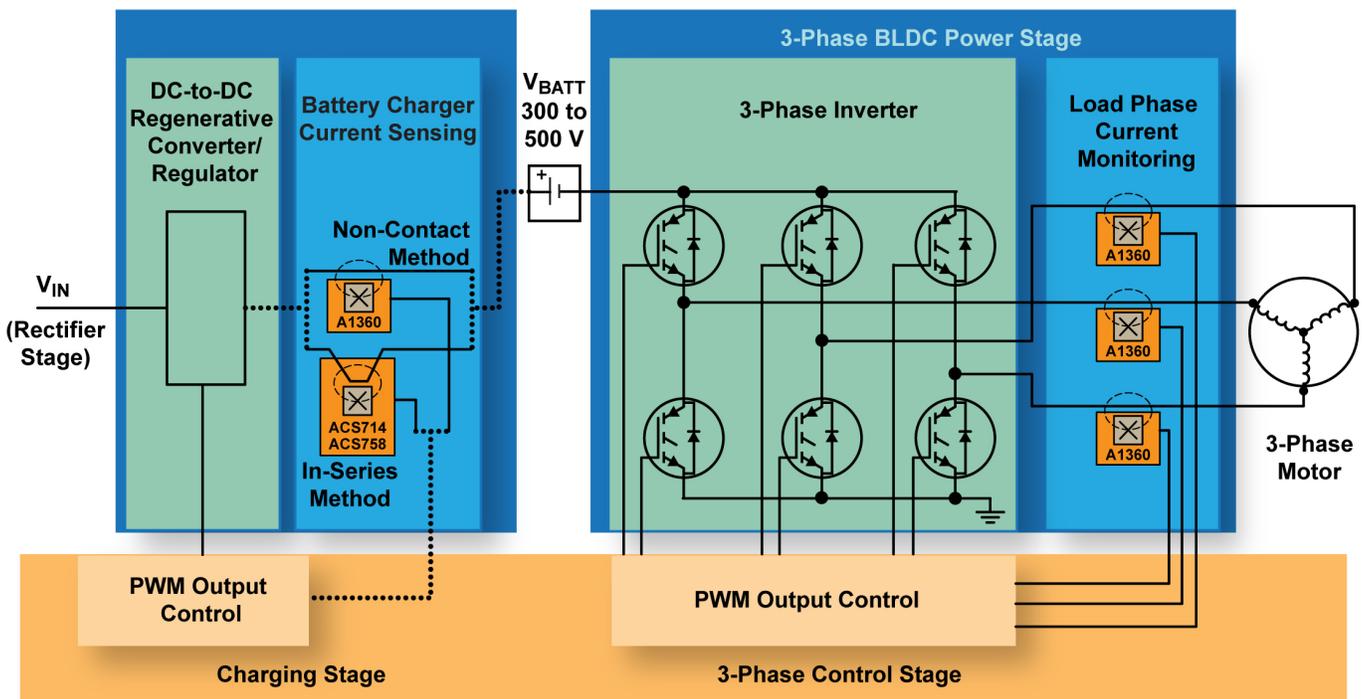


Figure 3. (Left): DC-DC Converter Charger, and (right): Three-Phase DC-AC Inverter

formance that allows higher-speed control of the PWM switches in an inverter system. Additionally, these SIP sensor ICs offer a 3 μ s output response time for IGBT overcurrent protection applications. The form factor of this solution is also much smaller than bulky current transformers. The Allegro SIP package easily provides the necessary galvanic isolation because the sensor IC output leads are not connected to the high voltage, current carrying conductors in each phase of the motor.

DC-DC Converters

The current sensing range and the isolation voltage required determine the optimum Allegro current sensor IC package for use in DC-DC converters.

Current sensors in DC-DC converters are often required to sense currents down to DC frequencies. This requirement precludes the use of current transformers in fully optimized systems. Using shunt resistors in these applications is also challenging (or impossible) since the high input or output DC voltages require expensive, high common-mode input operational amplifiers. As a result of the inherent galvanic isolation of Allegro Hall-effect sensor ICs, and their ability to sense both DC current and high frequency current signals, they are a logical choice for HEVs in DC-DC converter applications.

A simplified regenerative DC-DC converter is shown in figures 1 and 3. The regenerative converter utilizes a current sensor that can operate at battery voltage levels. Accurately sensing the converter output current is a critical function as HEV battery life is extended by limiting the charge current delivered to the battery.

The ACS714 current sensor is ideal for many lower current, sub-system DC-DC converter applications. The ACS714 is a factory trimmed, galvanically isolated sensor IC that is available in an extremely small form factor SOIC8 package with an integrated 1.2 m Ω conductor for low power loss. Additionally, the Allegro ACS758 device incorporates both a 100 $\mu\Omega$ conductor and a ferromagnetic core into a small form factor, galvanically isolated package capable of sensing 50 through 200 A. Currents above 200 A can be sensed with the SIP based toroid configuration mentioned earlier. All of these Allegro solutions offer industry leading high bandwidth output performance and exceptional current resolution capabilities.

Summary

Allegro's latest generation Hall-effect current sensor IC technology offers significant advantages in sensing both AC and DC currents in HEVs. Hall current sensors have inherent galvanic isolation for high side current sensing, and offer low power loss in high efficiency HEV applications. Recent improvements in Hall IC technology by Allegro have resulted in the development of industry leading high bandwidth, high resolution current sensor ICs that are ideally suited for use in HEV inverter and DC-DC converter applications.

References

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[1] "Global Automotive Industry Outlook 2009: Impact of Economic Slowdown on the Future of Auto Sales and Production," Frost & Sullivan, 2009, p. 31, online edition accessed June 2010, <<http://www.frost.com/prod/servlet/report-homepage.pag?repid=M3A1-01-00-00-00>>.

REVISION HISTORY

Number	Date	Description
–	July 12, 2010	Initial Release
1	March 1, 2021	Minor editorial updates

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