KEMET
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Technical Resources

Fluxgate-Based Residual Current Sensors for Electric Vehicle Chargers

Charging Electric Vehicles

In principle, charging the batteries within electric vehicles (EVs) is a straightforward operation. One must convert an external voltage source (AC or DC) to an appropriate output voltage that achieves constant current followed by constant voltage energy transfer into the battery. Doing this safely, however, is an entirely different proposition with a host of engineering challenges. The difficulty is exacerbated when chargers are required to output high levels of power for quick charging performance, while at the same time they are required to be designed for ease of use.

To codify the safety requirements for EV chargers, regulatory agencies around the world have defined standards to which every charger topology must be held, which are described in the IEC 61851 for conductive charging systems. Four modes of charging have been defined: Mode 1 involves connecting the vehicle directly to the AC power grid, and it is generally disallowed in most countries. Mode 2 requires that an intermediate control system (IC-CPD) is used between the AC power grid and the vehicle to monitor for safety issues and is connected to an AC power outlet socket. This device is usually a mobile device one would carry in the car's trunk. Mode 3 relies on a dedicated safety control system that is permanently connected to the AC power grid; these are the typical AC charging stations seen in many parking lots and garages, as well as installed at private homes. Mode 4 is the only DC-based system, and it converts AC grid energy into the DC voltage for charging the vehicle while also monitoring safety. Each of these modes has a dedicated safety standard to govern the performance requirements of the associated equipment. IEC62752 / UL2231-2 is a representative standard for Europe and the USA that covers Mode 2 chargers. IEC62955 / UL2231-2, similarly, covers Mode 3 chargers.

One of the key parameters called out in these types of safety standards is the residual operating current, which is effectively the leakage current that finds a path to ground through some means other than the AC power grid. This is a critical parameter because this unknown current path could very well be a human interacting with the system. Monitoring the magnitude of this current, therefore, is a primary safety concern. For Mode 2 chargers, residual current is restricted to 30 mA AC and 6 mA DC. For Mode 3 chargers, it depends on the rated AC current which residual AC current is allowed. It is 60 mA if the rated current is 125 A; but there are no AC chargers on the market that support more than 22 kW, therefore realistically the AC residual current here is also 30 mA maximum. For residual DC currents, the 6 mA limit applies to both Mode 2 and Mode 3 chargers.

To satisfy these safety requirements, charging equipment must contain a highly sensitive device for measuring very small residual current flow in the presence of very large nominal currents. As it is a safety device that can interrupt the charging process, this device needs to be reliably working over a wide temperature range with high accuracy. In addition, Mode 3 requires that it also withstands up to 3'000 A inrush or short currents without being damaged.

Fluxgate Current Sensor

The fluxgate (FG) current sensor is one of the most robust solutions for measuring residual current. As shown in the figure below, the AC primary lines are simply passed through a magnetic core just before these lines enter the charging line toward the vehicle. This is an important distinction when comparing to any other technique as these large, high current cables require no modification, a non-invasive measurement technology. A pickup coil is wrapped around the same core and integrated into an external low voltage oscillator circuit. Imbalances in the high current feed and return paths couple into the pickup coil through the magnetic core. As a result, any residual current in both AC and DC can be detected by a change in the oscillator frequency or oscillator duty cycle respectively. For DC residual currents, it can also identify the direction of the DC current.

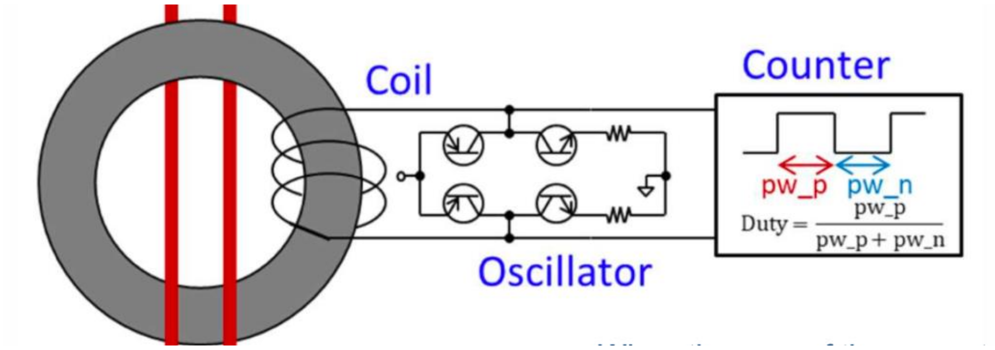

Figure 1 – Fluxgate current sensor

This elegant device is capable of sensing very small leakage currents in the presence of very large charging currents, and it is completely isolated electrically from the circuits being monitored. The resulting low voltage output can be directly processed to create alarms that immediately shut down the charger in the event of an over-leakage threshold condition.

KEMET's FG Sensor Lineup

KEMET's patented FG sensor solution is shown in the figure below. Primary conductors pass through a magnetic core and the pickup coil and oscillator are used to generate AC and DC pull-down alarms on dedicated pins. An additional conductor is included within the magnetic core for the purposes of self-testing the FG sensor. A 5 V test signal can be applied to intentionally create residual current alarms and validate the health of the sensor before a charging process will be initiated -- typically this is demanded by the UL regulation. An analog output is also included for optional analysis of the FG signal by an external analog to digital converter (ADC) and microcontroller (MCU). This can be of interest in case of pre-evaluating the residual current situation before a threshold is reached -- for example, to inform the owner of the charger that there is potentially a reason for maintenance or to evaluate if moisture present in the charger's device.

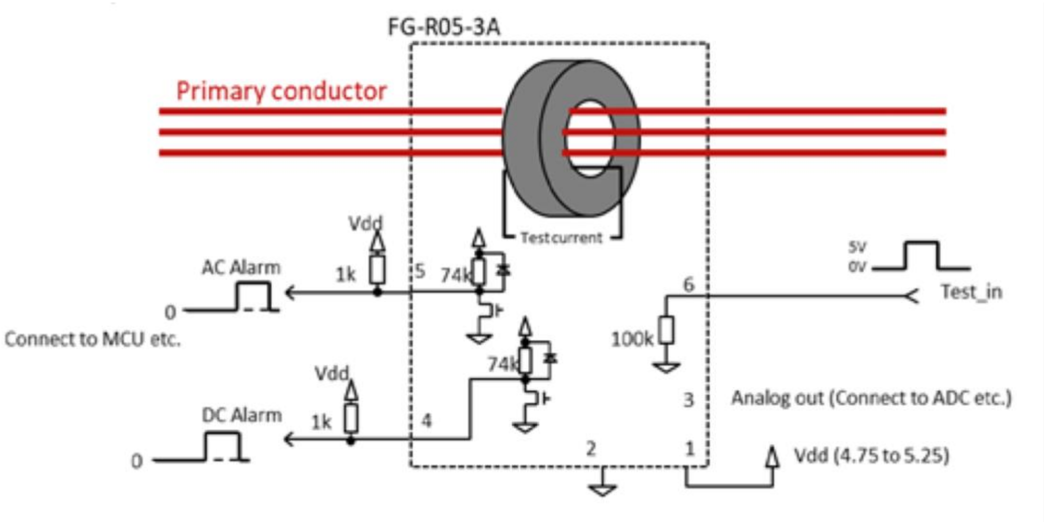

Figure 2 - KEMET's FG-R05-3A fluxgate current sensor internals

KEMET's FG sensor lineup includes the FG-R05-3A for Mode 2 chargers, and the FG-R01-4A, FG-R02-4A and FG-R05-4A for Mode 3 chargers. Each flavor fits within an extremely compact footprint and is available in different orientations and mounting styles.

FG-R01-4A FG-R02-4A FG-R05-3A & FG-R05-4A

Figure 3 - KEMET's FG-R sensors' different form factors

The FG-R series is rated to 105° C max ambient temperature: the highest in the industry. An example is shown in the following figure, where the magnetic core passthrough is visible along with the simple six pin interface.

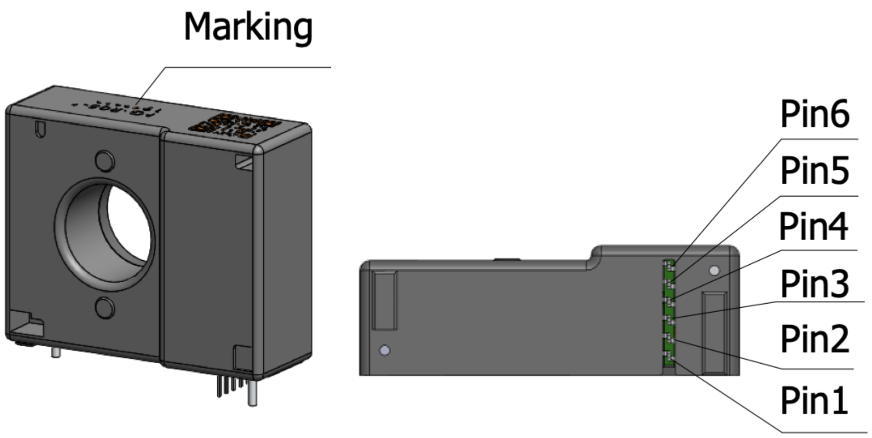

Figure 4 - KEMET FG-R05-3A fluxgate current sensor

The most important feature of the KEMET FG-R lineup is that these devices each complies with all applicable regulatory standards. A customer does not need to ship a UL-compliant device to the USA market and an IEC-compatible device to the European market. With KEMET's solution, the customer only needs one sensor and can ship anywhere in the world. This greatly simplifies the bill of materials, maintenance and complexity.

Conclusions

The fluxgate current sensor is a remarkable modular device that is perfectly suited to safety monitoring of residual currents in EV chargers. The open-loop, or pass-through, operation makes product integration as simple as possible, while the electrically isolated monitoring circuitry bolsters safety. KEMET's fluxgate product lineup is affordable, compact, and compliant with numerous regulatory standards and pre-tested EMC compliance where possible was tested with the full lineup for emissions and immunity. These components should be a staple in the toolbox of any design engineer looking to maximize product safety while simplifying system integration.

To learn more, visit: https://www.kemet.com/en/us/new-products/fg-series-residual-current-sensor.html?3=555766+555767+555768+555765