SKYWORKS®

Isolation in Electric Vehicle Systems

Quick Reference Guide

Introduction to Isolation in Electric Vehicle Systems

Automotive OEMs across the globe are announcing aggressive plans to launch new models of battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and full-hybrid electric vehicles (FHEV). Both BEVs and PHEVs are experiencing double-digit growth rates. BEVs bring smooth, quiet, emissions free transportation to the market. PHEVs add performance and luxury tiers with range extension capabilities and all-electric drive modes. FHEVs continue to enhance fuel economy and quell concerns with "range anxiety" since they use traditional petroleum-based fuel sources.

As automotive designs move to electrification, high-wattage power electronics become critical components in the new electronic drive train and battery systems. These high-wattage electronics need to be communicated with and controlled by low-voltage digital controllers requiring electrical isolation of the low-voltage side from the high-power system. In these applications, galvanic isolation, usually semiconductor-based isolation, is required to allow the digital controllers to safely interface with the high voltage systems of a modern EV.
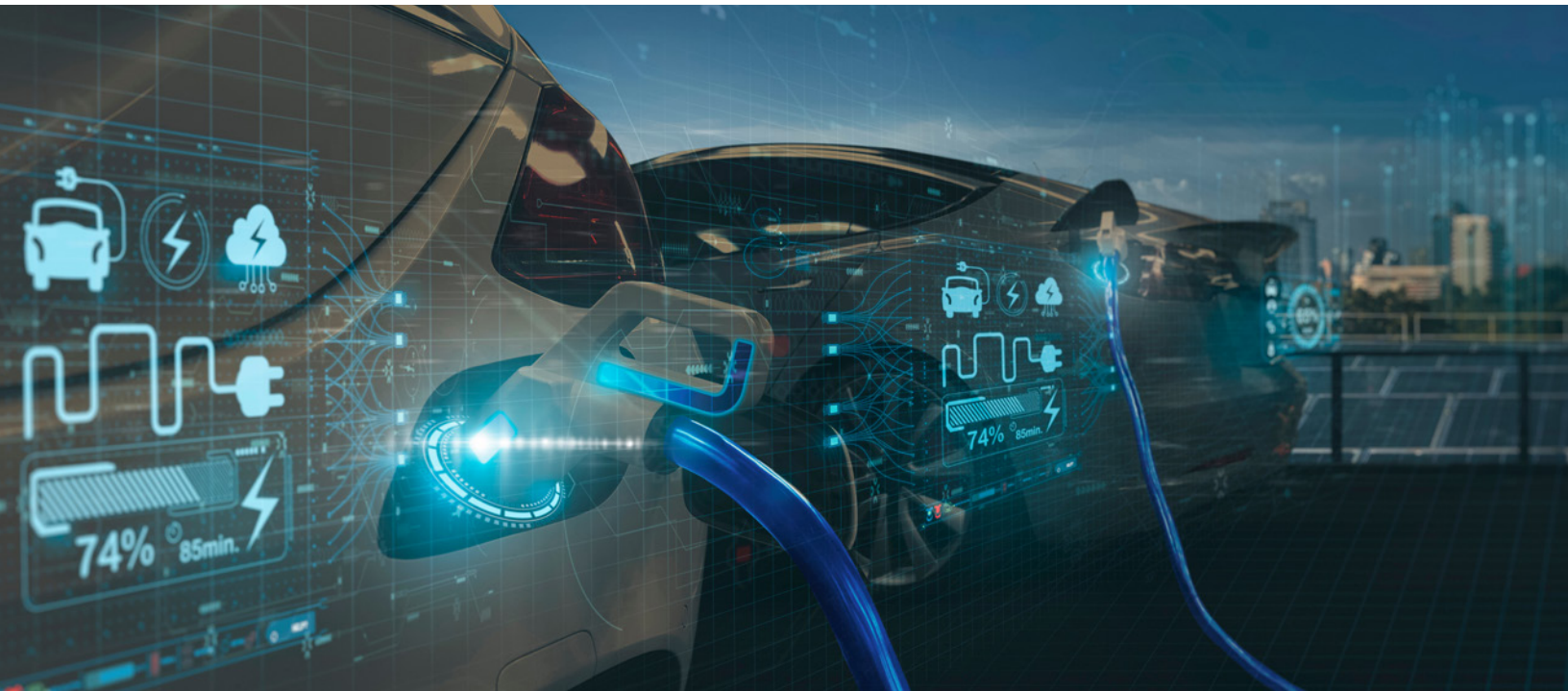
EV System Overview

To be competitive with traditional ICE vehicles, the batteries used in EV/HEVs must possess very high energy storage density, near zero self-leakage current and the ability to charge in minutes instead of hours. In addition, the battery management and associated power conversion system must be of minimal size and weight and "sip" battery current while delivering large amounts of high-efficiency power to the electric motor. Modern EV/HEV designs use modular components in the drive train and energy storage/conversion systems. EV/HEV battery management systems typically include four major circuit assemblies:

- Battery management system (BMS): Battery cells are monitored and managed by the BMS to ensure high efficiency and safety. The BMS controls the charge, state of health, depth of discharge and conditioning of individual battery cells.

- DC/DC converter: The dc/dc converter connects the high-voltage battery to the internal 12 V dc network, which also provides power to the accessories and bias to the local switching converters.

- On-board charger (OBC): Energy storage is provided by Lithium-Ion batteries charged by an onboard charger consisting of an ac-to-dc converter with power factor correction and supervised by a battery management system.

Traction Inverter: The main inverter drives the electric motor and is also used for regenerative braking and returning unused energy to the battery.

In this reference guide, we discuss system overview, including isolation requirements. In addition, we include recommendations from our portfolio of automotive isolation solutions for BMS, DC/DC, OBC, and traction inverter applications.

Isolation in EV Battery Management Systems

EV BMS Isolation Quick Reference

Battery Management Systems (BMS) are used to monitor and control power storage systems, assure health of battery cells, and deliver power to vehicle systems. Isolation products have numerous uses inside BMS in the electrical domains of Electric Vehicles (EV) or Hybrid Electric Vehicles (HEV).

Key Isolation Features for BMS

- 10+ years of automotive market experience, supporting automotive standards and customer needs

- Top isolation provider for OEMs and Tier 1 EV suppliers, over 30 million shipped

- Automotive-grade ready: AEC-Q100, enhanced manufacturing, and ultra-low defectivity

BMS Overview

The systems in an EV are shown below. There are numerous modules that use Isolation such as: on-board chargers (OBC), BMS, dc-dc converters, traction inverters, engine control units, braking systems, transmissions, and heating/cooling units.

The BMS manages stored power in an on-board high voltage (HV) battery and delivers power to the rest of the vehicle. The main functions include cell balancing, cell health and wear leveling, charge and discharge monitoring, and safety assurance.

All these functions require galvanic isolation to separate lower voltage systems from high voltage domains.
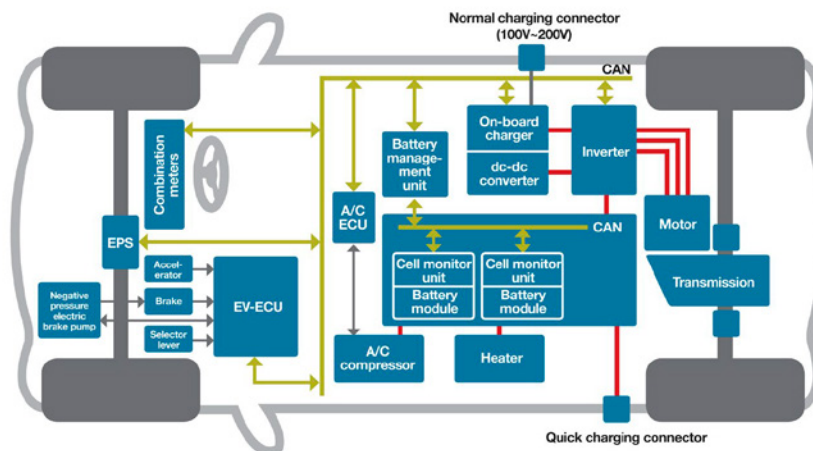
BMS Module

EVs utilize BMS for the main battery-based power supply, and HEVs use BMS for battery-side portion of power, complimentary to the internal combustion engine (ICE). BMS monitors the voltage, current, temperature, and wear leveling of battery cells. Additional functions include monitoring faults, system health, available energy, and remaining useful lifetime. Individual lithium-ion battery cells are in the 3 – 4V range. They are connected in series to deliver higher voltage, and in parallel to increase capacity.

To monitor the modules and cells, the BMS may have a centralized architecture, or a distributed/modular architecture consisting of a BMS master and several remote BMS units. In distributed BMS systems, remote units monitoring individual cells may be connected in parallel to the BMS master, or they may be daisy-chained in series. In any case, connections from the battery modules or BMS remote units to the BMS master must be isolated to protect the BMS master from the battery voltages.

The diagram depicts a distributed BMS with multiple packs of cells, each with a remote BMS control unit. In this configuration, measurements on cells within the battery modules are made by the remote BMS units and reported over a series connection to the BMS Master controller. Current measurement for the full stack is made using a shunt resistor at the bottom of the stack and an isolated current amp like the Si892x or Si894x. The BMS controller can calculate the voltage of the full stack by summing the voltages of the modules, but a redundant safety-check isolated voltage measurement of the full stack can be made using a resistor divider and isolated voltage sense amp like the Si893x.

The entire system can be monitored and controlled via an automotive bus such as CAN. The CAN is isolated with digital isolators like Si86xx and digital isolators with integrated dc-dc power converters like Si88xx.
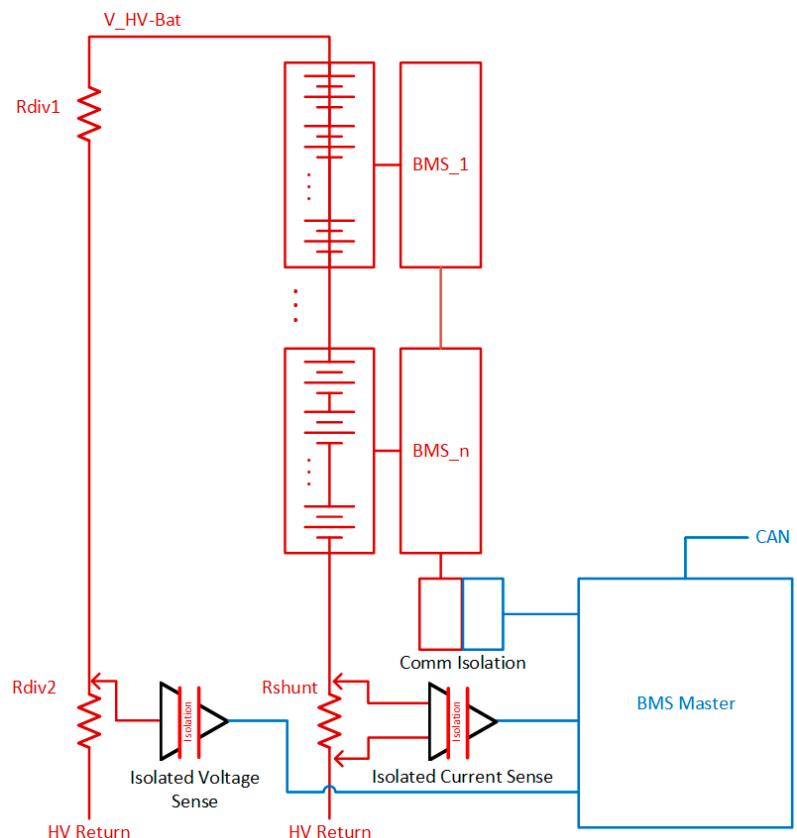
Where Isolation is Needed

- **Voltage:** Assure safe and useful battery voltage output
  - Isolated voltage sensor for the full battery stack
- **Current:** Protect batteries from overload or high charging rates
  - Isolated current sensor monitors discharge and charge current
- **Communications:** CAN or serial bus for module data
  - Digital isolators enable safe and robust communication

Isolation Product Offering Summary

Family	Purpose
Si86xx	System communication
Si88xx	Communication with power transfer
*Si893x	Amplifier for Voltage Measurement
*Si892x	Amplifier for Current Shunt Measurement
Si894x	Delta-Sigma Modulator for Current Shunt Measurement

*Please note that this guide contains references to some products that are in development. Please check with your Skyworks sales or distributor contacts for specific product status.

Isolation in EV DC-DC Converters
EV DC-DC Isolation Quick Reference

DC-DC converters are used to convert dc voltages from one voltage domain to another for powering various auxiliary systems. Isolation products have numerous uses inside dc-dc converters in the electrical domains of Electric Vehicles (EV) or Hybrid Electric Vehicles (HEV).

> **Key Isolation Features for dc-dc converters**
> - 10+ years of automotive market experience, supporting automotive standards and customer needs
> - Top isolation provider for OEMs and Tier 1 EV suppliers, over 30 million shipped
> - Automotive-grade ready: AEC-Q100, enhanced manufacturing, and ultra-low defectivity

EV System Overview

The systems in an EV are shown below. There are numerous modules that use isolation such as: on-board chargers (OBC), Battery Management Systems (BMS), dc-dc converters, traction inverters, and heating/cooling units.

The main dc-dc converter changes dc power from an on-board 200-800V (HV) battery into lower dc voltages, like 48V or 12V, to power headlights, interior lights, wiper and window motors, fans, pumps, and many other systems.

This high voltage to low voltage (HVLV) dc-dc converter is often referred to as an auxiliary dc-dc, or Auxiliary Power Module (APM). These functions require galvanic isolation to separate control systems from high-vz
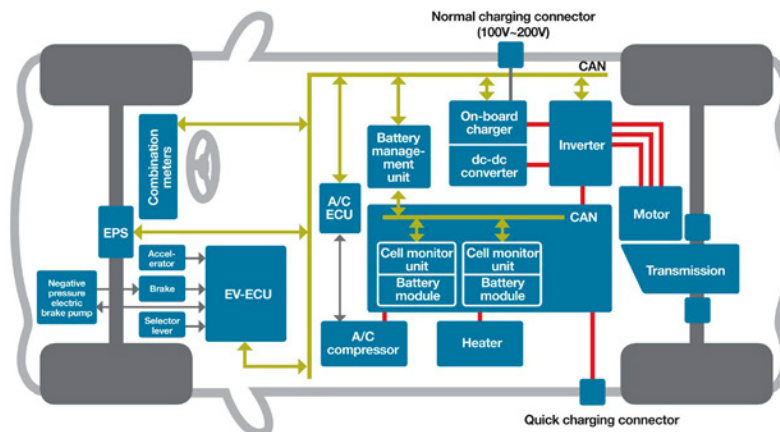
DC-DC Converter Module

The APM may be in the 2 to 3 kW range with expected efficiency in the 92-95% range when under medium to heavy loading. The return, or ground, for the low-voltage side is normally connected to the vehicle chassis, so galvanic isolation between the low-voltage side and high-voltage side is required for safety as well as for protection of the LV controller. Isolation between the HV input and the LV output of the converter is accomplished using a transformer.

Switching frequencies can be relatively high (e.g. 100 kHz) to keep transformer magnetics sizes minimal. In some applications like an HEV, the dc-dc can be run in reverse to boost the power from a 12V domain to a 48V or HV domain, to assist in starting or to provide backup power.
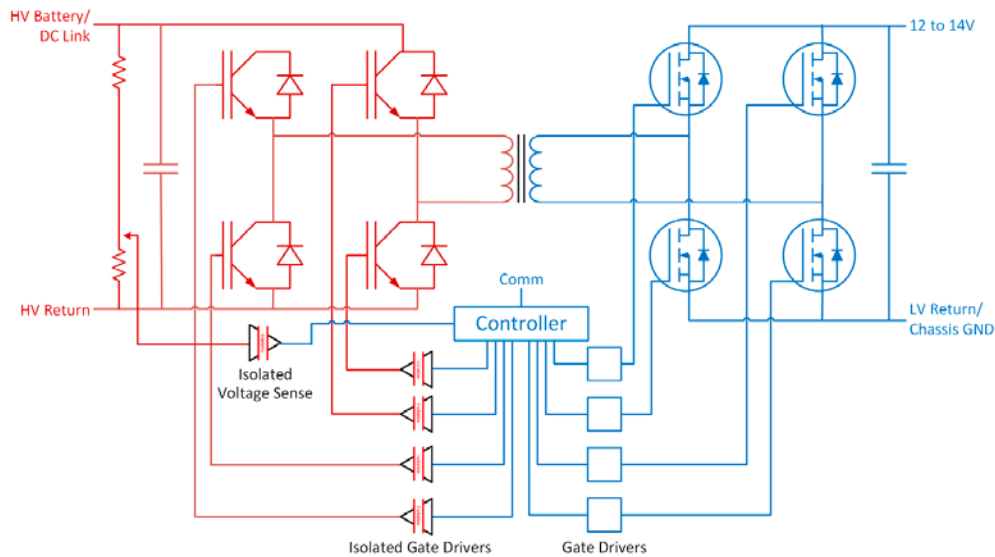
The APM depicted uses a full bridge on the high-voltage primary side of the transformer, and a full-bridge synchronous rectifier on the low-voltage secondary side of the transformer. The HV switches are often implemented as fast IGBTs (as shown) or high-voltage MOSFETs; the HV switches on the primary side of the transformer require isolated gate drivers. The gate drive for these switches uses isolated gate drivers like the Si8239x, Si823x, Si823Hx, Si827x, and Si828x. The latest dc-dc converters are implemented using SiC MOSFETs to increase power density and reduce size.

The converter may be unidirectional, supplying energy only from the high-voltage domain to the low-voltage domain, or it may be bidirectional. While a unidirectional dc-dc can use diodes instead of witches on the LV side, a bidirectional module requires switches. However, gate drivers for the low-voltage switches generally do not need to be isolated.

The APM controller will also need to sense the input and output voltages of the converter to provide closed-loop control. The Si8931 isolated voltage sensor is well-suited for this purpose.

The entire system can be monitored and controlled via an automotive bus such as CAN ("Comm" in the diagrams). The CAN is isolated with digital isolators like Si86xx and digital isolators with integrated dc-dc power converters like Si88xx.

Where Isolation is Needed

- **Converters:** Implemented with silicon FETs, IGBTs, or SiC FETs
  - Isolated gate drivers for the four high/low-side switches
  - Isolated voltage sensor for input and output of the converter
- **Communications and Sensing:** Data for closed-loop control
  - Isolators for digital CAN or other bus types

Isolation Product Offering Summary

Family	Purpose
Si86xx	System communication
Si88xx	Communication with power transfer
Si823x	FET driver in switch and sync blocks
Si828x	IGBT driver with integrated dc-dc
Si8239x	FET driver with enhanced safety features
Si823Hx	FET driver with 4A drive strength and high CMTI
Si827x	High CMTI Driver for SiC FETs
*Si8931	Isolated Voltage Sensor

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Isolation in EV On-Board Chargers

EV OBC Isolation Quick Reference

On-Board Chargers (OBC) are used to convert 120V or 240V AC from a wall socket or wall charger into a DC voltage for charging an automotive battery. Isolation products have numerous uses inside OBCs for Electric Vehicles (EV) and Plug-In Hybrid Electric Vehicles (PHEV).

Key Isolation Features for BMS

- 10+ years of automotive market experience, supporting automotive standards and customer needs

- Top isolation provider for OEMs and Tier 1 EV suppliers, over 30 million shipped

- Automotive-grade ready: AEC-Q100, enhanced manufacturing, and ultra-low defectivity

EV System Overview

The systems in an EV are shown below. There are numerous modules that use Isolation such as: OBCs, Battery Management Systems (BMS), DC/DC converters, traction inverters, and heating/cooling units. The OBC converts AC power from an external charging source into a DC voltage that is used to charge the battery pack in the vehicle.

In addition, the OBC performs other functions including charge rate monitoring and protection. Key standards and terminology are shown in the table below. AC Level 2 OBCs and some Level 1 require isolation. Note that with DC Fast Chargers—which plug in the Quick charging connector—the OBC is bypassed.
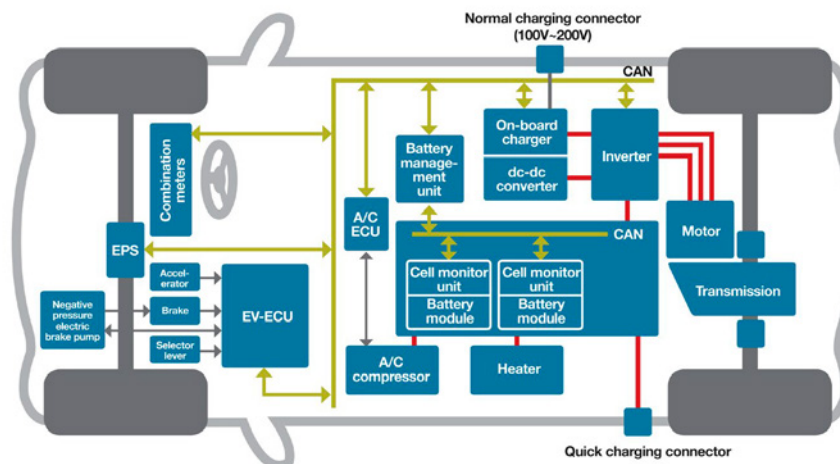
Parameter	Changing Standards			EV Supply Connector	Regions
Level	AC Level 1	AC Level 2	DC Fast Charge	CHAdeMO	Japan
Voltage	120V	220V or 208V	480V	J1772/CCS	Americas, Europe
Current	15A max	40A max	125A max	GB/T	China

OBC System

The OBC system takes the AC input source, converters it to high voltage DC through the rectifier and provides Power Factor Correction (PFC). The resulting DC signal is chopped into a switched square wave to drive a transformer to create the required output DC voltage. The chopping of the input signal is accomplished using isolated gate drivers like the Si8239x, Si823x, Si823Hx, and Si827x.

The output voltage is filtered to the final DC voltage using sync FETs under the control of additional isolated gate drivers. The output voltage can be monitored to provide closed-loop feedback to the system controller using isolated analog sensors like the Si892x, Si8931, and Si894x.

The entire system can be monitored and controlled via an Isolated CAN bus. The CAN is isolated with digital isolators and digital isolators with integrated DC/DC power converters like the Si86xx and Si88xx.
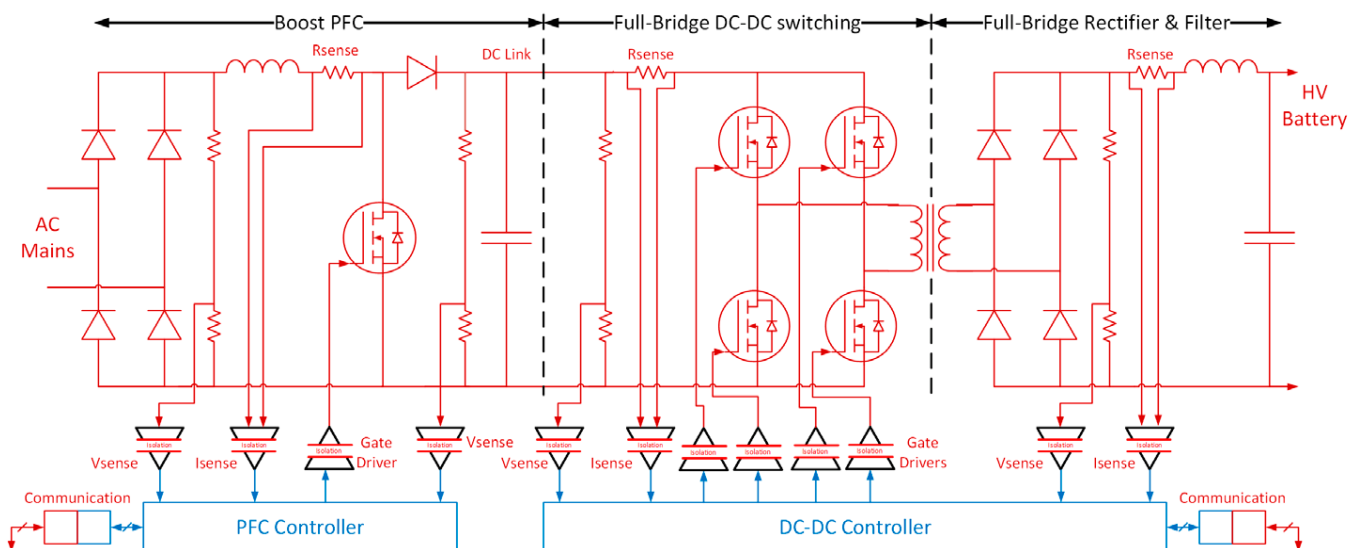
Why Skyworks

- Broad portfolio
  - Rich variety of digital isolators, isolated gate drivers, and current sensors
  - Pin-compatible, second-source options for many popular products
- Robust qualification and support
  - Fully compliant AEC-Q100 qualification
  - Documentation: PPAP, CAMDS, IMDS
- Excellent technical performance
  - EMI reports help ensure customers will pass regulatory tests
  - Industry-leading common mode transient immunity (CMTI)

Isolation Solutions in OBC

- Si86xx and Si88xx digital isolators for communication buses like CAN and SPI
- Si82xx isolated gate drivers for driving currents into the transformer and synchronizing for DC/DC conversion efficiency
- Si892x/3x/4x isolated analog sensors for monitoring charging current or battery voltage for closed-loop control

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Isolation Product Offering Summary

Family	Purpose
Si86xx	System communication
Si88xx	Communication with power transfer
Si823x	FET driver in switch and sync blocks
*Si8931	Voltage measurement amplifier
Si8239x	FET driver with enhanced safety features
Si823Hx	FET driver with 4A drive strength and high CMTI
Si827x	High CMTI Driver for SiC and GaN FETs in sync FET block
*Si892x/4x	Current shunt sense amplifiers w/digital or analog output

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Isolation in EV Traction Inverters

EV Traction Inverter Quick Reference

Traction inverters are used to convert stored dc high voltage from a battery or dc bus link into multi-phase ac power for driving a traction motor. Isolation products have numerous uses inside traction inverters in the drivetrain of Electric Vehicles (EV) or Hybrid Electric Vehicles (HEV).

Key Isolation Features for Traction Inverters

- 10+ years of automotive market experience, supporting automotive standards and customer needs

- Top isolation provider for OEMs and Tier 1 EV suppliers, over 30 million shipped

- Automotive-grade ready: AEC-Q100, enhanced manufacturing, and ultra-low defectivity

EV System Overview

The systems in an EV are shown below. There are numerous modules that use Isolation such as: on-board chargers (OBC), Battery Management Systems (BMS), dc-dc converters, traction inverters, and heating/cooling units.

The traction inverter converts dc power from an on-board high voltage (HV) battery into ac power to drive the main motor or motors of an electric vehicle. In addition, traction inverters perform functions such as voltage boosting, switch protection, and regenerative braking support.

All these functions require galvanic isolation to separate control systems from high voltage domains.
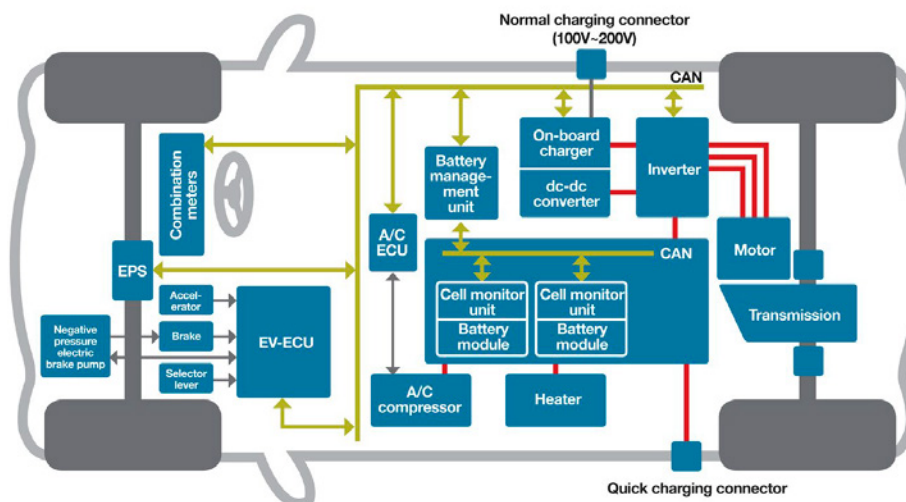
Traction Inverter System

EVs and HEVs require a traction inverter to convert dc energy from the high-voltage battery or dc link bus to the threephase ac energy used to drive the traction motor. The traction inverter is typically capable of transferring power in the 20 to 100 kW range, with switching voltages in the 200 to 800V range, and currents in the hundreds of amperes.

The entire system can be monitored and controlled via an automotive bus such as CAN ("Comm" in the diagrams). The CAN is isolated with digital isolators like Si86xx and digital isolators with integrated dc-dc power converters like Si88xx.
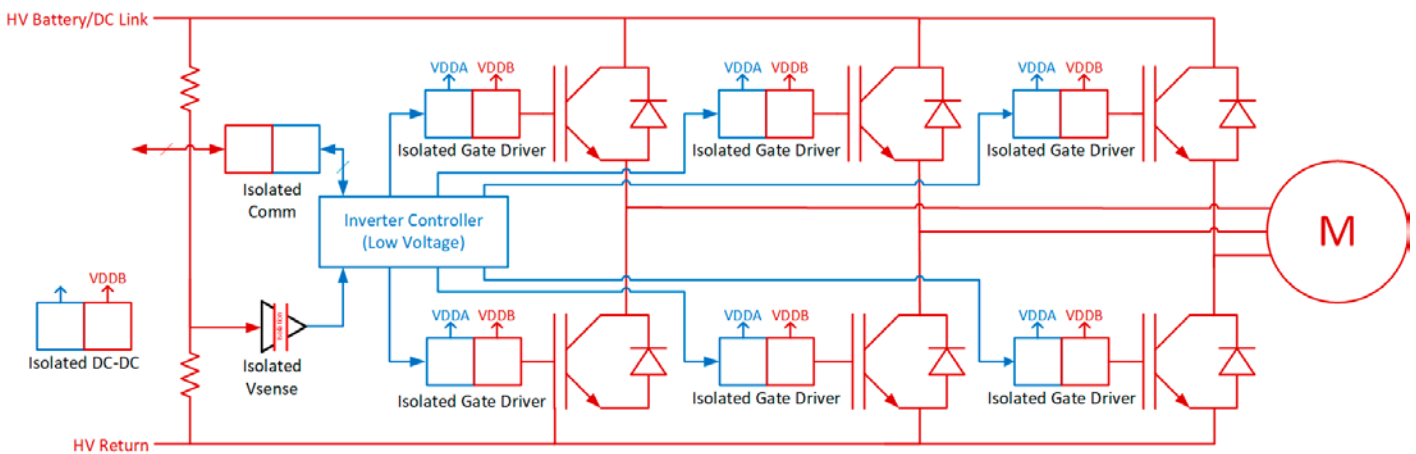
The traction inverter function is accomplished using six switches; one high-side, and one low-side switch for each phase. Isolation separates the controller domain from the high-voltage ac domain. The gate drive for these switches uses isolated gate drivers like the Si8239x, Si823x, Si823Hx, Si827x, and Si828x. The output side of the isolated gate drivers require a supply (typically 15 to 30 Vdc for IGBTs) that is isolated from the low-voltage domain and can be provided by the built-in dc-dc converter in the Si828x IGBT driver family.

Getting optimal efficiency from the system may require peak ac voltages that exceed the vehicle's HV battery voltage, so the traction inverter is often preceded by a bidirectional dc-dc boost converter. This boost converter often contains 2 switches, which require isolated gate drivers. The system voltages can be sensed before the booster and traction inverter and a measurement taken with the Si8931 isolated sensor ("Sns" in the diagram).
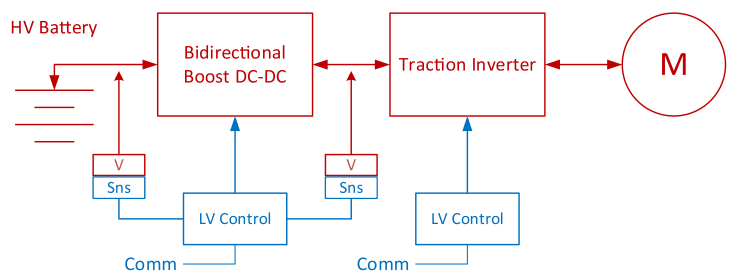
HEVs also include a generator that converts mechanical energy from the internal combustion engine (ICE) into electrical energy to recharge the battery when the ICE is running. A block diagram for the generator's ac-dc converter looks the same as the traction inverter, with the motor ("M") replaced with a generator and the power flowing from generator towards the HV battery. Isolated gate drivers are needed for the switches.

Where Isolation is Needed

- **Inverter**: Solutions available for silicon FETs, IGBTs, or SiC FETs
    - Isolated gate drivers for the six high/low-side switches
- **Booster**: Optional dc-dc booster to increase HV battery voltage
    - Isolated gate drivers needed for 2 switches
- **Generator** (Hybrid): Recharges battery when ICE is running
    - Isolated gate drivers for high/low-side switches

Additional Inverter Types

- HVAC compressors, oil and water pumps, PTC heaters, and turbo chargers may run from HV
- These auxiliary inverters also utilize isolation technology

Isolation Product Offering Summary

Family	Purpose
Si86xx	System communication
Si88xx	Communication with power transfer
*Si823x	FET driver in switch and sync blocks
Si828x	IGBT driver in Inverter Block
Si8239x	FET driver with enhanced safety features
Si823Hx	FET driver with 4A drive strength and high CMTI
Si827x	High CMTI Driver for SiC FETs
Si826x	MOSFET/SiC FET driver with diode input

*Please note that this guide contains references to some products that are in development. Please check with your Skyworks sales or distributor contacts for specific product status.

Conclusion

The race to electrify automotive fleets is accelerating with more vehicles arriving from more manufacturers every year. This increase in the number and type of EVs creates opportunities for electronic suppliers to grow their device footprint in the vehicle's power electronics systems. The high voltages and noisy environments in these drive systems require robust, high-performance galvanic isolation to ensure safe and reliable operation. Ever-increasing power densities from raising the wattages and shrinking the sizes of EV subsystems creates demanding thermal and electrical noise conditions. Semiconductor-based isolation offers significant advantages over legacy optocoupler solutions, which make them an ideal choice in these demanding EV applications.

Automotive customers demand wider operating temperatures, higher quality, and more stringent documentation and systems than industrial customers. Electronics suppliers that can meet all of these demands are poised to ride the coming EV wave.

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