

Connecting the Future of Electric Vehicles

Electric vehicle (EV) technologies continue to make inroads in various industries, from traditional riding mowers to motorcycles and automotive applications—EV is an accepted alternative to gasoline engines. In recent years, EVs have started infiltrating markets dominated by diesel engines. Tractors and other agricultural equipment are now available in EV versions. No matter the application, EV powertrain designs demand higher-power connectors in a smaller footprint to meet the needs of larger, more powerful systems. Connector solutions must handle the rugged demands of agricultural vehicle applications, including resistance to heat, shock, vibration, dust/dirt, and liquids. Advancements to rugged wire-to-board and board-to-board connectors can help increase electric battery performance while reducing design and assembly costs.



Background

EVs and hybrid electric vehicles (HEVs) provide a more efficient alternative to traditional combustion engine vehicles. HEVs use less gasoline, while EVs eliminate gasoline use entirely. These vehicles are quieter, cleaner during operation, and cheaper to refuel compared to internal combustion engines. EV batteries convert 59% to 62% of energy into vehicle movement, whereas gas-powered vehicles only achieve 17% to 21%. EV drivers spend approximately \$1.20 per gallon equivalent for charging, and the average annual operating cost for an EV is \$485 compared to \$1,117 for a conventional vehicle.

EVs and HEVs have fewer moving parts, resulting in reduced wear and tear, lower maintenance costs, and extended operating life.

Government policies, such as subsidies, grants, and tax rebates, along with improved charging infrastructure and strong support from automotive OEMs, are accelerating global sales of HEVs and EVs. Additionally, advancements in driving range make these vehicles a more practical and environmentally friendly choice for consumers.

Subsistence farms owned by families and small business farmers account for the majority of global farming. To reduce long-term costs, these farmers are turning to electric farming equipment, such as mowers and tractors, for low power applications. Electric motors offer double the torque of traditional engines, enabling them to pull heavier loads. For instance, a 60-HP electric tractor can perform the same tasks as a 120-HP diesel tractor. As a result, electric agricultural vehicles lower operational costs, making farming more cost-effective and increasing overall yield.



With unpredictable fuel cost and government incentives encouraging the use of clean technologies, electric farming and agricultural vehicle sales are predicted to grow in years to come.

According to [Markets and Markets](#), the global EV market size was valued at USD 132.6 billion in 2023 and is expected to reach USD 508.8 billion by 2033. Growing environmental awareness and a shift toward sustainable transportation are key factors driving consumer interest in EVs. Improvements in battery life, charging speed, and driving range are further boosting consumer adoption and market expansion.

EV Powertrain Basics

The powertrain of an EV is a simpler and more efficient system compared to internal combustion engines. EVs can run solely on electric propulsion or have an internal combustion engine working alongside it. Powertrains that employ other energy source modes alongside a battery are often called hybrid EVs (HEVs). An EV system has fewer parts by up to 60% and fewer moving parts than a traditional gas powertrain. At its core, a standard EV system contains a charger, battery pack, converter, controller, and motor.

- **The charger** converts AC power received through the charge port to DC and controls the amount of current flowing into the battery pack.
- The **battery pack** consists of multiple Lithium-ion cells and stores the energy needed to run the vehicle. It provides direct current (DC) output.
- **The DC-AC converter** transfers DC power from the battery pack to AC to power the electric motor.
- The **electric vehicle controller** is the electronics package that operates between the batteries and the motor to control the electric vehicle's speed and acceleration, much like a carburetor does in a gasoline-powered vehicle. This includes the powertrain ECU (electronic control unit), which manages the power flow from the battery to the electric motor
- The **electric motor** converts electrical energy to mechanical energy to move the vehicle via a simple single-speed transmission, reducing wheel speed and multiplying torque.

EV Powertrain Connector Requirements

In all automotive applications, connectors must offer high-reliability performance in terms of resistance to heat, shock, vibration, and other environmental conditions. In addition, powertrain systems require rugged and reliable interconnect solutions that can handle higher currents. For example, an EV motor can run anywhere from 96 to 800 Volts DC. HEVs typically feature nominal pack voltages ranging from 96V to 200V, while EVs must support 400V to 800V and higher. A three-phase AC motor is most likely operating at 240 V with a 300 V battery pack.

The downside of higher voltages includes the demand for higher-voltage-rated connectors.

EV Power Supply Connectors

As EV technology continues to evolve, high-power connectors must combine rugged safety features with advanced functionality in a smaller package size.

IP69K rated 2-position power and 2-position signal connectors now feature compact, low-profile designs that offer significant space-savings of up to 40% compared to previously used technologies. Instead of a traditional four-point screw lock, high power EV connectors utilize a robust two-point lock that results in size and height reduction, while still exceeding strict automotive/off-highway vehicle reliability standards. The two-point lock also ensures resistance to shock and vibration.

High-voltage connectors, like the [HVH-280 Series](#), deliver 30A and 600V AC/DC and a wide operational temperature range of -40°C to 120°C. Rated to IP69K, these connectors are waterproof and dust/dirt proof for reliable long-term operation.

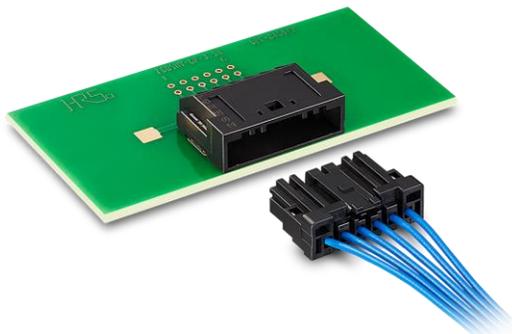


Caption: The IP69K rated HVH-280 Series power connector features waterproof and dust proof design for harsh environment applications

IP69K rating is currently the highest protection rank available in the industry—IP69K rated products are protected against ingress, high temperature, and high-pressure liquids (water and chemicals). This is a requirement for agricultural vehicles that must be washed down periodically.

Additional safety features include IPXXB finger protection to JIS C 9020 and an interlock design that prohibits hot-swapping. Terminal position assurance (TPA) and connector position assurance (CPA) capabilities ensure a connector is locked into place via a secondary lock often with clear tactile click mechanism.

Offering a high-voltage wire-to-board solution, the [Hirose ZG05HV](#) features a compact housing design that provides sufficient creepage and clearance distances, enabling a high voltage rating (1,000V) and withstand voltage (3,000V). The 0.5mm tab-sized connector combines space-saving and high performance without compromising reliability. Its three-point contact design (one spring and two embossed contact points) and double-layered spring increase contact force and vibration resistance, ensuring reliable connections in harsh conditions.



Caption: High-voltage ZG05HV Series connector combines vibration and heat resistance with electric shock prevention.

In addition, the depth of the contacts within the housing eliminates the risk of electric shock during assembly. By offering a combination of high-voltage handling, thermal resistance, safety

features, and space-efficient design, the [Hirose ZG05HV](#) connector supports applications a wide range of automotive applications, including battery, converter, ECU, inverter and on-board charging connectivity.

EV Battery Converter

For EV applications requiring higher ingress protection, IP69K-rated wire-to-wire connectors are indispensable. The [ZE064W Series](#), with its 2.2mm pitch, maintains high electrical conductivity in harsh environments and is designed for long-term performance under exposure to fluids, high heat, shock, and vibration.

A double-layer spring with a three-point contact design ensures reliable connectivity in high-vibration and shock conditions. A contact retainer prevents incomplete mating and provides a pull force strength of 50N, while mating keys prevent misalignment when using multiple connectors.

The [ZE064W Series](#) connector provides heat resistance up to 125°C and stable contact resistance for up to 3,000 cycles, meeting the heat resistance requirements for engine compartments. Rated to 5A @ 250 VAC, these

connectors are ideal for automotive applications such as converters, inverters, batteries, on-board chargers, ECUs, and more.



Caption: Waterproof wire-to-wire ZE064W Series connector combines high vibration and high heat resistance with a space saving design

Connectors for Powertrain ECU

Traditional wire-to-board connectors have protruding male contacts on the board side that can short-circuit due to dust adhesion between adjacent contacts. These conventional connectors also present a risk of electric shock when a worker touches a contact during insertion and removal. Featuring box-shaped female contacts on the board side, [the ZH05 Series](#) wire-to-board connector was designed to provide high performance and prevent electric shocks. By physically surrounding contacts with resin for insulation, the ZH05 Series' innovative design eliminates short-circuiting, even if dust enters the contact. Furthermore, the design prevents workers from touching the contacts, eliminating the potential for electric shock. The unique design is compatible with potting (resin

encapsulation), and the ZH05 Series is safe to use even in environments where condensation easily forms. Female contacts have a double-layered spring design for higher contact force and reliability than single-spring contact. The double-layered springs also offer enhanced vibration suppression. In addition, three contact points are provided for each line on the top and bottom to maintain stable contact even under continuous vibration. The ZH05 Series is commonly used in automotive electronic components such as batteries, chargers, and electronic control units (ECUs).

Connectors for EV Control Panels

Versatile IP67-rated wire-to-board and wire-to-wire connectors combine a small footprint with high current ratings up to 5A, where previous versions could only support 3A, a necessity for daisy chaining power cells and increasing the driving range of HEV/EV vehicles. These innovative connectors feature a pitch of only 2.0mm and a low profile of only 8.24mm, meeting size and weight constraints.

In addition, wire-to-wire and wire-to-board connectors, such as Hirose's ZE05 Series, require 30% less PCB mounting area compared to older technologies and eliminate the need for grounding one side of the PCB. They offer high pin counts of 12 or 24 in a dual-row design, delivering higher density and higher temperature sustainability, which ensures safer and faster charging of HEV/EV batteries; this is particularly important when operating at higher currents, as the derating curve intensifies. A higher nominal temperature combined with higher current carrying capability ensures safer and faster charging of the HEV/EV batteries.

Many new connector designs feature terminal position assurance (TPA) and connector position assurance (CPA) capabilities. These design elements ensure a connector is locked into place via a secondary lock, often with a clear tactile click mechanism.

These connector's terminals are polarized, meaning their intrinsic shape prevents incorrect mating. This safety feature further increases reliability. The IP67 rating protects against heat, shock, vibration, water, oil, dust, and dirt.

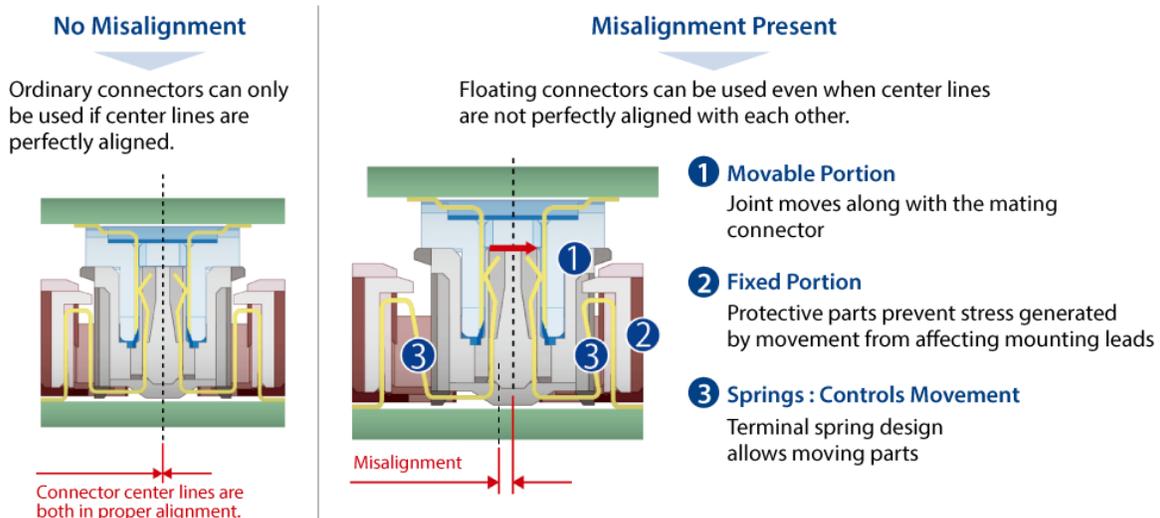
Flexible Connectors

Previously, wire-to-board connectors were the primary choice for HEV and EV drivetrain applications, such as motor controllers and inverters. However, these connectors often occupy more space and complicate the integration and assembly process. New board-to-board connectors with a floating contact system

now offer a better solution by simplifying assembly, reducing labor costs, and saving space.

These versatile board-to-board connectors support high voltage ratings up to 125V AC/DC in a compact design with a 1mm pitch. Featuring high temperature resistance up to 140°C, the floating contact design provides superior vibration resistance for reliable operation.

Floating contacts can compensate for alignment errors up to $\pm 0.7\text{mm}$ in both the X- and Y-axis directions, as well as $\pm 0.75\text{mm}$ tolerance in the Z direction. This feature helps prevent misalignment during installation and mounting. Because the spring portion of the terminal absorbs assembly errors, it minimizes the need for corrective re-work operations. The floating contact system is ideal for HEV and EV drivetrain systems that require multiple connectors on the same board.



In addition, the floating contact system like the one found in Hirose's [FX26 Series](#) board-to-board connector increases reliability by reducing the stress on solder joints caused by misaligned connectors. The floating design also enhances durability by preventing solder cracking.



Conclusion

Hybrid and electric vehicles will continue to gain traction as technology advances to meet specific application requirements. With improvements in driving range, horsepower, emissions, maintenance, and long-term costs, HEVs and EVs are here to stay. To support the growing demand, connector manufacturers are developing innovative interconnect solutions for EV powertrains. These connectors provide reliable and durable operation with enhanced functionality and features—all within small, lightweight packages. HEV and EV connector solutions simplify design, ease assembly, and enhance overall product performance.