BOURNS®

Advanced Powertrain Protection Solutions in Electric Vehicles

WHITE PAPER

Introduction

In recent years, automotive manufacturing has been moving toward a future dominated by Electric Vehicles (EVs). According to J.D. Power, nearly a quarter of vehicle shoppers are considering choosing an EV, highlighting the significant growth potential of this market. Several factors are driving this shift, including government incentives, expanding charging infrastructure, decreasing production costs, and, most importantly, a rise in environmentally conscious consumers.

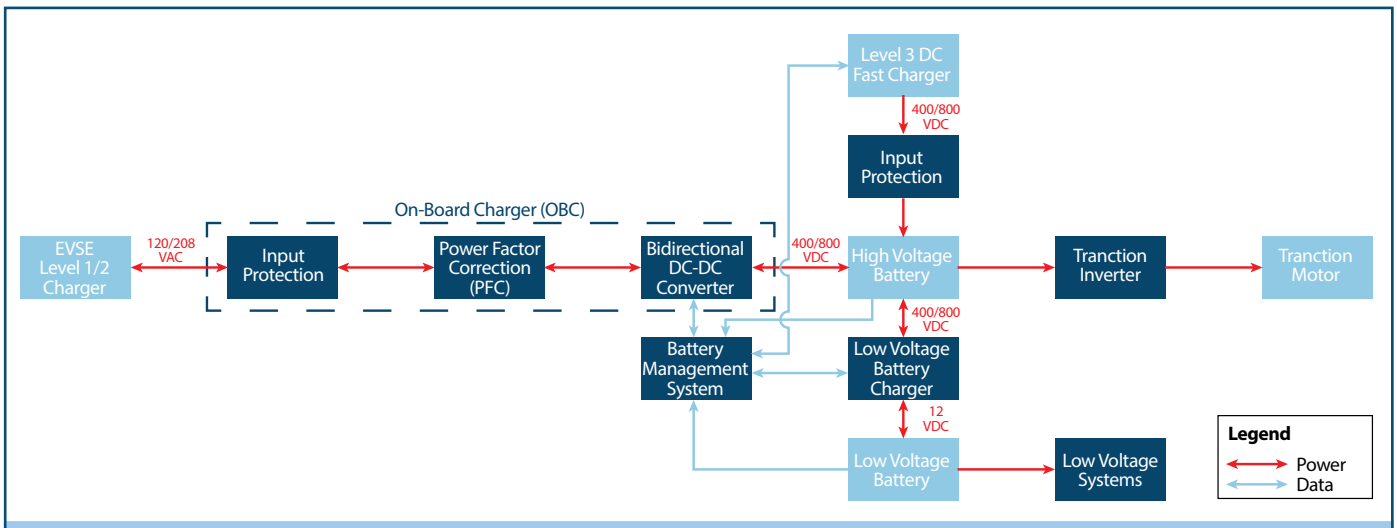
A major factor driving the popularity of EVs is their zero tailpipe emissions. Unlike traditional Internal Combustion Engine (ICE) vehicles, which burn gasoline or diesel and emit carbon dioxide and other pollutants, EVs run on electricity and produce no emissions. While ICEs rely on fuel combustion to rotate the wheel axle, EVs use high-efficiency electric motors to turn the wheel axle. There are several types of EVs on the market today: Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Fuel-Cell Electric Vehicles (FCEVs). BEVs are the most common type and operate solely on electricity, using a rechargeable battery to power the electric motors. HEVs and PHEVs both combine an internal combustion engine with electric motors; however, the key difference is that PHEVs can be plugged in to recharge their battery, allowing them to operate longer on electricity alone. In contrast, FCEVs, the least common type, rely on the intake of hydrogen as fuel to create electricity in the car.

As EVs continue to reshape the automotive landscape, ensuring the safety, efficiency, and reliability of their powertrain systems is paramount. This white paper explores the core architecture of EV powertrains and highlights how Bourns provides advanced circuit protection and sensing solutions for critical subsystems such as On-Board Chargers (OBCs), Battery Management Systems (BMS), inverters, and 48 V auxiliary networks.

The paper outlines the flow of electrical energy in a BEV — from grid charging sources to battery storage and motor propulsion — and the need for precise voltage and current monitoring and overvoltage and overcurrent protection throughout the process. The paper also highlights how Bourns' comprehensive portfolio enhances EV system resilience, reduces component failure, and supports compliance with automotive safety standards. These technologies play a critical role in improving the durability and performance of EVs, boosting consumer confidence, and accelerating the global shift toward electrified transportation.

Background

Inside a BEV, electricity follows a critical path from the charging port to the battery and then to the motor. Charging input typically comes in three forms: 120 VAC, 240 VAC, and DC fast charging, with each offering progressively faster and more powerful charging. When Alternating Current (AC) is used, it passes through an OBC, which rectifies AC into Direct Current (DC). Both the rectified AC from the OBC and DC fast charging inputs must then be regulated to a voltage level suitable for the battery, usually around (400 V or 800 V). This power flow is monitored and controlled by the BMS, which helps to ensure safe charging by managing cell balancing and determining when charging should stop. The high-voltage DC power, converted from AC is fed into an inverter, which transforms it into AC to power the electric motor.



Block Diagram of an EV Powertrain

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WHITE PAPER

Charging Stations & On-Board Charger

The AC voltage from the electrical grid that is needed by the vehicle's battery must first be converted into high-voltage DC power. This rectification is handled either by the OBC or the charging station and both play a role in rectifying AC power. In Level 1 (120 VAC) and Level 2 (208-240 VAC) charging, the OBC inside the vehicle performs the AC-DC conversion. In contrast, Level 3 DC fast charging performs this conversion externally at the charging station, sending DC power directly to the vehicle's high-voltage battery.

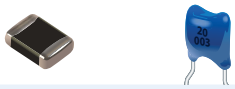
For Level 1 and Level 2 charging that utilizes the OBC, the AC-DC conversion is accomplished using a high-voltage full-bridge active rectifier circuit, which consists of switching elements such as IGBTs or MOSFETs, along with high capacity diodes that eliminate the negative portion of the AC waveform. However, the resulting DC voltage is not ideal – its current and voltage may be out of phase; which reduces efficiency. To correct this, the signal is passed through a Power Factor Correction (PFC) circuit.

The PFC is a circuit composed of switching elements and diodes, and is necessary to align the current and voltage waveforms to reduce reactive power and increase overall energy efficiency. After passing through the PFC, the DC voltage, typically in the range of 200 V to 400 V, is adjusted to match the required charging voltage of the high-voltage battery, usually around 400 V or 800 V. This voltage conversion is performed by an isolated DC-DC converter, which either steps the voltage up or down as needed. With rectification handled by the stationary charging station, power is delivered directly to the vehicle's high-voltage battery pack.

Accurate Monitoring and Effective Protection

Critical to the reliable operation of the OBC is the integration of many supporting devices that measure, control, and regulate its performance. Accurate monitoring of both the input AC voltage and current, as well as the regulating DC voltage is essential for efficient and safe AC-DC conversion in the OBC circuit. This is typically handled with high-voltage precision resistors and low-resistance shunts, respectively. Bourns offers advanced precision resistors for voltage sensing and high-power shunt resistors for current sensing to effectively satisfy these essential measurement requirements. Bourns engineers its innovative precision resistor solutions and high-power shunts to provide accurate, stable performance under demanding high voltage conditions.

To protect sensitive switching elements, Bourns has a superior line of TVS diodes and Multilayer Varistor (MLVs) for overvoltage protection. These components are especially effective in safeguarding gate-controlled devices such as MLVs and TVS diodes, which typically have maximum gate voltage ratings between 12-20 V. Additionally, power thick film resistors play a critical role in protecting snubber circuits, where they help suppress transient overvoltage spikes caused by inductive switching in Switch-Mode Power Supply (SMPS) topologies.

Product Image	Model	Description
	CSM2F	Shunt resistors for monitoring high current in high power applications.
	PWR	Power resistor manufactured using thick film on alumina ceramic technology, used in current measurement, snubber, bleeder and discharge circuits.
	CDSOD323-T12C-DSLQ	Gate inputs at switching elements such as IGBTs and MOSFETs are prone to transient overvoltage events. To protect these inputs, TVS diodes clamp harmful transients to typical gate input voltage levels (12-20 V).
	AV-SMD, AV HT-SMD, AV-TH	Overvoltage protection for gate inputs at switching elements.
	CAT-A, CR-A, CRM-A, CMP-A, CHP-A, CRT-A	Bourns offers a broad portfolio of resistors and resistor arrays to meet any design requirement. Thick and thin film technologies available in varying tolerances.

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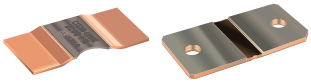
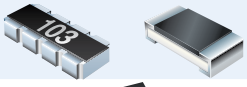
WHITE PAPER

Safeguarding Battery Management Systems

Battery Management Systems (BMS) are responsible for monitoring and controlling the charge level and charging status of each battery. This ensures the optimal use of each battery cell, helping to extend the battery lifespan and maintain overall vehicle performance. These sensing functions are also supported by Bourns' precision resistors and high-power shunt resistors, which enable accurate voltage and current measurements with minimal power loss. Since the BMS also manages real-time data processing and communication, it is a requirement to protect its sensitive components, such as sensors and microcontrollers. Delivering the level of protection needed here are Bourns automotive-grade TBU® High Speed Protectors (HSPs) and TVS diode arrays.

Product Image	Model	Description
	TBU® High-Speed Protector (HSP)	TBU® HSP is a resettable, ultra-fast overcurrent protection device. Offered in dual and single DFN packaging, the TBU® HSP guards against power cross, lightning, and other energy surges on communication lines.
	CSS, CSM2F	Precision shunts are ideally suited for battery monitoring circuits and DC/DC converters. These shunts provide tight tolerances with low temperature drift in a small footprint.
	CAT-A, CR-A, CRM-A, CMP-A, CHP-A, CRT-A	Bourns' broad portfolio of resistors and resistor arrays are designed to meet any broad application requirements. Thick and thin film technologies available in varying tolerances.
	CDSOT23-T24CAN-Q	Diode arrays are commonly used for overvoltage protection of critical communication interfaces. Bourns' TVS diode arrays feature various voltage levels suited for common Ethernet, CAN, and I2C protocols.

Traction Inverter & Motor Data Protection

In the final stage of a BEV powertrain, the electric motor is powered by a high-voltage battery. An inverter is used to convert the DC output from the battery into an AC waveform. An inverter is a device that uses synchronized switching elements that imitate an AC waveform from a DC voltage. In the inverter, where the switches are controlled by high frequency PWM signals, high-speed responsiveness is necessary. Bourns® TBU® HSPs and low-capacitance TVS diode arrays are excellent solutions that provide robust protection against overvoltage and overcurrent events without compromising performance.

In electric vehicles, Front-Wheel Drive (FWD) requires two electric motors, while All-Wheel Drive (AWD) requires four motors for constant communication with the central computer of the car to ensure responsive and safe conditions. This data link is one of the most critical connections in an EV powertrain because it demands zero tolerance for failure. To safeguard this essential communication channel, multiple layers of protection are implemented.

Bourns components play a key role in helping to secure these connections with a range of circuit protection solutions. Among the most impactful are Bourns® TBU® HSP devices, which act as high-speed, resettable overcurrent protectors that isolate sensitive components in the event of a fault, helping to preserve the integrity of the vehicle's control and communication systems. TBU® HSPs are resettable devices that restore normal circuit protection once the overcurrent event has dissipated. This high-speed responsiveness and flexibility are vital for preserving the integrity of communication between the powertrain and the vehicle's CPU, protecting against overcurrent threats.

Bourns also has low-capacitance diode arrays that designers can implement as an effective solution for overvoltage protection in high-speed data lines. These diode arrays redirect any stray overvoltage events in high-speed scenarios. They are essentially the first line of defense against transient overvoltage events by helping to safely divert harmful surges away from sensitive components. Because they protect the vital communication link between the CPU and the powertrain, they must be rigorously tested and engineered for reliability and ruggedness.

Product Image	Model	Description
	TBU® High-Speed Protector (HSP)	TBU® HSPs are a resettable, ultra-fast overcurrent protection device. Offered in dual and single DFN packaging, these devices guard against power cross, lightning, and other energy surges on communication lines.
	CDSOT23-T24CAN-Q	Diode arrays are commonly used for overvoltage protection of critical communication interfaces. Bourns full line of TVS diode arrays are offered in various voltage levels suited for common Ethernet, CAN, and I2C protocols.

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WHITE PAPER

48 V in Supporting Devices

Both electric and internal combustion engine vehicles increasingly rely on higher power for subsystems such as control units, displays, sensors, small motors, and data communication. To meet these demands, automobile manufacturers are shifting from the traditional 12V electrical architecture to 48V systems. This increase in voltage enables greater power delivery while allowing smaller-gauge wiring, which helps reduce weight, cost, and heat generation. However, they require greater protection from overvoltage and overcurrent events.

In 48V vehicle systems, circuit protection is implemented using a variety of devices such as Gas Discharge Tubes (GDTs), TVS diodes, resettable fuses and MLVs. These protection devices are designed to guard against overvoltage or overcurrent events. While overvoltage and overcurrent are related to each other, their origins are different. Overvoltage conditions often stem from external threats, such as Electrostatic Discharge (ESD) (e.g., static electricity from passengers), lightning strikes, automotive load dumps or mechanical faults, like sensor miscalibration. Overvoltage protection devices, such as TVS diodes, GDTs, MLVs, and diode arrays, address these types of threats by clamping the voltage to safe levels and diverting excess current to ground, shielding sensitive components from damage. In contrast, overcurrent events usually result from internal faults in the vehicle, such as short circuits or load spikes. These conditions can cause overheating and permanent damage to components. When overcurrent protection devices, like PPTC resettable fuses trip due to an increase in current, they increase their resistance. The increase in resistance absorbs the high current until the current entering the device reaches a safe level. By including protection against overcurrent and overvoltage events at a higher 48V system level, designers are able to increase the reliability and lifespan of important subsystems in a vehicle.

Product Image	Model	Description
	SinglFuse™ SMD Fuses	Fuses act as non-resettable, overcurrent protection devices for critical components.
	Multifuse® SMD Fuses	PTCs are resettable overcurrent protection. Excellent for low voltage and low current DC busses and inputs, PTC devices are particularly developed to give robust and cost-effective protection. They also reduce short circuits, especially in a range of demanding settings with high temperatures.
	2027-A Series	GDTs are commonly used in front-end and data line protection circuits designs to guard against high-energy transients. They are capable of absorbing large surge currents, making them ideal for protecting sensitive components.
	AV-SMD, AV HT-SMD, AV-TH	Provides overvoltage protection for gate inputs at switching elements.
	SMAJ-Q, SMLJ-Q	Designed for precision overvoltage protection of low voltage DC busses, these components safeguard against residual surge energy and Electrostatic Discharge (ESD). They offer fast clamping response and are available in a range of power ratings and voltage options to suite many application needs.

Conclusion

The evolution of EVs has driven significant advancements in automotive technology, particularly in the powertrain and its supporting systems. Bourns' advanced protection components are key solutions that enable designers to enhance the reliability and safety. By integrating high-performance protection devices such as Bourns® TBU® HSPs, low-capacitance diode arrays, GDTs, and precision resistors, these now important solutions significantly help safeguard BEV powertrains and supporting electronics against overvoltage and overcurrent events.

Bourns' solutions not only enhance the durability and performance of EV powertrains but also contribute to greater customer satisfaction. By providing robust protection against electrical faults, these components reduce the likelihood of component failures, lowering the frequency of service calls and maintenance. This increased reliability results in fewer disruptions for drivers, improving the overall ownership experience and building greater confidence in EV technology.

Safety and reliability are critical in automotive components, especially in the demanding environment of electric vehicles. Bourns protection devices ensure that vital systems operate within safe electrical parameters, preventing damage from electrical anomalies. This commitment to safety supports compliance with rigorous industry standards and regulations and offers peace of mind to both manufacturers and consumers. The proven reliability of Bourns solutions allows EVs to endure the challenges of daily operation, delivering a dependable and secure driving experience.

In summary, Bourns commitment to delivering innovative and quality protection components is a key contributor in advancing powertrain technology for the electric vehicle industry. Bourns' solutions not only help ensure the safety and reliability of EV systems, but also afford significant benefits to manufacturers and end users alike so that a more sustainable, efficient, and customer-focused automotive future can be realized.