Breaktor® circuit protection technology
White paper

Paramount Power Protection

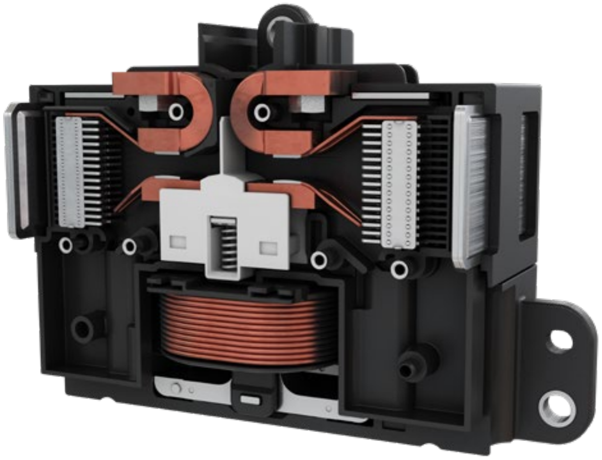
for EV Systems

Powering Business Worldwide

Advanced protection for high voltage circuits in electric vehicles

Executive summary

The Eaton Breaktor® is the next generation of electric vehicle power switch and circuit protection, protecting vehicle operators, first responders, and service technicians by covering the full range of over current and short circuit fault conditions from high voltage battery packs. The Breaktor actively senses and quickly interrupts high voltage power system faults, while improving electric vehicle service convenience with the ability to reset.



Electric vehicle trends

The vehicle electrification era is here, bringing with it a wave of innovative technologies and exponential advancements. However, there are important safety implications to be considered as these technologies and market trends are adopted. What are these trends and how do they impact circuit protection of electric vehicles?

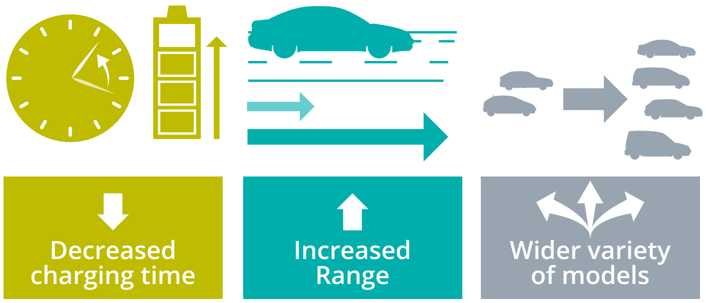


Figure 1: EV market requirements for mass adoption.

Demands on electrical architecture increase

The market today sees demand and development towards decrease charging times, increased range requirements, and a wider variety of vehicle models. All of which are impacting the electrical system performance and design.

Decreasing charging times result in a demand for higher voltage charging and systems. Due to the higher overall power levels that can be achieved as the system voltages are increased, platform and charging voltage fall into two segments around 400VDC and 800VDC. Today's electric vehicle can be mainly found at the 400VDC with some exception and plans to develop 800VDC system voltage platforms.

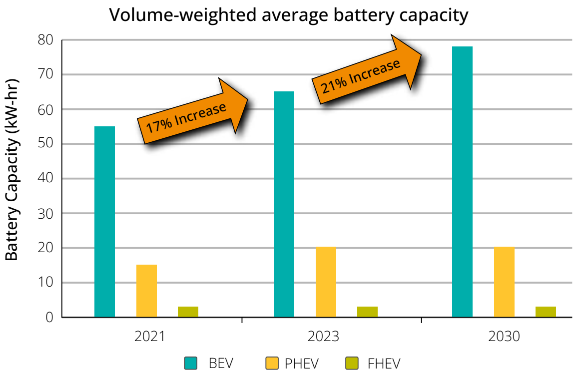


Figure 2: xEV fault current directly related to battery capacity [S&P Global, 2023].

Increased range requirements influence the size of batteries and the total power provided by the battery. As a result, battery development will see increased battery capacities [IHS], which results in the directly related available fault current that can be delivered to a vehicle electrical system in the event of a short circuit on the battery. The manufacturers must consider the increased fault current in the protection component requirements.

On top of that, the motor power and current is ramping up [IHS]. By that, circuit switching and protection devices will face higher requirements. They must withstand the higher operating currents and cyclic requirements.

Market requirements for larger batteries are pointing towards an increased system voltage level for future platforms in order to meet customer charging time expectations. Planning data is indicating a steady deployment of 400VDC system voltage throughout future years [IHS], but an increasing share of passenger car vehicles will be 800VDC to take advantage of increased efficiency and shorter charging times.

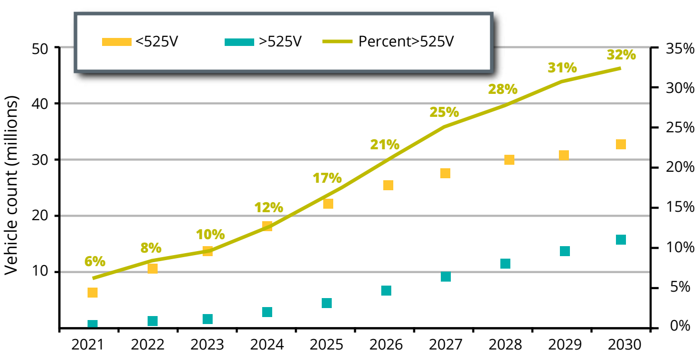


Figure 3: Share of 800V increasing [S&P Global, 2023].

Summing up, all three trends are challenging developments for circuit protection and need careful consideration. The decreased charging time requirement promotes higher system voltages. Increased range results in higher fault currents. And the variety of models planned indicates a higher operating current requirement.

Critical protection considerations

Conventional system architecture design for main protection involves a coordinated fuse and contactor solution within the power distribution box. The two components must be coordinated to ensure coverage of the full range of possible fault scenarios, which can derive from different battery states of charge and route causes.

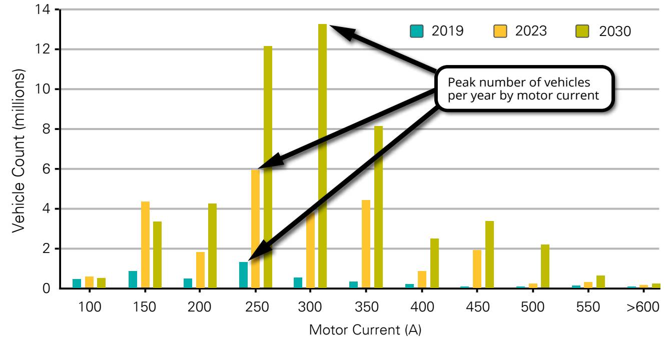


Figure 4: xEV protection devices need to withstand higher operating currents [IHS, 2019].

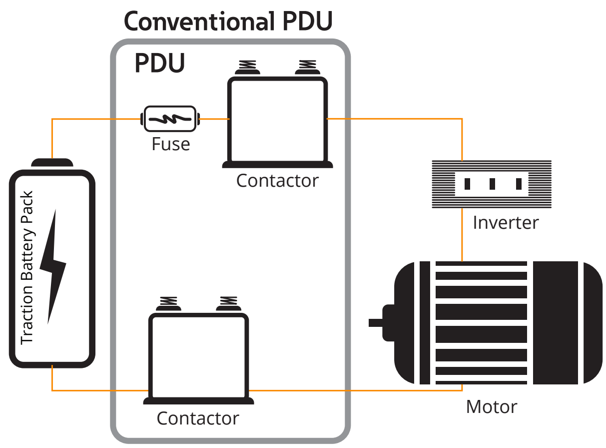


Figure 5: Conventional xEV circuit protection.

The conventional circuit protection solution of fuses and contactors has contradicting design requirements. Current levels in a vehicle can vary widely from <100A during regular driving conditions to as a high as 20kA or more during a short circuit event. It is critical that the contactor performs the switching function during normal operation modes while the fuse is able to interrupt quickly during unsafe modes of operation like overloads and short circuits. Fuse and contactor coordination requires a seamless handoff between these two independent devices at a certain current level and this is not always possible to achieve.

Poor coordination can lead to reduced fuse reaction time, melted contacts, nuisance tripping, and fuse fatigue. Late tripping can cause the contactor to weld and creates a safety issue for the system components. Nuisance tripping is a safety issue as well and can result in loss of vehicle propulsion which can be both a safety issue and result in customer dissatisfaction.

As a goal, the coordination must address these issues and ensure consistent, fast reaction time to protect against overload and short-circuit, and consistent switching of rated current. By the physical nature of a fuse design, the coordination is a trade-off between fuse durability and fuse speed. Selecting a smaller rating equates a faster reaction time, while the system current will cause higher fatigue and reduces lifetime of the fuse. Therefore, just choosing a smaller rating for the fuse cannot be the appropriate measure. In the contrary, fuse selection for coordination scenarios requires enhanced expertise in the coordination challenge of the application, as well as fuse design and fatigue simulation capabilities. If the above points can be met, a conventional architecture with fuse and contactor is competitive solution for the system protection.

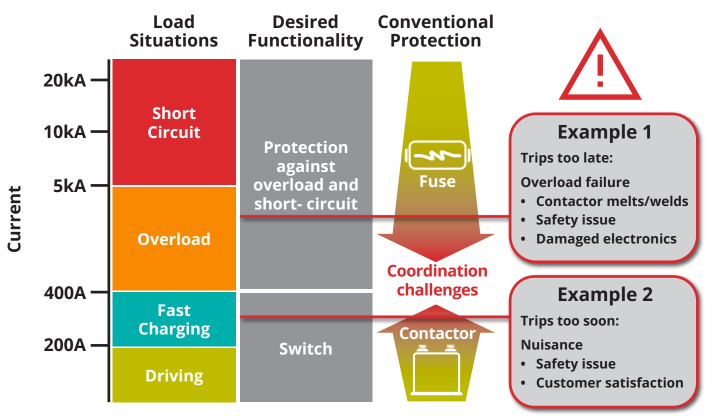


Figure 6: Conventional protection has contradicting design requirements.

A potential solution to the durability consideration with fuses is the implementation of a pyrotechnical switch. A pyrotechnical switch is a triggerable circuit protection device that relies on a controlled explosion to severe a conducting busbar. Pyro solves the coordination challenge but introduces new functional safety challenges, as this system loses its passive reaction to fault situations and relies on accurate triggering. The additional components must ensure a reliable triggering including potential failure modes in the electronic which involves functional safety considerations.

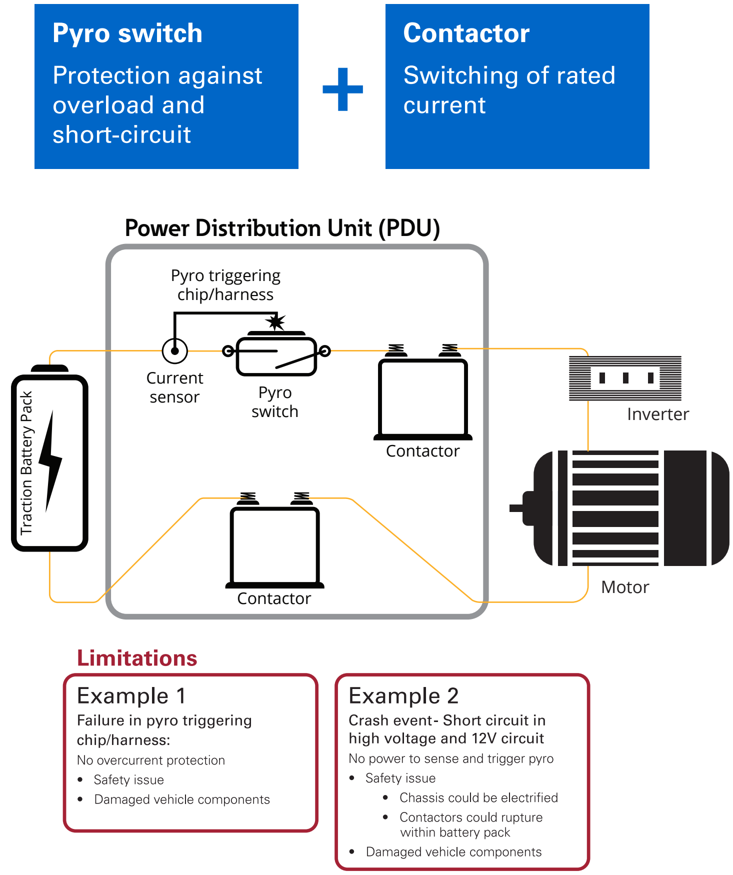


Figure 7: Pyro switches present functional safety challenges.

Critical protection considerations

The analysis of conventional circuit protection considerations concludes that there is clearly a need for a new protection solution. The development trends in the voltage and power levels underline the increasing complexity to protect against the electrical fault scenarios. The solution needs to:

- offer a fully coordinated circuit protection and switching solution;
- actively interrupt but also passively trigger in case of power loss;
- improve functional safety of critical protection systems; and
- deliver improved component serviceability and/or ability to reset.

Eaton developed a solution considering the criteria above. Breaktor circuit protection combines two key components into one: the circuit breaker and the relay, and thereby is capable of handling the full protection range from overloads to short-circuits as well as the switching functionality in normal operation.

Key features include:

- the contacting area with splitter plates in the upper part of the device;
- the driver coil in the lower part of the device; and
- the onboard electronic including current sensing.

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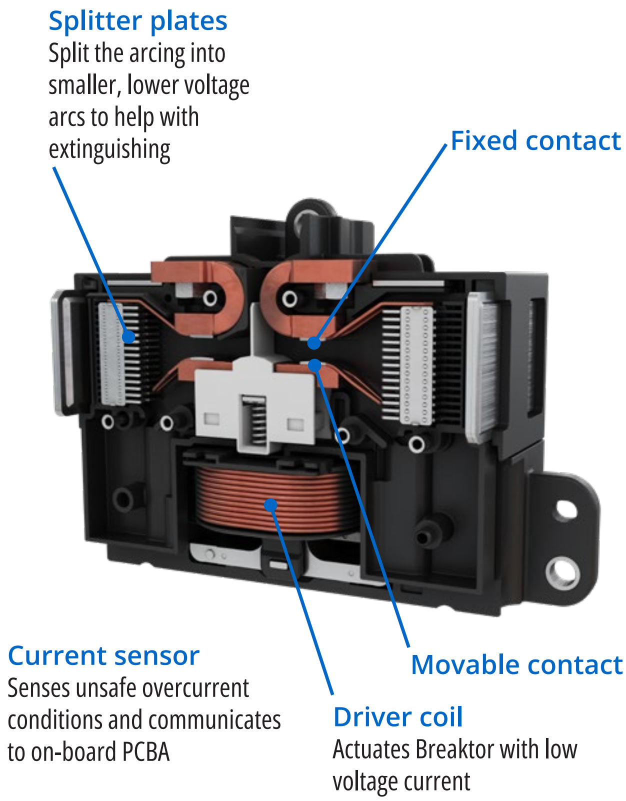


Figure 8: Breaktor circuit protection key features.

In normal switching operation, the driver coil closes the contacts powered by a 12V supply to switch the device on and falls back into off-mode when the supply voltage drops off.

Breaktor constantly monitors the current levels with the onboard current sensor and shuts-off the power to the driver coil once an overload condition is detected. The trigger overcurrent level is adjustable.

For short-circuit situations, Breaktor detects the condition in less than 1ms and disconnects the driver coil. This high-speed deactivation helps to prevent contact welding. Furthermore, Breaktor utilizes the effect of electrodynamically contact levitation positively to limit the current through to the system. This effect is threatening in the case of contactor and fuse combinations, since the levitation of conventional contactors can disrupt the fuse reaction to the fault. In any fault case, after the respective safety checks, Breaktor can be re-activated.

Breaktor advanced circuit protection

Breaktor advanced circuit protection is the perfect combination by covering the full protection range for overloads and short-circuit conditions, it can actively interrupt a system short for quick response time, and also passively interrupt in the event of system power losses. Breaktor improves the functional safety of the electric vehicle protection system and includes the ability to reset by way of controls for service convenience.

How do you apply this device in an electric vehicle system?

Breaktor not only replaces protection and switching components, but also eliminates high voltage busbars and auxiliary voltage harnesses in the system due to the reduced number of overall components and connections within the system protection architecture. The integration of Breaktor therefore poses advantages form a system perspective with regards to optimized cost, power density, and safety assurance.

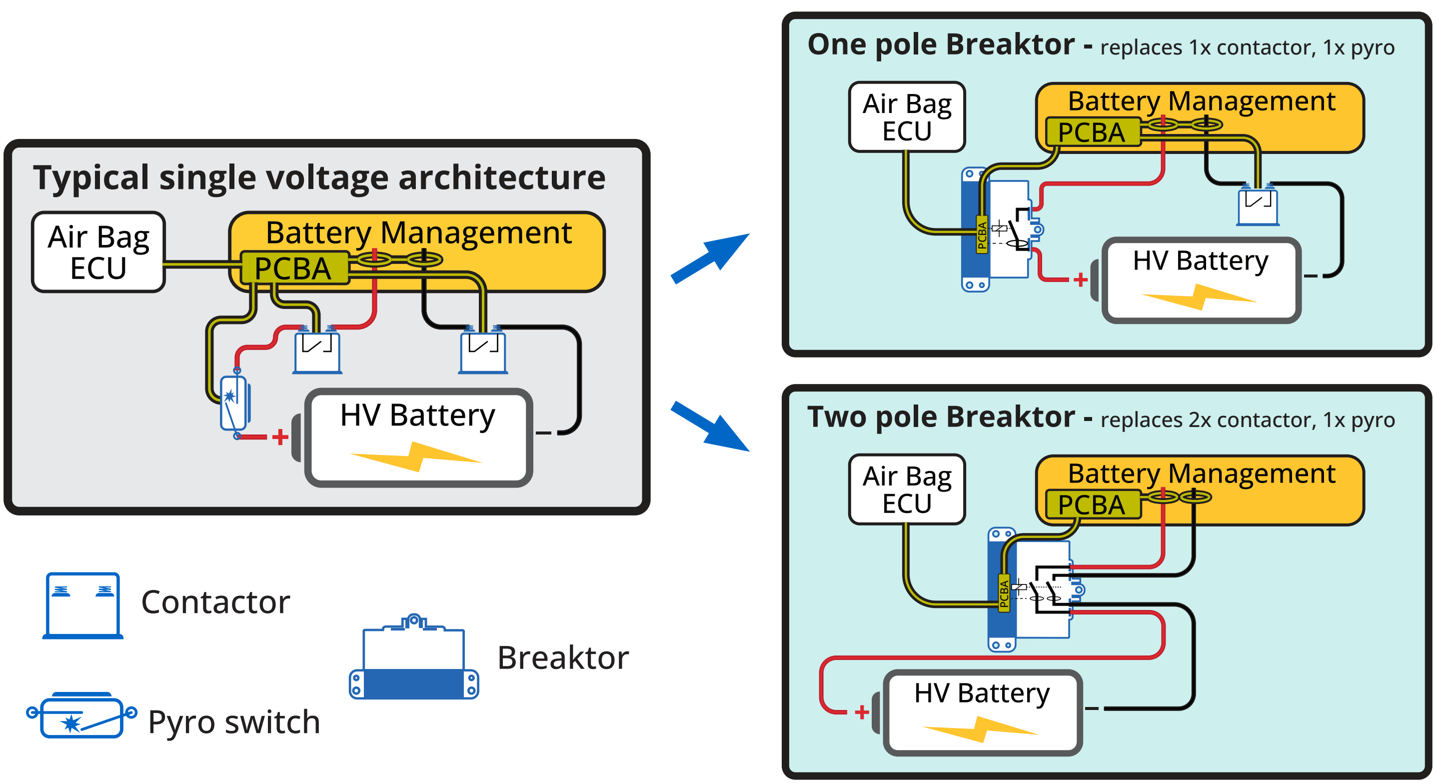
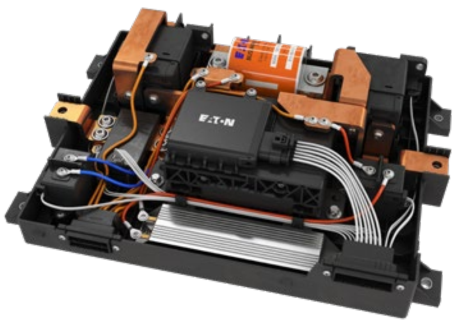


Figure 9: Breaktor integration functional architecture.

Summing up, fuses can still be considered viable solutions for electric vehicle protection. Eaton's fuse design and application expertise will help to identify applications here a fuse and contactor system can be fully coordinated or whether an advanced protection system like Breaktor should be considered. Alternative pyro technology solves the coordination issue but introduces new challenges to the application and system design with regards to its need for active triggering.

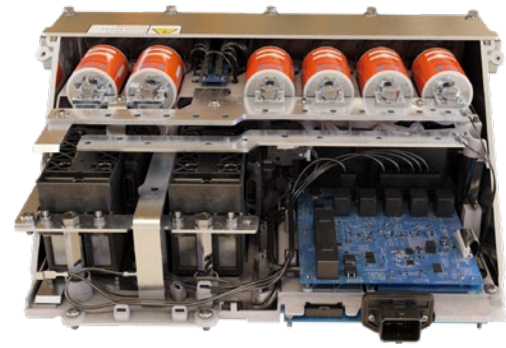
Products featuring Breaktor circuit protection



Battery Disconnect Unit

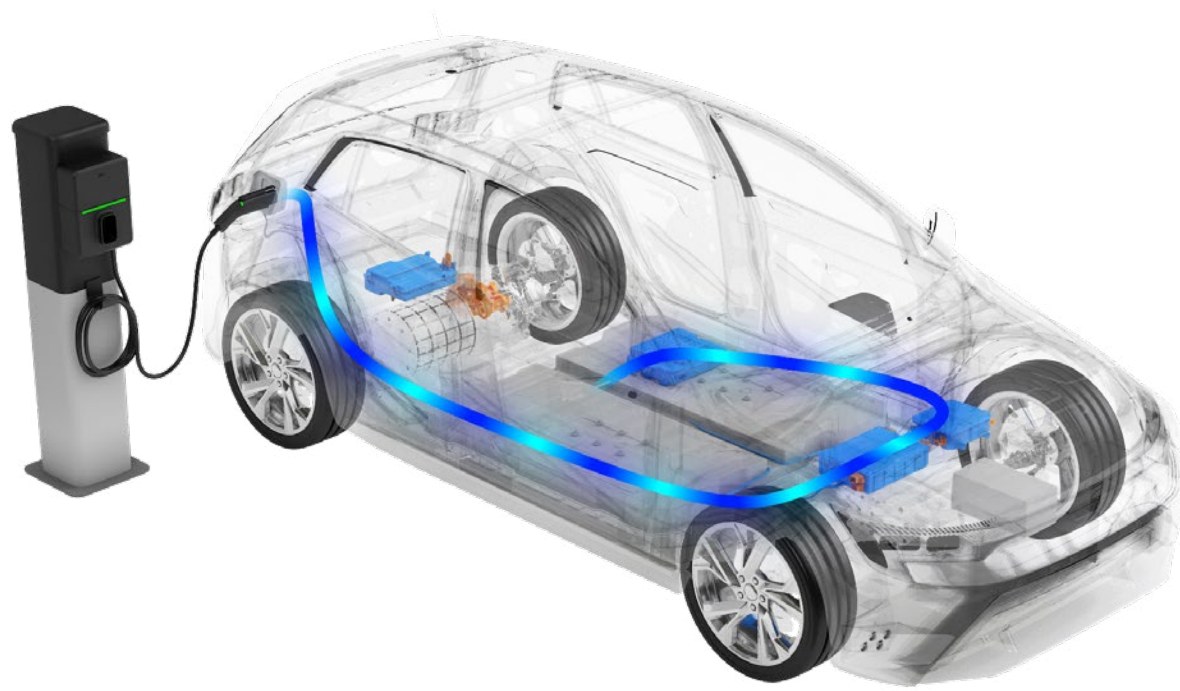
The battery disconnect unit (BDU) is designed to efficiently distribute power throughout the EV system. With the integration of Breaktor, the BDU provides improved quality and simplified architecture by combining current switching and resettable bidirectional short-circuit protection with fast actuation (up to 900V).

Enabling reduction of up to 15 components from the BDU assembly, Breaktor's integrated coil driver, economizer, and sensing/triggering circuit reduce overall cost and complexity. Additionally, it's self-triggering design, diagnostic electronics, and mirror contact help to ensure utmost safety and reliability.



FLEX power distribution unit

The next generation high-voltage intelligent FLEX power distribution unit (FLEX PDU) monitors and manages all power distributed to power electronics and provides central protection for the electrical system for hybrid, fuel cell and fully battery electric commercial vehicles. Fully customizable to meet a commercial vehicle's specific requirements, the FLEX PDU can be integrated with Breaktor. This allows for integrated over-current protection for high power loads including traction inverters and DC fast charge.



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