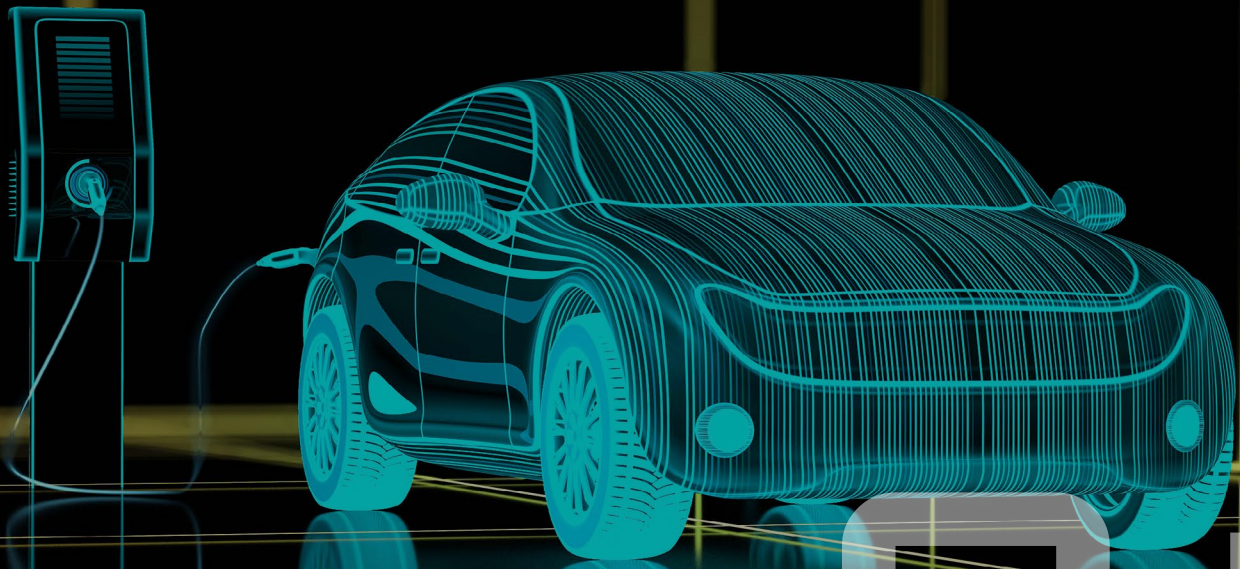




Enhancing EV safety: the innovative use of pyro fuses in electric vehicle protection systems

Executive summary

For decades, pyrotechnic components have been crucial in vehicle safety systems, ensuring rapid deployment in emergencies. This whitepaper highlights the use of active trigger and dual trigger pyro fuses in electric vehicle (EV) protection. The active trigger pyro fuse disconnects a current-carrying busbar within 2 milliseconds during electrical emergencies, while the dual trigger model offers redundant activation pathways for enhanced reliability. Compared to traditional thermal fuses alone, pyro fuses provide lower internal resistance, no ageing concerns, and consistent switch-off times, making them superior for EV safety.



Powering Business Worldwide

Standard active trigger protection

Pyrotechnic components have been used in vehicle safety systems for decades, protecting passengers in case of emergencies. Whether it's an airbag module that must be triggered or the hood of the car needs to be lifted instantly for crash-protection purposes, pyrotechnic ignitors are used to achieve rapid movement. With the advent of electric vehicles (EVs), another pyrotechnic product has gained prominence: the pyro fuse.

Much like the airbag module, the pyro fuse employs a pyrotechnic capsule to disconnect a current-carrying busbar in the event of a crash or electrical emergency, preventing any further current flow. This mechanism, which can be activated externally, such as by the Battery Management System (BMS), ensures that the current is severed within 2 milliseconds. The self-contained nature of the pyro fuse allows for safe handling without posing risks to the environment or surroundings, making it easy to service and/or replace after operation.



Figure 1: Eaton Active Trigger Pyro EBPSXXF40

Early EV protection architectures relied heavily on multiple thermal melting fuses to provide layers of overlapping protection. These fuses needed a fault current to be tripped and required reliable coordination with each other and with switching devices like contactors. As protection strategies have advanced, traditional thermal fuses have been augmented or replaced altogether by pyro fuses or alternative protection devices like [Breaktor® circuit protection technology](#).

Compared to fuses, pyro fuses have several advantages:

- Lower internal resistance
- No ageing concerns
- Constant switch-off time (e.g., 2ms) independent of fault current
- Capability to disconnect without a fault current when triggered externally

These features allow pyro fuses to provide isolation under circumstances that would not trip a thermal fuse, such as mechanical crashes, damaged battery packs and outgassing events. In such events, isolation is crucial to prevent further damage, making pyro fuses a more advantageous protection option compared to only using fuses.

Figure 2 illustrates the disconnecting speeds between a pyro fuse and a conventional main fuse. The total time to isolate the system, which includes the activation of the pyrotechnic capsule, disconnection of the busbar, and quenching of the arc, is in the range of a few hundred microseconds. The key to achieving fast disconnection times with a pyro fuse at the system level is the time taken to recognize a fault current, process and verify it within a microcontroller, and issue the trigger signal. This means that at the system level, the response times of pyro fuses can vary significantly.

In complex electrical systems, such as those in commercial trucks, or in low-cost architectures like economy cars, these measurement delays can last several seconds. In contrast, in high-complexity luxury or high-performance electric vehicles, the delay can be reduced to just a few microseconds. The crucial factor is to evaluate and compare the current sensor readings and be absolutely certain that they indicate an electrical fault requiring a pyro fuse trigger, rather than just interference or a false alarm causing a nuisance fault.

TC curve

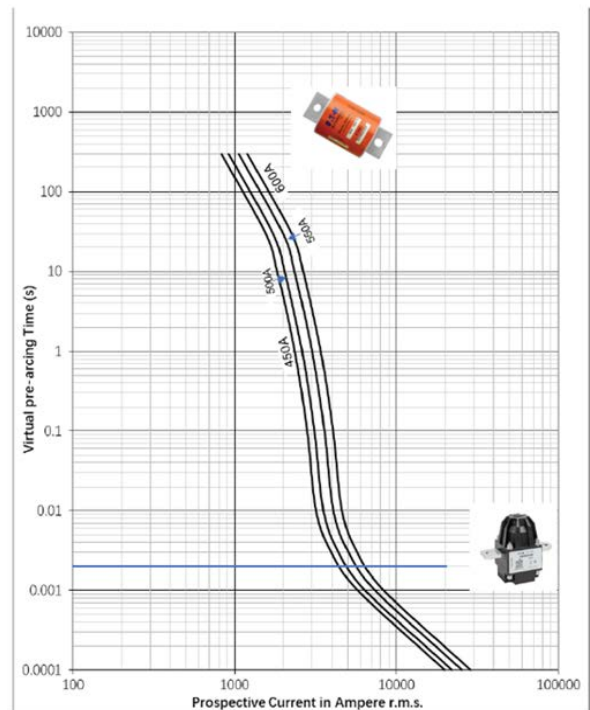


Figure 2: Comparing Fuse Time-current curves to Pyro fuses disconnecting speeds



Innovative dual trigger protection

To address concerns of detection and signal delay, Eaton has developed the dual trigger pyro fuse (Eaton pyro fuse F40A). While the active trigger pyro fuse (Eaton pyro fuse F40) requires an external trigger signal from the BMS, the dual trigger pyro fuse can activate itself when higher fault currents are present. Starting at an overcurrent of 3,000A, the internal protection function will automatically trip the triggering mechanism, disconnecting any further current flow. This innovative approach combines pyro and fuse technologies within Eaton to create a single component.



Figure 3: Eaton Dual trigger pyro fuse EBPSXF40A

The dual trigger pyro fuse effectively addresses two critical concerns:

1. Ensuring protection even if the pyro trigger signal from the BMS arrives late or fails to arrive.
 - a. If only an active pyro fuse is installed in the system, the absence or delay of the pyro trigger signal can result in a thermal overload, fire, and/or explosion due to the lack of protection.
 - b. The dual trigger pyro is capable of triggering even when 12V power is lost
2. Safeguarding contactors from welding, fire, or rupturing.
 - a. The dual trigger pyro fuse provides an additional layer of protection by activating quicker than the contactors' rupture curves, thus preventing severe damage. Below is a more detailed explanation:

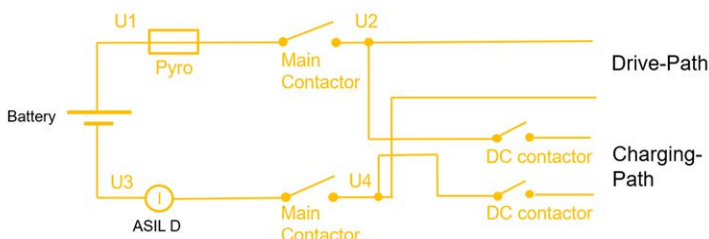


Figure 4: Regular EV Architecture

In EV architectures, the pyro fuse plays a crucial role in protecting the system. Two contactors, one in the positive pole and one in the negative pole, are used for the switching functionality. These contactors can handle relatively small loads up to their rated current (e.g., 400A).

If the fault current rises significantly, the contactors can experience minor degradation or severe damage, including levitation of the contact, welding, fire, and explosion at fault currents between 5,000A and 10,000A. Contactors are designed to withstand such high fault levels temporarily, such as 10,000A for 5ms. During this period, the protective component (pyro fuse, fuse, or Breaktor) must disconnect the current to prevent severe damage.

The Eaton dual trigger pyro fuse addresses this dangerous condition by coordinating its internal or self-triggering function to activate quicker than the contactors' rupturing curve, providing effective protection and ensuring system safety.

As displayed in Figure 5, the blue and green lines represent the rupturing curves of two contactors, illustrating the maximum time and fault current they can withstand before welding, fire, or explosion occurs. The black line represents the self-triggering pyro fuse curve from Eaton. In all instances, the Eaton dual trigger pyro fuse F40A activates quicker than the contactor, eliminating any risk within the system. The F40A offers 500V and 1000V versions.

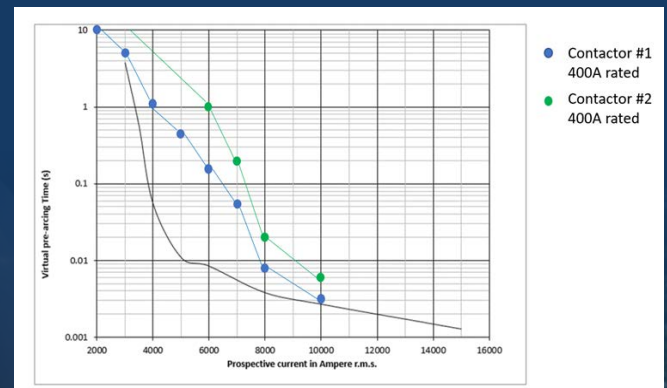


Figure 5: Self-triggering function of dual trigger pyro fuse



Eaton's versatile offering in circuit protection technology

As a supplier of pyro fuses, fuses, and Breaktor circuit protection technology, Eaton offers the unique ability to discuss your switching and protection strategy impartially. Whether you prefer to safeguard your system using aR or gG type fuses, have contactor-fuse coordination issues, favor pyro-based disconnecting functions with or without dual triggering, or need protection through electromechanical levitation that includes resetability after short circuits – Eaton has a versatile offering and is ready to assist.

Eaton's application specialists are ready to discuss your contactor coordination, speed requirements, and help design safe architectures. Please reach out with any questions.

Eaton Bussmann series EV fuses

Eaton's Bussmann® series electric vehicle fuses are tailored protection solutions that feature market-leading compact and high-speed designs, with lifetime durability simulation capabilities.



Breaktor circuit protection technology

EV systems must safely and reliably protect people and components during all load situations including short circuits, overloads and collision events, as well as quick charging and normal driving scenarios. Eaton's Breaktor® circuit protection is the complete solution

