Five Factors to Consider when Selecting an Overcurrent Protective Device for an Electric Vehicle System to Ensure Safe and Reliable Performance

Introduction
In electric and hybrid vehicle applications, electrical systems are often pushed to their limits. Aggressive current pulses, combined with high temperatures and vibration profiles, push the limits of electrical system reliability. When selecting an over current protection device (OCPD), care must be taken to account for these complex variables while still providing a system that is safe and reliable. During a short-circuit event, very high levels of energy can cause damage to a large number of system components. An electric vehicle (EV) OCPD should be selected that can protect against the maximum current the battery can produce in a short-circuit event, while also being coordinated with upstream and downstream components to ensure protection of the complete electrical system. This article will discuss five critical and often overlooked factors in OCPD selection in EV applications in order to ensure safe and reliable system performance.

1. Fuse/Contactor Coordination
In selecting an OCPD for any electrical application, it is critical to ensure that the device is rated to protect against the full range of overcurrent conditions that might be seen in the application. In the case of electric vehicles, this is often accomplished by using fuses and contactors in series, each of which has unique advantages for overcurrent protection.

Contactors are designed to protect against lower current overload conditions and can do so quickly and, depending on the degree of overload, can perform this function many times for a single device. The contactor also serves as a switch that can energize and de-energize the electrical system during startup and shutdown. While contactors are ideal for protecting against low current overloads, they are unable to protect against fault currents above 400-800% of their rated current, depending on the contactor model. Alternatively, electric vehicle fuses are designed to protect against high fault currents up to 20 kA in some cases. Electric vehicle fuses have industry-leading current limitation that allows them to protect a wide range of system components including wires/cables, DC/DC converters, inverters, auxiliary circuits, and even the contactor itself (Figure 1). While fuses are designed to protect against high short-circuit currents, they can have a limited range of protection against overload currents. Care should be taken to ensure that the maximum interrupting rating of the contactor is the same or greater than the minimum interrupting rating of the fuse.

A properly designed fuse and contactor system provides a vehicle complete protection against all possible overcurrent conditions; however, these are two devices that must be coordinated and designed together as a system. Since contactors are not rated to carry large short-circuit currents for a long period of time, they have the potential to rupture when protected with a fuse that has inadequate current limitation. Similarly, if there is no overlap between maximum interrupting rating of the contactor, and minimum interrupting rating of the fuse, there can be a range of overcurrent conditions that the system is unable to protect.

2. Selective Coordination Between Upstream and Downstream Protective Devices
Coordination and selective coordination in overcurrent protective devices has been a long-standing requirement...
for many industrial electrical applications. Specifically, the need for selective coordination increases for critical-to-life applications such as emergency lighting and healthcare facilities. Selective coordination not only ensures unrelated systems stay operational during an overcurrent event, but also can significantly reduce downtime and maintenance costs in any industrial or commercial facility.

As the trend for electrification in passenger and commercial vehicles continues, an increasing number of automotive Original Equipment Manufacturers (OEMs) are considering coordination between onboard OCPDs. In high-voltage EV applications, it is common to have one primary OCPD protecting the main battery system of the vehicle, with power distributed to several auxiliary loads such as HVAC, charging systems, and DC/DC converters. Coordination between auxiliary and primary OCPDs is of vital importance as the main motor of the car can be considered a critical-to-life application. As such, it is important that a short-circuit on an auxiliary load does not interrupt power to the main vehicle battery and motor, preventing vehicle mobility.

Fuses have been long established as the industry leader in providing selective coordination solutions for critical applications. The physics of fuse technology lends itself well to providing selective coordination for the widest range of current ratings. In traditional electrical distribution systems, selective coordination is expressed as a ratio of the current rating of the upstream fuse to downstream fuse. For example, if a fuse has a 2:1 selective coordination ratio, as long as the upstream fuse is, at a minimum, two times the current rating of the downstream fuse, selective coordination can be achieved. These selective coordination ratios are not only specific to the fuses under evaluation, but also unique to the resistance and inductance of the electrical circuit. Similar coordination ratios can be established for electric vehicle OCPDs as a general rule, but it is recommended to perform short-circuit testing to ensure that all system parameters are considered.

One of the challenges of selective coordination in EV applications is the time associated with clearing DC arcs. In today’s electric vehicles, batteries can produce a voltage as high as 1000 Vdc. DC arcs oftentimes take longer to clear by an OCPD because the voltage supplied by the battery will never cross zero as it would in an AC application. As a result, it is common for DC OCPDs to show a notable shift in the time current curve for clearing times associated with melting times below 10 ms. Figure 2 highlights this by showing the comparison of similarly rated fuses clearing AC vs. DC voltages. This tailing behavior during high-voltage DC faults causes a potential for time current curves of different ratings to overlap when performing a coordination study. This can effectively increase the coordination ratio between fuses and must be accounted for in fuse selection. If such an overlap exists, the only way to prove out coordination is through empirical testing. Figure 3 shows an example of two properly coordinated high-voltage EV fuses through 10 ms.

Figure 2: Comparison between AC and DC time current curves.
3. Cyclic Loading

In any electrical system, effects of cyclic loading and transient surges can affect the entire electrical system, including components, cabling, screw connections, and OCPDs. In the case of fuses, care must be taken to size the fuse to carry the Root Mean Square (RMS) load of the system, and the pulse profile (magnitude and duration) of a typical electrical load. In electric vehicles, this is further complicated by the fact that different drivers exhibit different driving habits, resulting in high variability of thermal and mechanical strains on the system. In electric vehicle applications, these are typically referred to as driving profiles, and care should be taken to account for a wide range of driving conditions in designing an electrical system to ensure reliability.

Mechanical fatigue is the common cause of failure in an electrical system if cyclic loading and transient surges are not accounted for. During peak current loading, a fuse element can see a very high temperature for a short period of time, followed by rapid cooling during the off cycle. The expansion and contraction of the fuse element from large temperature swings can result in strain hardening of the element and eventually failure by means of fatigue. While this is a notable risk in an electric vehicle system, fuses have been successfully employed in EVs for high-voltage circuit protection for decades and have a track record of reliability, provided these factors are taken into consideration.

There are several methods employed today to evaluate whether or not a fuse is properly sized to withstand a specific driving profile, first of which is through durability testing. Testing is an ideal method of evaluating various driving profiles; however, it is often not possible to test actual driving profiles due to the extensive test durations. Often accelerated aging tests are performed with more aggressive driving profiles, which can yield results much more quickly, but it is difficult to ensure that the accelerated test truly represents the actual conditions. Another method of determining suitability of a fuse to a specific driving profile is through simulation analysis. By incorporating factors such as current profiles, elevated ambient temperatures, and electrical connection details into a simulation, a wide array of driving profiles can be evaluated in a relatively short amount of time. Regardless of what method is implemented, it is critical to take this factor into consideration to ensure reliability of the electrical system.

4. Available Fault Current

In battery applications, the amount of fault current a battery can produce in a short-circuit event is of utmost importance when selecting a protective device. Fault current is dependent on many factors, including battery chemistry, size, resistance, and inductance of the system. As the range and performance of EVs in the market is continually increasing, so is the size of vehicle batteries and, similarly, the available fault current. Some of the largest electric vehicle batteries in the market today can produce in excess of 15 kA of fault current in a short-circuit event.
OCPDs are rated to a maximum interrupting rating or maximum breaking capacity. It is important that the maximum interrupting rating of the OCPD is greater or equal to the maximum fault current that the battery can produce to ensure safe operation.

5. Electrical Connections and Conductor Size

In the automotive industry, there is a consistent trend to reduce the size and weight of system components in order to improve the power efficiency of the overall system. Electrical conductors are some of the components in an electrical system that often get pushed to their limits to optimize system size and weight. Sizing conductors for continuous currents and short-term overloads based on the insulation rating is generally a well understood process in the industry. However, conductor sizing, and more specifically, the design of the conductor/fuse interface can also have a significant effect on the life of the fuse in the application.

As mentioned in the previous section, the largest contributor to mechanical fatigue in a fuse is rapid heating and cooling of the fuse element resulting from cyclic loading. Heat can be dissipated from a fuse through many ways, but is primarily achieved through the electrical conductors. Since the fuse is generally one of the most resistive components in a system, specific care must be taken to optimize the fuse/conductor interface to quickly dissipate heat during high current pulses. This can be achieved by sizing the conductor properly, and maximizing the cross sectional area of the fuse/conductor interface.

Another way fuse life can be increased is by balancing the thermal conductivity of the connections between the two sides of the fuse. Since fuses are designed with a series of current restrictions in the fuse element, it is desirable for all of these to see a uniform temperature distribution to avoid increasing the rate of fatigue at specific parts of the fuse element. This can be evaluated by comparing the temperature rise between the two fuse terminals and comparing the voltage drop between the fuse terminal and conductor on the two sides of the fuse.

Conclusion

A properly designed fuse and contactor system provides a vehicle complete protection against all possible overcurrent conditions. Fuses have been successfully employed in EVs for high-voltage circuit protection for decades, and have a track record of reliability, provided the five factors described in this article are taken into consideration to ensure safe and reliable performance.

Authors

Kevin Calzada is Product Manager for Bussmann series EV fuses, and Greg Brossier is Strategic Account Manager for Bussmann series EV fuses at Eaton, St. Louis, MO. For more information, visit Eaton at www.eaton.com/bussmannseries.