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Evaluating Fuses, Breakers, PTCs And Electronic Fuses For Automotive Applications

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Conventional fuses have always been a widely accepted choice for robust protection of wired systems from fire and physical damage in automotive (as well as many other) applications. The classic fuse is designed and intended to fail open. This makes classic fuses the best method of wire protection, although fuses are often rated below the point where wire is damaged to protect particular loads.

While at first glance solid-state replacements for fuses seem desirable, these devices can and do fail shorted, an unacceptable failure mode for robust wiring circuit protection. With functional safety becoming more and more of a system requirement, care should be taken in choices of protective devices or circuits. Note that functional safety is defined as actively preventing the failure of a system from causing harm to people and property, a task accomplished very well with fuses. Nonetheless there are several “middle grounds” of circuit protection available.

This article explains the differences between the popular circuit protection devices available to electronics designers including fuses, circuit breakers, PTCs and electronically assisted circuit breakers also known as electronic fuses or eFuses. Their tripping mechanisms and other characteristics such as isolation, accuracy, reset ability and programmability are discussed with an eye toward evaluating their flexibility and reliability, and helping designers to select the right device type for their applications.

This article uses examples from industrial devices to illustrate the functionality that is needed for automotive applications and functional safety. It concludes by looking ahead to the next step in the evolution of electronic fuses—a device that can meet functional safety requirements.

Fuses And Breakers

The challenge in specifying fuses is shown most readily by reviewing typical fuse opening curves like those shown in Fig. 1. Despite their high ratio of fusing current to operating current, and, by electronic standards, a long opening time, fuses are second to none for robust protection of wire and circuits. A physical open circuit is an ideal circuit protection response.

The essential attribute of the classic fuse is that it fails open because that is exactly what it is designed to do. While it may seem sometimes to be a nuisance to have to replace a fuse or reset a classic mechanical breaker, it certainly is less of a nuisance than the consequences of not using such a device.

The next step up from the fuse is the circuit breaker which offers overload trip performance similar to a fuse yet can be reset rather than replaced. One thing the circuit breaker has in common with the fuse is that it physically opens, or isolates, the circuit. However circuit breakers subjected to frequent trips or trips in heavy overloads have occasionally been known to weld their contacts together and fail closed. As such the fuse still stands alone in providing the highest level of functional safety for circuit protection. Fig. 2 depicts a typical circuit breaker trip curve.

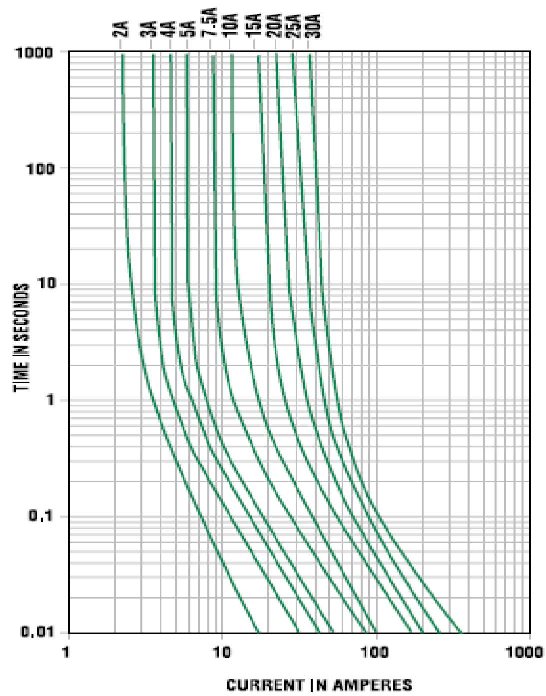

Fig 1. Typical fuse opening curves show the broad relationship between overload level and opening time. Nonetheless, fuses have proven to be a best choice for wire protection. Their only failure mode is "open," and it performs this with unquestioned reliability (graph courtesy of Littelfuse).

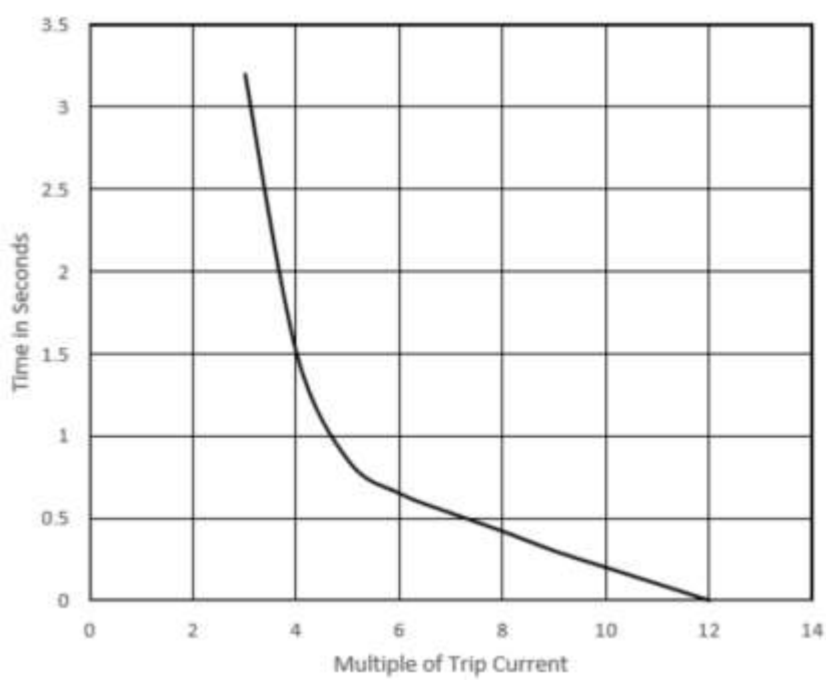

Fig. 2. This breaker trip time vs. overload curve for mechanical circuit breakers also shows a slow response, which is acceptable when protecting wiring.

Fuses and circuit breakers both share the attribute of physical isolation when they open which provides unquestioned protection of the circuit (although aged or damage circuit breakers can fail to open).

But so far the most robust circuit and wiring protection devices are less than optimum when it comes to protecting electronic devices. That's because they lack certain attributes required in protecting solid-state electronics such as the ability to limit current and to shut down quickly when conditions merit shut down.

PTCs For Overcurrent Protection

PTCs, or positive temperature coefficient resistors, are resettable overcurrent circuit protection devices. The PTC is a series element, made of a resistive material with a positive temperature coefficient. Under normal conditions, the PTC has a low resistance, and has little influence on the circuit.

The PTC changes from a low resistance state to a high resistance state in response to an overcurrent condition, which heats up the PTC material. This high resistance reduces current to a safe level. After the overcurrent state is removed, the device cools and returns or resets to its normal, low resistance state yielding a self-resetting device. PTCs are simple, economical, and easy to use.

When evaluating the PTC in light of functional safety, several failure characteristics need to be considered which are discussed in an application note published by Vishay (see the reference). This application note documents several cases where PTCs can fail shorted, which can occur as a result of

- overvoltage
- overpower for higher voltage (>400 V) devices
- reduction effect (unstable material, e.g. wax, potting, glue, lacquer, etc. in contact with PTC).

Because the PTC can exhibit a fail-shorted mode they would not be a good choice where functional safety is an objective.

Enter The eFuse

Electronic circuit breakers, or more accurately, electronically assisted circuit breakers—commonly referred to as electronic fuses or eFuses when offered as integrated circuits (ICs)—present the opportunity to provide shutdowns as quick as microseconds as well as several categories of retry and reset ability. Electronic circuit breakers easily provide better accuracy of trip points. Furthermore functionality can be included to report, or set, parameters such as voltage and current. These capabilities are often essential in protecting electronic devices.

An example of the performance an electronic breaker can provide is shown by a typical trip curve for an electronic breaker used in industrial process control systems. This trip curve, which is plotted in Fig. 3, allows overloads up to 130% for 5 s.

When exceeding that level, the electronic breaker current limits (using the semiconductor components) for up to 50 ms, after which the breaker shuts off. This provides a high tolerance for short-term faults or surges where recovery is expected, reducing false shutdown problems. And lastly, the electronic breaker can be reset electronically. The block diagram in Fig. 4 shows the functional elements contained in an electronic breaker.

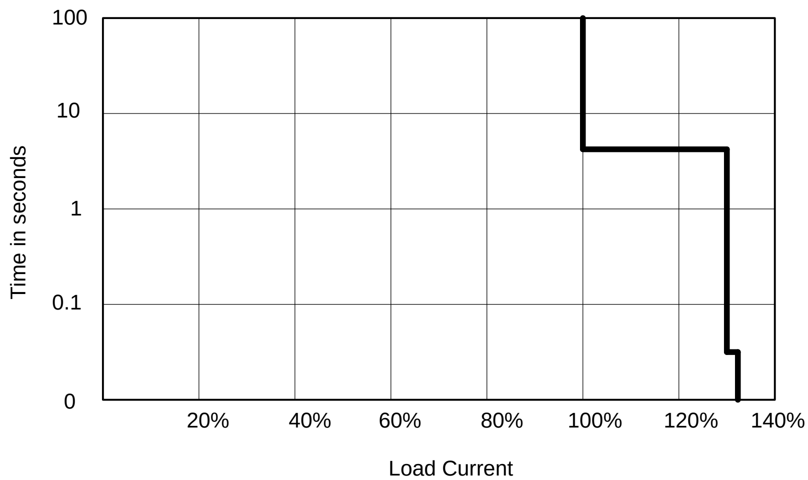

Fig. 3. Typical trip curve for an electronic breaker in 24-V industrial process control systems.

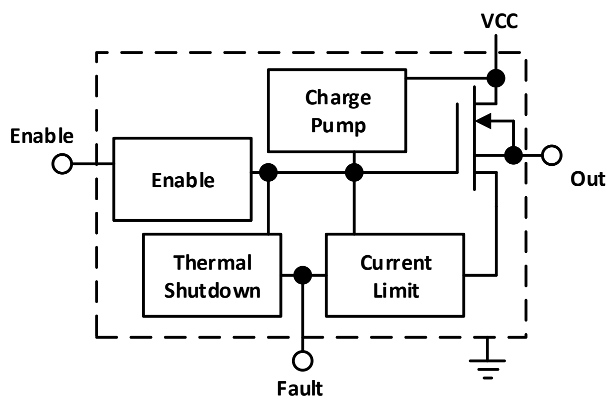

Fig. 4. Typical block diagram for a basic electronic breaker also known as an eFuse. Note the use of a MOSFET as the control switch. What differentiates the eFuse is its ability to limit current without actually opening the circuit. The efuses can offer a lot of flexibility, programmability, and features in trip points.

A weakness of the electronic breaker shown so far is the lack of what is referred to in the breaker world as "physical isolation". The use of a MOSFET is a weakness when concerned with fail-safe conditions since the most frequent failure mode of MOSFETs is to fail shorted. Even when the MOSFET is off you still have an electronic device in the circuit path that is vulnerable to overstresses and can fail. A valuable enhancement would be to have a mechanical mechanism to open at the highest level of stress to provide dependable wire protection.

For an example of breakers with physical isolation, consider the E-T-A ESS30-S series of 24-V breakers shown in Fig. 5. Not only does this breaker provide current limiting, it provides a physical isolation disconnect for higher-level failures. Particularly commendable is that it also includes a fuse to provide guaranteed fail-safe in that it will completely open the circuit in a worst-case scenario. While this requires breaker replacement it greatly increases system safety. Note that this electronic breaker is a modular assembly, not a single IC as many eFuses are.

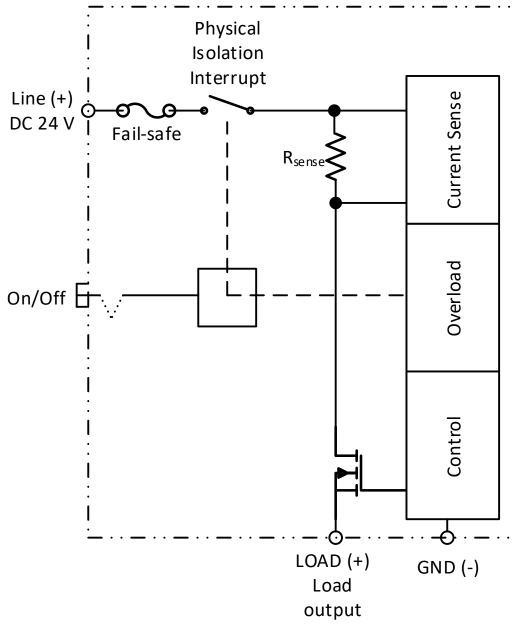

Fig. 5. E-T-A ESS30-S series breakers include both electronic current limiting as well as physical isolation. This provides a device that has electronic limiting but protects wiring for faults that exceed the electronic limit. The inclusion of the internal fail-safe fuse, makes this device particularly robust and one of the most complete solutions for circuit protection available.

The Future For Semiconductor eFuses

The electronic breaker with physical disconnect and fail-safe fuse represents the highest state of development in circuit interruption. However, it is a multi-component solution, which is relatively large compared to an individual circuit protection device. All that is missing is having an integrated circuit solution that is capable of fail safe.

At this time eFuses alone cannot satisfy functional safety requirements despite their many desirable features and specifications. To truly satisfy functional safety at the current state of the art can only be accomplished by including a classic fuse along with the eFuse.

There is a technical solution for eFuse IC design that could provide the necessary level of protection. What is required for a device that can be used in lieu of a traditional fuse is that the eFuse must exhibit a permanent open circuit at some level above the electronic trip. One possible way to accomplish this in the construction of these ICs is to size the wirebonds inside the package to provide the required physical fuse break level. When this occurs the IC must be replaced, but remember that efuses exhibit high reliability and long lifetimes.

The case of an eFuse failing shorted is very rare statistically, but robust wire protection must be maintained. When the semiconductor eFuse is developed that can be guaranteed to fail open there will be true electronic replacement for fuses, opening the way for true “smart” fuse boxes in automotive applications that have the required ability to meet functional safety requirements.

Reference

“Failure Mechanisms of Ceramic PTC’s,” Vishay document, revised Dec. 5, 2005.

For Further Reading

1. “Solid-state relay,” Wikipedia entry describing the characteristics, operation, advantages and disadvantages of solid state relays.

2. "Solid-state Relays," All About Circuits' entry describing these relays.
3. "Solid state relays make inroads" Design News article, November 1, 1999.
4. "Electromechanical Relays Versus Solid-State: Each Has Its Place," by Tom Mahaffey, Library.AutomationDirect entry comparing traditional and solid-state relays, 2007.

These sources all discuss the fail-shorted problem in solid-state relays.

About The Author

Jerry Steele has a long association with power management products from his early days at Burr-Brown, Apex Microtechnology, National Semiconductor, Maxim, and at Texas Instruments as a senior member of technical staff. His experience has covered a variety of products including precision analog and mixed signal devices dedicated to temperature, current, and power measurement to system management and protection devices including devices such as eFuses and hot swap controllers. Jerry has authored a considerable number of analog and mixed-signal articles over the years, and co-authored five patents.

For further reading on circuit protection techniques and devices, see the How2Power Design Guide, locate the Design Area category and select "Power Protection." Also see the Component category and select "Circuit Protection Devices".