Focusing On Fuses

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There are fuses and there are fuses. Using the wrong electrical fuse in the wrong circuit can produce results as explosive as those produced by the fuse in a large firecracker. In this Code Corner, information will be presented on the various types of fuses that can be safely used in a photovoltaic (PV) power system.

Why Use a Fuse?

A fuse is one type of overcurrent device that is designed to be a sacrificial element in an electrical power system. Fuses are designed to open circuits when excessive currents are present due to overloads or faults, and in this manner are designed to prevent further damage to the system that might result if the fuse were not present. Fuses are sacrificial in that they are generally good for one time use and are destroyed in the process of operating. The use of fuses in a circuit provides cheap insurance should there be an accidental or unintentional fault in the system wiring or components.

Properly used, fuses can prevent fires and other damage when accidents happen. Such accidents include: a cable coming loose in the battery-to-inverter circuit, a cable in a module junction box contacting a grounded terminal, a nail driven through unprotected wiring, a wrench dropped across the DC inverter terminals, or an animal chewing through insulation and causing a ground fault.

In general, fuses melt internally when subjected to currents above their rating, and if the fuse rating is below the rating (ampacity) of the connected cable, the fuse will melt before the cable melts or is otherwise damaged. There are resettable fuses, electronic fuses, and renewable link fuses, but these types are not generally applicable to direct-current renewable energy systems.

Fuse Ratings

Fuses are rated by current, voltage, interrupt capability, and whether they are designed to operate on ac or DC circuits. The current rating of a fuse is the current that it can carry for indefinite time periods without opening. The voltage rating relates to the ability of the fuse to function and extinguish internal arcs when it opens. The interrupt rating is how large a short-circuit or fault current the fuse can interrupt or stop safely without allowing a continuing arc and without damaging the fuse body or fuse holder.

Are ac and DC Fuses the Same?

Direct currents are very difficult to stop or interrupt when compared to alternating currents. Alternating-current sources reverse the flow of current 120 times a second (in some locations 100 times a second on 50 Hz systems). Each time the current reverses, it goes to zero in magnitude. A zero current is very easy for a melting fuse to stop or interrupt—it is already stopped, and there is no force trying to sustain an arc across the fuse element.

DC currents, as the name implies, are currents that travel in one direction only. They do not reverse. Fuses bear the entire burden (with no help from the current) of acting to stop these currents. The internal elements of a fuse must react to an overcurrent condition (usually by melting) and as they react, they must do so with enough capability to interrupt the current from flowing while extinguishing any arc that might form. DC fuses are relatively sophisticated devices that have many different internal elements that must work together. The complexity of DC fuses makes them cost more than ac fuses that may contain only a single, meltable link.

What about fuses marked for both ac and DC? Fuses that can pass the harsh Underwriters Laboratory (UL) Standards testing for direct currents are also able to pass the less rigorous ac testing standards. Some manufacturers elect to put both markings on the fuse. To illustrate the difference in the tests used to evaluate fuses, consider the type RK-5 fuse (discussed below) which, from most manufacturers, has both ac and DC ratings. For a 100-amp fuse, the ac rating would be 600 volts with an interrupt rating of 200,000 amps. The DC rating for the same 100-amp fuse would be only 300 volts with an interrupt rating of 20,000 amps—both significant reductions from the ac ratings. There are fuses with equal ac and DC voltage ratings, but the DC interrupt rating is significantly less than the ac interrupt rating. In normal operation, a properly-designed fuse must carry the rated current and not respond to short-term (2-10 seconds) current surges from motors that are 2-6 times the fuse rating. Time-delay fuses, like the RK-5 fuses, can resist even longer surges.

Which Fuses are Suitable for DC?
Fuses suitable for DC fall into several types. Any fuse used in DC renewable energy circuits should have the DC ratings printed on the fuse or be shown in the UL Listing information in the technical data for the fuse. The technical data is available in the manufacturer's catalog, data sheets, and even on the WWW. Beware that seemingly identical fuses from different manufacturers may not have the same DC rating even though they are given as exact replacements in the manufacturer's cross-reference data. The DC rating and UL Listing should always be verified.

The branch-circuit rated "class" fuse is the most robust of the DC fuses for use in renewable energy systems. While the manufacturer's exact catalog number may vary, these fuses fall into several classes, each having different performance characteristics and sizes. Some of these classes are: RK-1 and RK-5 (1/10-600 amps), T (1-1200 amps), and CC (1/10-30 amps). Many manufacturers have DC ratings for some of these fuses, but not all of them.

The RK-1 and RK-5 fuses are the types of fuses that fit in the fused, safety-switch disconnects available from all electrical supply houses and many home centers. These RK fuses are grouped in sizes by voltage with the shorter sizes having a 125-volt rating and longer sizes having a 250 or 600-volt DC rating. They are also grouped by current range (1/10-30, 35-60, 70-100, 110-200, 225-400, and 450-600 amps). The actual sizes on the commonly used fuses range from 13/32" x 1-1/2" for the Class CC fuses up to 3-11/32" x 13-3/8" for the 600-volt, 600-amp RK-5 fuses.

For each voltage rating of fuses, there are fused safety switches that are sized to accept the largest and smallest fuse in each current range.

The "midget" type of fuse (13/32" x 1-5/16") is similar in size to the class CC fuse, but is not listed for branch circuit use. They may be listed and have DC ratings for use as a supplementary fuse. Ratings are 1/10-30 amps. The NEC allows the use of supplementary fuses in the PV source circuits. The values available below 10 amps make this fuse easy to match up with the maximum series fuse requirement listed on the back of PV modules.

Bussmann Division of Cooper Industries has a DC rating (125 volts) and a UL Listing on their type ABC ceramic-bodied fuse in certain ratings up to 20 amps. The DC interrupt rating of this 1/4" x 1" fuse varies from 35 to 750 amps depending on fuse size. These inexpensive fuses can be used in the PV source circuits as supplementary overcurrent protection, but should be protected by a current-limiting fuse in systems with batteries.

What is a Current-limiting Fuse?
Many people are not familiar with the concept of a current-limiting fuse. They think that since a fuse opens a circuit, it must limit current to zero and therefore all fuses are current limiting. Current limiting actually refers to how fast a fuse can open under fault conditions. When a fault occurs in a circuit without a fuse, the current ramps up to the short-circuit value that is determined by the voltage and current characteristics of the power source and the resistance and inductance of the circuit. The time the current takes to get to the final value is very short, but not zero. A fuse that is not current limiting operates so slowly (still in fractions of a second) that it lets the current get to the final value before opening the circuit. The entire circuit, and any other components in the circuit, are exposed to the full value of the short-circuit current.

A current-limiting fuse, on the other hand, operates so fast under fault conditions, that it limits the current in the circuit before it has had time to reach the maximum. With this fast action, components in the circuit are not subjected to the full fault current, and are somewhat protected from the abuse of being subjected to fault currents in excess of their interrupt rating.

There are no listed circuit breakers that are DC-rated and tested to UL Standards that meet the definition of current limiting for DC circuits. Some distributors carry circuit breakers that are identified as current limiting, but these items have been tested to European standards that are not the same as the UL Standards for current limiting.

When should a current-limiting fuse be used? The National Electrical Code (NEC) requires that current-limiting overcurrent devices be used wherever the available fault current exceeds the interrupt rating of the other components in the system. In PV systems, this might happen when circuit breakers or fuses with limited interrupt ratings (i.e. 3,000-5,000 amps) are used with a battery having a 15,000-20,000 amp short-circuit current capability. If these circuit breakers or fuses were subjected to the full 15,000 amps of fault current, they would probably not be able to open the circuit and would more than likely be destroyed in the attempt with flames evident. A current-limiting fuse installed near the battery would limit the fault current at the second overcurrent device location to 3,000 amps that could be safely interrupted. The class RK-1, RK-5, and T fuses described above are current-limiting fuses.

Are current-limiting fuses required in all systems with batteries? There are two cases where current-limiting fuses are not needed. If all of the overcurrent devices and switchgear used in the system have sufficiently high interrupt ratings for the fault currents in their respective circuits, then each device will have no trouble interrupting fault currents should they occur. In this case, current-limiting fuses would not be necessary. Some of the power centers and power panels on the market are designed this way.

In small PV systems, the conductors to the battery may be small gage conductors (i.e. 18-10 AWG) and these small conductors have a resistance per foot that quickly adds up in a very few feet. Since the resistance of the circuit determines the magnitude of fault current, the available fault current at the overcurrent device may be limited to a value that is less than the interrupt rating of the overcurrent device. The calculations required to make this determination are beyond the scope of this article.

What About Automobile Fuses?
Automobile electrical systems are designed to operate in a different manner from stationary PV systems. In an automobile, the electrical loads are designed to operate when the engine is running and the alternator is charging the battery and supplying the loads. The alternator output is in the 14–16-volt range and the radios and lights are designed to run at about 12.8 volts. A voltage drop is allowed in the conductors to reduce the alternator voltage to that needed by the loads. With the exception of the starting circuit, most conductors to the lights, fans, and other loads have relatively high resistance. This circuit resistance includes the resistance of the steel body parts used for the negative conductor. The system is not designed to power the loads for any length of time on the battery alone when the engine is stopped—the result would be a dead battery. This high-resistance wiring limits the available fault current from the battery and allows the use of automotive fuses with a very low interrupt rating.

A PV system, on the other hand, operates for extended periods of time on the battery without charging from the PV. Voltage drop must be minimized since the batteries start out at only 12.6 volts when fully charged. To minimize voltage drop, larger, low-resistance conductors are used in PV systems. These low-resistance conductors allow higher fault currents throughout the circuits. These higher fault currents are substantially in excess of the very limited interrupt ratings of automotive type fuses.

Another factor in the use of automotive fuses is that most PV systems (except the very smallest) have several batteries with high short-circuit current capabilities when compared to the single automobile battery found in vehicles. While there are a few UL-Listed automotive fuses, most are not listed. Even those that are listed are listed for use only in vehicles, and are tested to standards for use in vehicles. They have none of the conventional interrupt and voltage ratings. Automotive fuses do not meet NEC requirements for installation in PV systems that come under the Code. For these reasons, it is inadvisable to use automotive fuses in renewable energy systems to meet NEC requirements.

Who Makes the Proper Fuses?
UL-Listed, DC-rated fuses are available from a number of manufacturers. They include Littelfuse, Bussmann, Gould Shawmut, and Ferraz. These manufacturers will provide technical information on the correct fuse to use in renewable energy applications that require listed, DC-rated fuses.

Where Can I Get the Proper Fuses?
Many of the advertisers in *Home Power Magazine* carry the proper fuses and can advise a RE system designer on the correct fuse to use. Local electrical supply houses and home building supply centers also carry fuses. There are a few large mail-order sources, but some require minimum purchases that may run into hundreds of dollars. Digikey Corporation, Newark Electronics, and Allied Electronics are also sources. In every case, the UL-Listed, DC rating of the fuse should be verified.

Questions or Comments?
If you have questions about the NEC or the implementation of PV systems following the requirements of the NEC, feel free to call, fax, email, or write me at the location below. Sandia National Laboratories sponsors my activities in this area as a support function to the PV Industry. This work was supported by the United States Department of Energy under Contract DE-AC04-94AL8500. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

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