QA Quality Assurance

Available Fault-Current Calculation and Protection

A *short-circuit fault,* which is an abnormal condition that occurs when current bypasses the normal load due to unintentional contact either between phases or to ground, is possible in any electrical system. PV power systems are somewhat unusual in that the PV source itself is current limited. However, the potential short-circuit current increases dramatically when you connect a PV system to the grid. In the event of a short circuit in an interactive PV system, circuits designed for 10s or 100s of amps of current may suddenly carry fault currents on the order of 10,000 or 100,000 amps.

If you do not deploy electrical systems with the available fault current in mind, a short-circuit fault could result in a catastrophic explosion or electrical fire. Overcurrent protection devices (OCPDs), of course, are the first line of defense against short-circuit faults. *NEC* Section 110.10 states: "The overcurrent protection devices, the total impedance, the short-circuit current rating and other characteristics of the circuit to be protected shall be coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical equipment of the circuit."

Since the 2011 *Code* cycle, Section 110.24 has required field markings on service equipment that identify the available fault current in multifamily, commercial and industrial applications. *NEC 2017* takes this a step further: "The [available fault current] calculation shall be documented and made available to those authorized to design, install, inspect, or operate the system." To verify that electrical system designers have selected appropriate OCPDs, it is therefore increasingly common for AHJs to require that PV system integrators document both the available fault current and the ampere interrupting capacity of OCPDs in their plan sets.

Available Fault Current

The *available fault current* is the highest electrical current that can exist in a particular electrical system under short-circuit conditions. The two potential sources of fault current in interactive PV power systems are the inverter and the utility. From a system design point of view, the available fault current from the utility is what matters.

Like the PV power source itself, an interactive inverter is a current-limited device. According to the National Renewable Energy Laboratory (NREL) technical report, "Understanding Fault Characteristics of Inverter-Based Distributed Energy Resources," independent testing conducted at NREL suggests that "inverters designed to meet IEEE 1547 and UL 1741 produce fault currents anywhere between 2 to 5 times the rated current for 1 to 4.25 milliseconds." The authors explain: "Inverters do not have a rotating mass component; therefore, they do not develop inertia to carry fault current based on an electromagnetic characteristic." In effect, this means that fault current from an interactive inverter is insufficient to open OCPDs.

The utility, by comparison, contributes sufficient fault current to not only open OCPDs but also potentially damage electrical equipment. Therefore, one of the first steps in designing an interactive PV system is to determine the available fault current from the utility, as this value will influence, if not drive, equipment selection. This value is primarily a function of the utility transformer—its capacity (kVA), voltage and impedance—that serves the premises wiring.

For existing electrical services, the easiest way to determine the available fault-current value at the transformer or main service is to contact the utility and request this value. Before doing so, be prepared to provide utility representatives with any relevant information, including site address, transformer location and number (if available), distance from transformer to main service, main service size and so forth. In some cases, you can find the available fault current noted on the electrical plans. If new construction plans do not identify this value, contact the project's electrical engineer of record.

Note that as you get farther away from the utility transformer, the available fault current decreases in proportion to the impedance of the conductors, as well as on the inverter side of a premises-sited transformer. If, for example, you have a step-down transformer between 3-phase 480 Vac inverters and 3-phase 208 Vac premises wiring, then the available fault current invariably will be lower at the inverter OCPDs than at the service point. In this scenario, you can find the available fault current at the inverter output by dividing the full load current on the PV side of the transformer by its impedance, as identified on the equipment nameplate. Assuming you were using a 3-phase 45 kVA transformer with 5% impedance, you would calculate the available fault current (AFC) thus:

AFC = (45,000 VA ÷
(480 Vac x 1.732)) ÷ 0.05 = 1,083 A

Though the effect of conductor impedance is relatively small compared to the standard interrupt ratings, this could make a difference in circumstances that involve long conductor runs, such as an inverter accumulation panel located a good distance away from the main service. In such a scenario, it might make sense to calculate the available fault current at the subpanel, factoring in the effect of conductor impedance, rather than using the value at the main service panel. While calculating fault current after a length of conductor is beyond the scope of this article, Thomas Domitrovich details the process in the *IAEI* magazine article "Calculating Short-Circuit Current" (May/June 2015).

Ampere Interrupting Capacity

Once you determine the available fault current, you can select appropriately rated circuit breakers or fuses. There are two basic short-circuit protection systems: fully rated systems, which you must selectively coordinate in certain circumstances (see "Selective Coordination of OCPDs," p. 16), and series-rated systems. As long as you use a listed circuit breaker (UL 489) or fuse (UL 248) in accordance with its ampere interrupting capacity (AIC) and voltage rating or in accordance with its listing as part of a series-connected system, a Nationally Recognized Testing Laboratory (NRTL) has verified its ability to clear a fault without extensive damage to the equipment or electrical system.

NEC 240.86 allows the available fault current to exceed the AIC rating of an OCPD under certain circumstances.

Fully rated system. Designing and deploying a fully rated system is relatively straightforward. Listed OCPDs are certified to and marked with an AIC, which identifies the maximum available fault current the device is rated to withstand on its own. These AIC ratings step up in standard increments, such as 10K, 18K, 22K, 25K, 35K, 42K, 65K, 100K and 200K. Listed panelboards, meanwhile, are marked with a short-circuit current rating (SCCR), which is the maximum current the component or assembly can withstand.

In a fully rated system, each OCPD device has an AIC rating that is greater than or equal to the available fault current. Moreover, the piece of equipment

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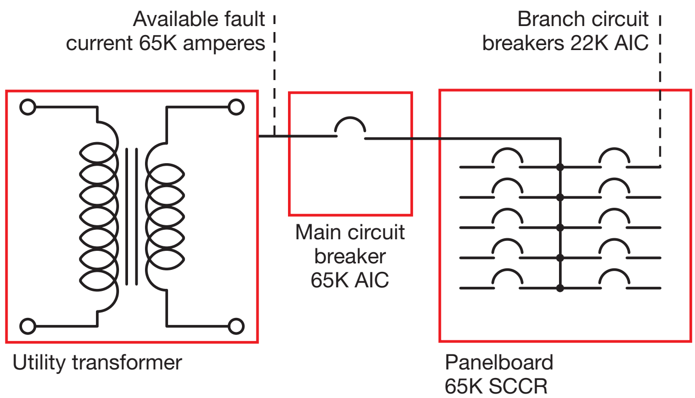

Courtesy UL

Figure 1 In a fully rated system, the lowest rating between the panelboard and the OCPDs determines the overall rating, which in this case is the 22K A-rated branch circuit breaker. If the main and branch circuit breakers are type tested and series rated together, then the equipment configuration can have an overall rating of 65K A, as long as the equipment is deployed in accordance with the product listing and manufacturer's instructions.

in the assembly with the lowest interrupt rating determines the full rating for a panelboard with circuit breakers installed. As an example, the equipment configuration in Figure 1 would have a full rating of 22K amperes—even though the panelboard and main breaker are rated for 65K amperes—as determined by the lowest-rated piece of equipment or OCPD, which in this instance is a branch circuit breaker.

You must design an electrical system with a single OCPD as a fully rated system. If you are designing an electrical system with multiple OCPDs, however, a series-rated system may provide the best value, which is an important consideration for your customers.

Series-rated system. The *NEC* allows the available short-circuit fault current to exceed the AIC rating of an OCPD under certain circumstances, as detailed in 240.86, Series Ratings. As described in the *NEC Handbook,* a *series-rated system* is "a combination of circuit breakers or fuses and circuit breakers that can be applied at available short-circuit levels above the interrupt rating on the load-side circuit breakers but not above the main or line-side device." This arrangement is allowed for tested combinations of equipment [240.86(B)] or under engineering supervision in existing installations [240.86(A)]; it is not allowed with certain motor-load levels or configurations [240.86(C)].

The most common way to design and deploy a series-rated short-circuit protection system is to use tested equipment combinations, which are combinations of OCPDs that have passed NRTL product safety and certification tests as an assembly. In a series-rated system, only CONTINUED ON PAGE 16

Series Equipment Rating for Breaker-Breaker Combination

Main breaker maximum amps	Series equipment rating—kA symmetrical					
	22	25	35	65	100	150
100						FCL
						GHB, GHQRSP
125			EGH	EGH		
			GHB	GHB		
200			FD, FDE	HFD, HFDE	FDC	
			GHB, GHQRSP	GHB, GHQRSP	GHB	
250	JD, JDB		JD, JDB	HJD	JDC	
	GHB		GHB (15A–50A)	GHB	GHB	
400	KD, KDB, CKD	HKD, CHKD	KD, KDB, CKD	HKD, CHKD	KDC	LCL
	GHB	GHB	GHB (15A–50A)	GHB (15A–50A)	GHB	GHB

Main devices shown centered in shaded area at top. Respective branch devices shown directly below.
All ratings in this table apply to 2- and 3-pole branch breakers only.

Table 1 Example of a series-rating table from Eaton for listed equipment combinations.

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the first OCPD needs to be AIC rated for the full available fault current. Downstream series-connected devices may have a lower AIC rating, provided that an NRTL has shown that the series-connected assembly works together to clear a fault and protect the electrical equipment from damage. If the main and branch circuit breakers in Figure 1 (p. 14) were part of a listed series-rated combination, then the assembly would be series rated for 65K amperes of fault current, as determined by the main breaker AIC rating and panelboard SCCR.

When using series-rated equipment, you must do so in a manner consistent with the product listing and the manufacturer's instructions. The first step is to get your hands on the series-rating tables for equipment you would like to use. These tables are readily available online. UL maintains these data in tabular form, organized by manufacturer, and most manufacturers also publish their own tables, which must comply with UL standards. The UL or the equipment manufacturer may organize and present these data in a number of ways: by service voltage, by type of breaker or fuse, by equipment combination (breaker-breaker, fuse-breaker, triple-series rating) and so forth. Regardless of the method of data organization, you basically need to find the series combination that matches your design voltage, available fault current and OCPD capacity. The following example illustrates this process for a breaker-breaker combination.

Example of a tested series configuration: This scenario assumes an available fault current of 28,000 amperes at 480 Vac. If you would like to use a 3-phase 250 A Eaton panelboard, subject to the series equipment ratings in Table 1 (p. 14), then you need to look at the 35 kA column and the 250 A main breaker row to meet or exceed the available fault current at the desired capacity level. According to the highlighted cell, you may use a JD- or JDB-type main breaker in series with GHB-type branch circuit breakers. However, this series rating only applies if all the branch circuit breakers in the panelboard are rated between 15 A and 50 A. To accommodate a GHB-type branch circuit breaker rated for more than 50 A, you would need to step up to the 65K A column, which calls for a HJD-type main breaker.

> Codes and standards require specific markings and labels for series-rated panelboards and switchboards.

In existing installations, the *Code* also allows a licensed professional engineer (PE) to select series-rated devices. In these calculated applications, the PE must evaluate the time-current curves for the OCPDs and ensure that the downstream circuit breakers will remain passive (closed) when the upstream device clears the available fault current. In addition to performing manual calculations, a PE can also use specialized software tools as a means of selecting appropriate devices.

Note that product safety standards require specific markings for panelboards and switchboards that a NRTL has investigated and approved for use in a series-rated system. These markings identify allowable combinations of integral and remote OCPDs, which you must observe to maintain the panelboard's marked SCCR. Furthermore, *NEC* Section 110.22 includes identification requirements for equipment enclosures with series-rated devices. Installers must field-identify these labels with the effective series-connected protection rating, as directed by a PE or the equipment manufacturer. To maintain this level of protection, the label must also state that identified replacement components are required.

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Selective Coordination of OCPDs

Selective coordination, defined in Article 100 of the *NEC,* is the process of coordinating overcurrent protection to localize the impact of an outage, which is accomplished via the selective operation of the device closest to the fault only. Assuming the fault condition in Figure 2, for example, selective coordination ensures that only the 100 A OCPD at location 1 opens and that the OCPDs at locations 2 and 3 remain closed. Generally speaking, PV systems are not subject to the selective coordination requirements in the *NEC.* The requirements for selective coordination apply specifically to emergency systems (Section 700.32), legally required standby systems (Section 701.27) and critical operation standby systems (Section 708.54).

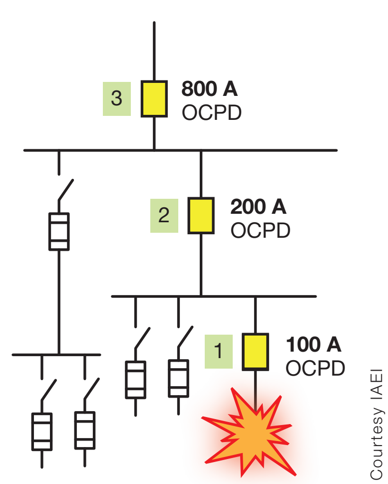

Figure 2 In a selectively coordinated system, only the 100 A–rated device at location 1 would open to clear this branch circuit fault.