Production Power on a budget: Ground-fault protection strategies, Part 4

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The fourth and final installment in a multipart exploration of how to safely use small portable generators in motion picture and live event production.

SO THAT THE ENTIRE SET DOES NOT GO DARK if a crewmember takes a shock, the upstream and downstream GFCIs of a tiered ground-fault protection system must be discriminated by trip time. To quickly summarize the reason given in the previous parts of this series, a hardware store style Class A GFCI with a 6 mA trip level and response time of 25 ms will, without a doubt, offer the maximum level of blanket protection to a portable generator's distribution system, but it will also be prone to nuisance tripping from the residual currents generated by electronic loads. For this reason, a better approach is a tiered ground-fault protection strategy with a more lenient film-style Class A GFCI placed upstream to protect the entire distribution system and hardware store-style Class A GFCIs providing protection for individual branch circuits. Unfortunately, even a film-style Class A GFCI will be prone to nuisance tripping in an upstream position because it will be subject to the cumulative current leaks of all the zones taken together which can approach 6 mA even under the best conditions. And in the event of an actual shock, the impedance of the human body is such that according to Ohm's law both film-style and hardware-style GFCIs will trip at the same time—inhibiting aid from being administered to the shocked individual.

For this reason, in less hazardous situations, it would be advantageous to have an upstream GFCI with a higher trip setting (up to 20 mA) to accommodate the cumulative current leaks of a typical distribution system. Of course, the combination of trip level and response time must still offer protection for personnel. Commonly referred to as "Industrial GFCIs," these special purpose GFCIs (Class C) are allowed for personnel protection by *UL 943C*.

As Nehad El-Sherif points out in his excellent article "Now that industrial GFCIs are here…" (*IAEI Magazine* January/February 2014), an important consideration in the use of Class C GFCIs is that the increase in the trip level is allowed by UL assuming the availability of a reliable ground in parallel with the body. The reason being that, during a fault, the grounding conductor will shunt the fault current around the body and cause the device to trip. This provides the let-go protection required by UL, while the 20 mA threshold provides protection against fibrillation. (If there is no grounding conductor, such as in two-wire household products, then the GFCI must provide both let-go and fibrillation protection, and a Class A device is required.) Unfortunately, there are no Class C GFCIs with higher trip thresholds suitable for this application. So what is a conscientious technician to do when they have to operate a portable generator in wet hazardous conditions?

. . . a better approach is a tiered ground-fault protection strategy . . .

They can look to a special informational note in *ANSI E1.19 – 2015, Recommended Practice for the Use of Class A Ground-Fault Circuit Interrupters (GFCIs)* intended for personnel protection in the entertainment industry, that reads: "RCD and ELCBs can be used to mitigate ground-fault risks on circuits where GFCIs are not required." Since *NEC* 445.20: "Ground-Fault Circuit-Interrupter Protection for Receptacles on 15-kW or Smaller Portable Generators" only requires the use of the GFCIs on 15 A and 20 A, 125 V receptacles, a technician is free to use a European style RCD as a means of assuring service continuity in the event of a catastrophic shock. Even though these devices are rated for higher voltages and have higher trip thresholds (usually 10 or 30 mA), when used properly, they can provide valuable additional protection against the risk of electrocution when using small portable generators.

The operating principle of an RCD is very similar to GFCIs. A sensor comprising a toroid that surrounds the conductors detects the algebraic sum of the current in the live conductors (phases and neutral). In the absence of a ground fault, the algebraic sum of the currents in the conductors is zero and the toroid does not detect any flux. If a fault occurs, the sum is no longer zero and the current difference in the toroid generates a current in the winding. This current is rectified, filtered for high frequency harmonics, and amplified. If the resulting signal is greater than a set threshold (usually 10 or 30 mA), a time delay is initiated (it may be zero for an instantaneous response or prolonged for a delayed response). If the fault is still present at the end of the time delay, an opening order is issued to a control device usually a contactor or breaker.

The major difference between RCDs and GFCIs is that the trip threshold in RCDs is user-adjustable while, according to the *UL 943* standard, GFCIs must follow a fixed current-time relationship. In place of the fixed curve of *UL 943*, the *IEC 60947-1* standard stipulates a maximum breaking time depending on the set trip threshold. The break time stipulated in standard *IEC 60947-1* for a trip threshold of 30 mA is rapid enough to avoid permanent organ damage and ventricular fibrillation. For this reason, a trip threshold of 30 mA has become the internationally accepted norm for RCDs intended to provide personnel protection against the risk of electrocution.

As the curves for RCDs with sensitivities 10, 30, and 300 mA illustrate, the tripping times are very short in comparison to the *UL 943* curves. For instance an RCD set for a trip threshold of 10 mA must trip within 300 ms, compared to approximately four seconds required by the *UL 943* curve. Even though the curves of the IEC standards for RCDs are different than those stipulated by *UL 943*, they fall within the *UL 943* curve and therefore are no less safe.

It is this more rapid response of RCDs that makes it possible for the user to program time delays into them yet still fall within safe limits (superimposing the time-current characteristic curves for RCDs with sensitivities (IΔn) 10, 30, and 100 mA over the curves

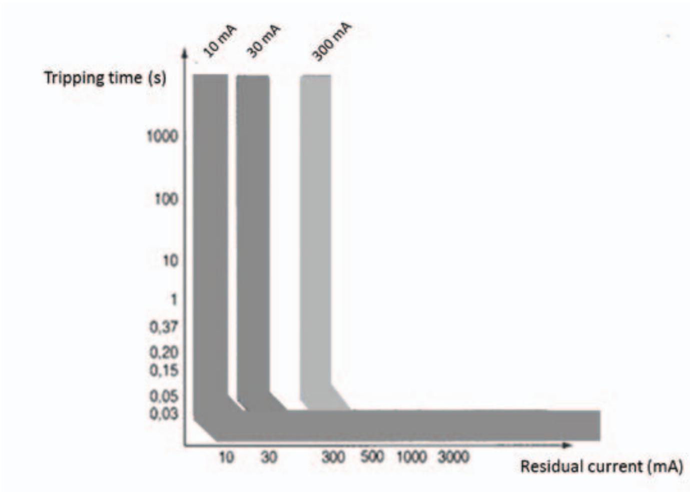

Figure 1 – Time-current characteristic curve of a RCD

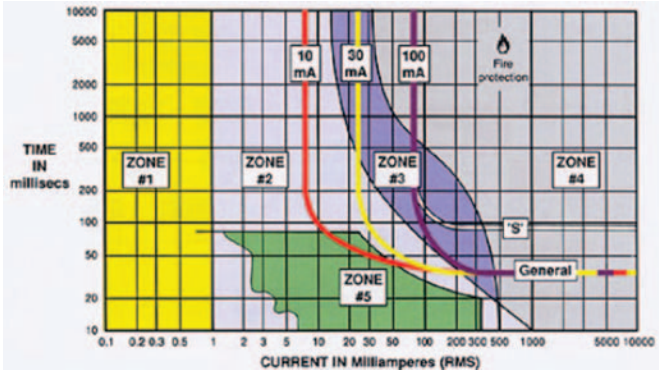

Figure 2

published in *IEC 60479-1*: "Effects of current on human beings and livestock" discussed in part one of this series clearly illustrates this.)

And, since user-handled loads statistically account for most shocks (Zone 5 in the **Figure 2** graph), time delayed RCDs can provide more than adequate ground-fault protection given the low touch voltages involved.

RCDs offer several benefits when providing set power from generators. First, the ability to adjust trip delay enables the coordination of RCDs and GFCIs in a vertical discrimination strategy using both time and current sensitivity. As discussed previously, a well-designed system ensures that only the part of the distribution system affected by the fault will shut down. By increasing the trip delay of rear RCDs, it is possible to guarantee that the only ground-fault protection device to trip in a catastrophic event is the GFCI nearest to the fault. Second, by increasing the trip threshold of upstream RCDs it is possible to assure that they do not nuisance trip from the accumulated residual current of multiple branch circuits. This is very useful when it is not certain what lighting loads will be connected where. But, how does a conscientious technician go about determining the current-time parameters of a safe ground-fault protection system consisting of multiple devices?

When designing a ground-fault protection system, two key levels of electric current need to be considered with regard to shock protection. The first is the "let-go" level, which is generally accepted to be around 8-15 mA (see chart in Part 1 in the Winter 2016 issue of *Protocol*.) At or above the upper limit of this range, muscles may seize, and a person touching or holding a live part may not be able to let go of it (the trip threshold range of RCDs intended for personnel protection typically go as low as 10 mA.) The second key level is the "fibrillation" level, which is generally accepted to be around 50 mA. At or above this level, heart fibrillation is likely to occur.

A third design consideration is that according to *IEC 64-8/563.3*, a factor of at least two is required between the settings of two ground-fault protection devices to avoid simultaneous operation of the two devices. Given the above, a trip threshold of 20 mA on an upstream RCD is more than sufficient to discriminate it from a downstream Class A GFCI device (with a trip threshold of 6 mA) while still offering adequate protection from electrical shock. Time discrimination between the two devices gets a bit more complicated.

The tripping times of two devices connected in series must be coordinated so that the total interruption time of the downstream device, the Class A GFCI, is less than the upstream RCD's no response limit time, for any current value. In this way, the downstream GFCI completes its opening before the upstream RCD is triggered. For safety reasons, the delayed tripping time of the upstream RCD must always be below the *UL 943* safety curve.

To program such a delay, and still stay within UL guidelines, it is necessary to take into account not only the non-actuating time (tr) and the disconnection time (tc) of the downstream Class A GFCIs (device "b" in this scenario), as well as the total response time of the RCD (device "a" in this scenario) (see **Figure 3** below).

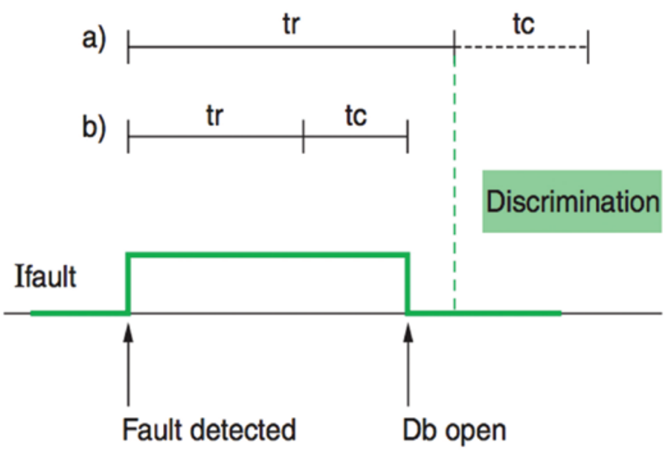

Figure 3 – The time delay of an upstream RCD (a) must take into account the non-actuating time (tr) and the disconnection time (tc) of the downstream ground-fault protection device (b).

As we saw above, longer response times help to avoid nuisance tripping in electrically noisy environments. For this reason *ANSI E1.19 – 2015* recommends that "GFCIs used in electrically noisy environments have response times that are at least 50% of the permissible response times described in *UL 943* for fault currents at least up to 40 mA," which works out to be 500 ms for a fault current of 20 mA. That means that an RCD can be set for a trip delay (tr) of 400 ms and still be well within *UL 943* standard and *ANSI E1.19* guidelines given that the disconnection time, (tc) (the time from receiving the signal to trip to actually interrupting the current), for a RCD is typically only 60 ms. Looking back at the trip threshold of hardware store-style GFCIs we see that 400 ms is more than sufficient time for a hardware store-style GFCI to trip and clear a 20 mA fault given their aggressive response curves.

To conform to *UL 943C* standards for personnel protection at 20 mA, all that is required is an Equipment Grounding Conductor (EGC) to shunt fault current around the body and cause the RCD to trip. A reliable equipment ground will also assure that touch voltage will be considerably less. This combination provides the let-go protection required by UL, while the 20 mA trip threshold assures protection against ventricular fibrillation, making it possible for RCDs to be programmed with trip delays up to 400 ms and still offer adequate personnel protection. If there is no grounding conductor, such as with two-wire household products, then a Class A GFCI must be used to provide both let-go and fibrillation protection.

The flexibility of RCDs enable their user to tailor the ground-fault protection system to the situation at hand. For example, in extremely hazardous situations, such as when working in water or rain (real or manufactured), an even lower trip threshold (from between 10-15 mA) can be programmed to assure greater chance a person touching or holding a live part may be able to let go of it.

Figure 4 – 60 A Shock Stop Ground-Fault Protection Device with 15 mA trip threshold provides blanket coverage to 120 V distribution system on the secondary side of a 240 V-to-120 V step-down transformer/distro.

The Shock Stop is a RCD device manufactured specifically for motion picture distribution applications that can be very useful in these situations. The trip level of its ground-fault monitor can be adjusted from 10 mA to 500 mA. An adjustable time delay is also available, from 0 to 10 seconds, and a digital display shows the measured fault current in real-time. This last feature is very beneficial because it enables the user to eliminate nuisance tripping due to system noise by enabling them to first assess the level of system noise and then set a trip threshold above the noise floor that will trip in the event of a real fault event. The Shock Stop GFCI also includes high frequency filtration so that it will not nuisance trip in electronically noisy environments.

Another device that is very useful in these situations is the Shock Stop Ground-Fault Simulator (GFS.) The Shock Stop GFS can be used to check the integrity of the grounding conductor, discrimination between GFCIs and RCDs, and the GFCIs/RCDs themselves. It can also be used to perform a nuisance trip test. To assure that the generator distribution system has been laid out properly, the Shock Stop GFS provides wiring diagnostics that signal

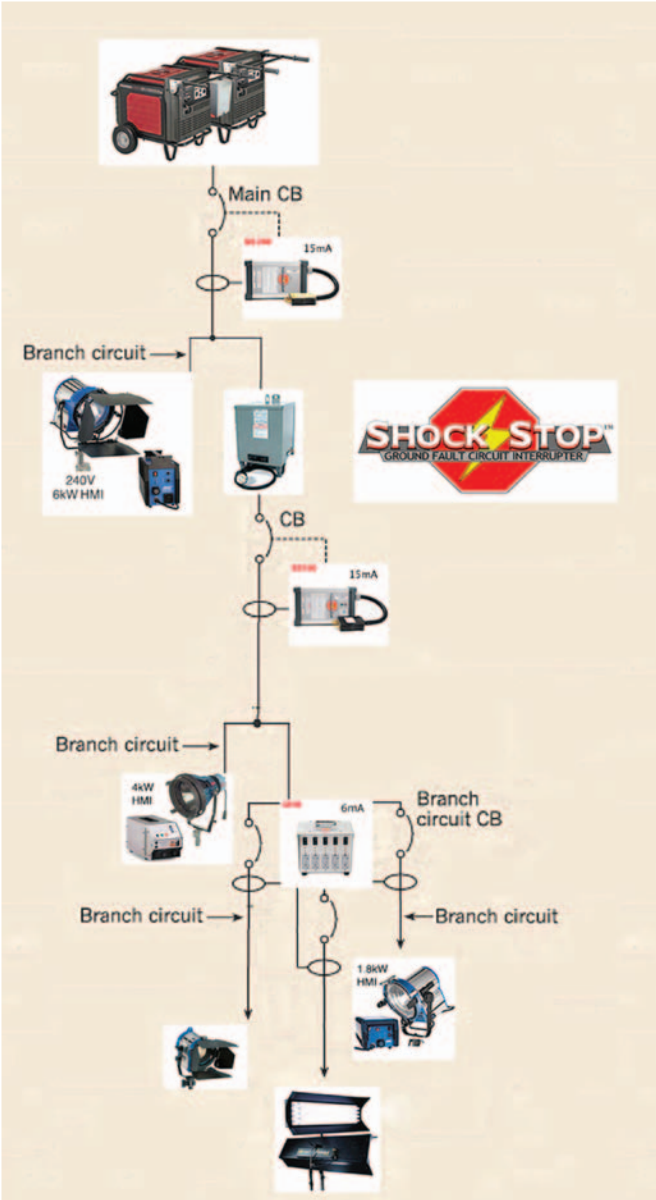

Figure 5 – A 100 A/240 V Shock Stop with 15 mA trip threshold located immediately after the common bus of paralleled Honda EU6500 generators provides blanket protection to the 240 V distribution system. A transformer steps-down the 240 V output of the paralleled generators into a single 100 A/120 V circuit, that can power a large light as well as be broken down into smaller 20 A branch circuits using standard film-style distribution equipment. A 100 A/120 V Shock Shop with 15 mA trip threshold located immediately after the transformer provides blanket protection to the 120 V distribution system. As a separately derived system, the transformer segments the distribution system in a tiered fashion, while Class A GFCIs on the individual 20 A/120 V branch circuits of the Shock Stop lunch box segment it in a horizontal fashion, thereby eliminating the nuisance tripping of the GFCIs.

correct wiring, Open Neutral, Open Hot, Hot/Ground Reversal, Hot/Neutral Reversal, and most important of all the integrity of the EGC as required by the *UL 943C* standard.

To assure a safe distribution system that will operate reliably and free of nuisance tripping, the Shock Stop GFS will also generate 3, 5, 7, 10, and 30 mA test currents. These test currents enable a technician to test the ground-fault protection system before any lights are even turned on. The 7 mA/200 ms test function can be used to test the trip threshold of Class A GFCIs. Since the *UL 943* standard requires Class A devices to trip at 5 mA +/- 1 mA (i.e. between 4-6 mA) a device that does not trip under the 7 mA test current should be taken out of service and replaced with one that will trip under the 7 mA test current. The 3 mA/200 ms test current can be used to test for defective GFCIs (too sensitive) or high levels of system noise that could lead to a nuisance trip as a result of a transient condition. If a Class A GFCI that tested positive in isolation at 7 mA trips at a 3 mA test current with downstream loads, it is a sure indication that the downstream loads are contributing system noise that could lead to nuisance tripping in the event of a transient condition.

Since the 30 mA/200 ms test current exceeds the trip threshold of both downstream 6 mA GFCIs and upstream 20 mA RCDs, it can be used to test for correct vertical discrimination between ground-fault protection devices in series. With a correct trip delay programmed on the upstream RCD, the 30 mA test current should trip the downstream 6 mA GFCI it is plugged into without tripping the upstream 20 mA RCD. If both trip, the trip delay of the upstream RCD can be increased as long as it does not exceed the safe limits. Testing the operability of a ground-fault protection system as it is being laid out will assure it will work trouble-free when the camera starts to roll. ■

Guy Holt has served as a gaffer, set electrician, and generator operator on numerous features and television productions. He is recognized for his writing on the use of portable generators in motion picture production (available soon in book form from the APT Press). Guy has developed curriculums on power quality and electrical hazard protection that he has taught through the IATSE Local 481 Electrical Department's "TECs" Program. He is the owner of ScreenLight & Grip, a motion picture lighting rental and sales company that specializes in innovative approaches to set power using Honda portable generators.