Production power on a budget: Ground-fault protection strategies, Part 1

BY **GUY HOLT**

The first in a multipart exploration of how to safely use small portable generators in motion picture and live event production

SMALL PORTABLE GENERATORS (<15 kW) are quite often used to provide power in situations where it is not possible to get a large tow plant. Many of these situations include working in, on, and around water to provide power on boats, beaches, and around remote lakes and streams. Since the risk of electric shock greatly increases in wet environments, it is important to have a reliable ground-fault protection strategy when using small portable generators. Unfortunately, inconsistent regulations, lack of proper equipment, as well as a culture of apathy, makes that difficult in motion picture production and event staging applications.

The benefit of GFCIs is indisputable, and given their required use in a growing number of areas covered by code, it is only a matter of time before their use will be mandated in portable power applications as well. According to research done by the National Electrical Manufacturers Association (NEMA), household electrocutions have fallen in inverse proportion to the number of GFCIs being used from about 1976 to about 2001. At the same time, model electrical codes and regulatory agencies have expanded the requirement for GFCI protection and restricted the alternative, Assured Equipment Grounding Conductor Programs. Prior to the 1996 *NEC*, either a GFCI or AEGCP could be utilized to meet the requirements of Section 305-6, temporary wiring systems. In the 1996 *NEC*, the use of the AEGCP was strictly limited.

Despite proven effectiveness and the introduction of more reliable GFCI devices, the culture in motion picture production and event staging has been to cling to the use of AEGCP except in extremely hazardous wet conditions. Perhaps the tragic event that took place a little over a year ago in Atlanta will lead to a re-evaluation of the industry's outdated strategy for ground-fault protection and recognition that GFCIs are not just for wet work.

On June 4, 2014, a lighting technician lost his career after coming into contact with up to 17,000 volts of electricity on the set of *Selma*. Electrician Ronnie Sands was setting up lights for the civil rights drama at the historic Wheat Street Baptist Church in Atlanta when he was shocked. He survived, but hasn't been the same since. Along with other side effects, Sands still experiences constant ringing in his head, chronic migraines, short-term memory loss, blurred vision, anxiety, heart palpitations, and mobility issues in his right arm.

The cause of the accident was the all too common rush to execute a lighting change. "The lighting had been pre-rigged the day before by the electric rigging crew," Sands told *Deadline Hollywood*. "On the day of filming, the director of photography and the unit production manager decided that the tungsten light on the Condors was not bright enough to shine through the stained glass windows of the church, and they decided to change the lighting from tungsten to 18K HMI . . .."

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This unexpected change-up put the set electric crew into such a rush that the bulb for the 18K was left on the truck. Sands said, "They were yelling at us on the walkie-talkie, 'How long is it going to take to get that bulb in there?'" As he had one hand and his head in the large light installing the bulb, he noticed out of the corner of his eye another crew member hurriedly plugging in the ballast.

Sands yelled, but it was too late. Seventeen thousand volts struck his right hand, ran up his arm and into his neck and head. Fortunately for Sands, the shock threw him backward to the ground below. Had he had his other hand on the fixture, he might have locked onto the light. "I am very lucky to be alive," Sands said. It has been over a year since the accident and Sands is still unable to work. Had the light had GFCI protection, he probably would have been back at work the very next day.

The day is rapidly approaching when the use of GFCIs will be mandatory on sets and outdoor events. The writing is figuratively on the wall and literally in the 2014 code revisions. Article 445.20 of the 2014 *National Electrical Code* reads as follows:

> "All 125-volt, single-phase, 15- and 20-ampere receptacle outlets that are a part of a 15 kW or smaller portable generator either shall have ground-fault circuit-interrupter protection for personnel integral to the generator or receptacle or shall not be available for use when the 125/250-volt locking-type receptacle is in use. If the generator was manufactured or remanufactured prior to January 1, 2015, listed cord sets or devices incorporating listed ground-fault circuit-interrupter protection for personnel identified for portable use shall be permitted. If the generator does not have a 125/250-volt locking-type receptacle, this requirement shall not apply."

As municipalities adopt the 2014 edition of the *NEC*, GFCI devices will have to be used on the 125 V outlets of generators such as the Honda EU6500is and the EU7000is when the 240 V twist-lock receptacle is in use.

NEC 445.20 requires GFCI protection on small portable generators supplying 240 V because, in the event of a double fault condition, like that illustrated in **Figure 1**, if an individual comes into contact with faulty equipment, it can expose them to a possibly lethal shock. In response to this code change, Honda is equipping the new EU7000is with GFCI protected 20 A/120 V duplex outlets.

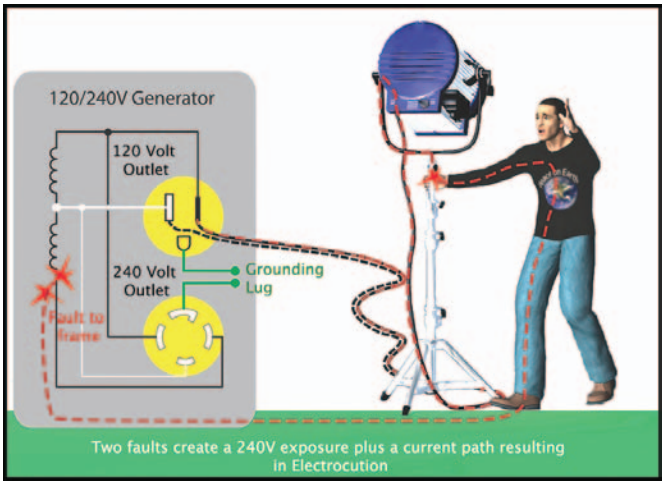

Figure 1 – Two faults can create 240 V exposure

The code revisions may be problematic for users of small generators for event staging and motion picture production because they can be outright dangerous if they create the illusion of protection against ground faults when, in fact, they offer very little protection. Since the power from a portable generator can kill you just as assuredly as power from a diesel tow plant, it is critical that you understand how these generators differ from diesel tow plants and what it takes for GFCI devices on them to operate reliably.

It is a commonly held belief that since the ground wire does not pass through the current transformer of a GFCI, the grounding of equipment does not matter. **Not true.** On some generators, the equipment grounding conductor is not bonded to the neutral point of the generator's stator winding. A GFCI will not operate reliably if the winding is not bonded to the equipment grounding conductor because this system, commonly referred to as a "floating neutral system," lacks the prescribed low impedance route for fault current to create the imbalance between the hot and neutral conductors required to trip a GFCI. Without this prescribed safe route, fault currents will find alternate routes that can expose personnel to potentially dangerous shocks without creating the imbalance required to trip the GFCI.

A good example is an electric operating a defective lamp on a condor. A lamp with a short to its chassis ground will not pose a hazard to the operator in the condor basket because there is no means for fault current to return to its source; he or she is insulated from the earth by the rubber tires of the condor and the EGC is not bonded to the neutral in the generator. But, should the cable supplying the light get pinched in the arm of the condor (which happens all too often) so that the neutral conductor makes contact with the metal, fault current will jump from the defective lamp head to the condor arm making the technician a part of a ground fault circuit. Since the lamp operator offers fairly high resistance to the flow of current, the fault current will not be high enough to open the circuit breaker on the generator, but will be sufficient to expose him to a potentially life threatening shock. And, since the fault current can return to the neutral conductor via the pinch in the cable before it passes through the CT of the GFCI on the generator,

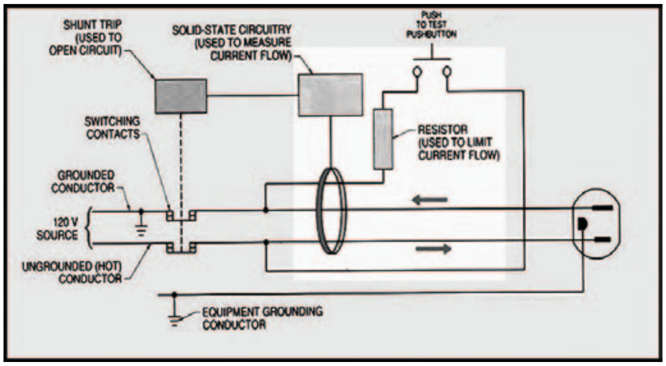

Figure 2 – The test circuit of a GFCI

the GFCI does not see a current imbalance and does not trip.

The test circuit of the generator's GFCI will test positive, creating the illusion of a safe system, when in fact, it is not. When the test button is pressed, it will draw power from the hot conductor through the CT and back through the CT again to the neutral conductor via a current limiting resister. (See the highlighted area of **Figure 2**.) So the test circuit of the GFCI will trip even though there is in fact no ground-fault protection in situations like that described above. There is no ground-fault protection because there is no safe means of conducting fault current back to the generator due to the equipment grounding conductor not being bonded to the neutral pole of the generator's windings.

These issues related to ground-fault protection with floating-neutral generators are well documented by The Construction Safety Association of Ontario (CSAO) in a report on tests they conducted that uncovered significant problems in using GFCIs on portable generators. While the CSAO conducted their tests to determine the effectiveness of GFCIs used on portable generators in typical construction scenarios, their findings are equally applicable to motion picture and event staging production applications. (The complete report is available online at http://www.ihsa.ca/PDFs/Products/Id/RR004.pdf.)

To prevent such scenarios from happening, many techs will establish a temporary bond in the generator. They accomplish this by simply inserting a jumper between the neutral and ground pins of a male plug (as pictured in **Figure 3**) that they plug into an open receptacle of the generator.

This simple device, called a "jumper plug," restores the equipment grounding conductor as a low impedance path for fault current back to the generator's windings. It assures that in the event of a fault there will be a current imbalance in the GFCI, which is necessary to trip it. However, the GFCIs on generators still may be unreliable for numerous other reasons.

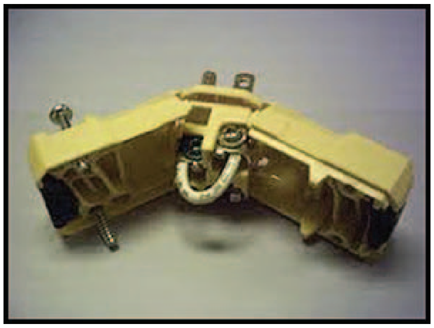

Figure 3 – A neutral/ground jumper plug

Outlet GFCIs are prone to nuisance tripping when powering non-linear loads. The residual currents generated by non-power factor corrected amplifiers, electronic lighting ballasts, and AC-to-DC power supplies, sensitize these GFCIs so that they are very susceptible to tripping under transient events without the presence of a hazardous ground fault. To improve the generally poor reliability of early GFCIs, in 2003 UL published a new standard (*UL 943*) for GFCIs designed to prevent nuisance tripping by transient conditions that are not of a sufficient duration to pose a hazard. The standard allows GFCIs to trip on an "Inverse Time Curve" that decreases as the magnitude of the current increases (as can be seen in **Figure 5**). What makes such a response curve possible is the way in which the human body responds to electric shock.

Studies into human and animal response to shock, summarized in *IEC 60479-1: Effects of current on human beings and livestock*, demonstrates that humans can withstand low fault currents if the exposure time is limited. As can be seen in **Figure 4** which is extrapolated from *IEC 60479-1*, the danger caused by electric current passing through the human body depends on both current and time. Currents of 0.5 mA or less (Zone 1) are harmless and generally imperceptible. Exposure to currents from 0.5 mA to 8 mA are perceptible but not painful. Currents from 8 mA to 15 mA are painful but not hazardous since the individual can let go at will and muscular control is not lost. Exposure to currents from 15 mA to 20 mA, depending on duration (Zone 2), may cause involuntary muscle contractions, and possible injury from striking nearby objects, but usually no harmful physiological effects as long as exposure is limited to line B. Extended exposure (greater than line B) to currents over 12 mA (Zone 3), will likely cause difficulty in breathing, but result in no permanent damage to organs as long as exposure is limited to less than line C1. Still higher currents (lines C1, C2, and C3) cause an increasing likelihood of permanent organ damage and depending on the duration of exposure, ventricular fibrillation, a condition in which the heart ceases to beat effectively. Ventricular fibrillation can be fatal.

To avoid nuisance tripping from transient conditions that are, according to *IEC 60479-1,* sufficiently short in duration or low in current that they do not to pose a hazard, the inverse time curve of *UL 943* allows for a delayed response. To protect against harmful shocks it requires a more rapid response as fault current increases or persists. For example, if the fault current is greater than 300 mA an almost instantaneous response time (no more than 20 ms) is required. If the fault current is only 6 mA a trip delay of up to 5.59

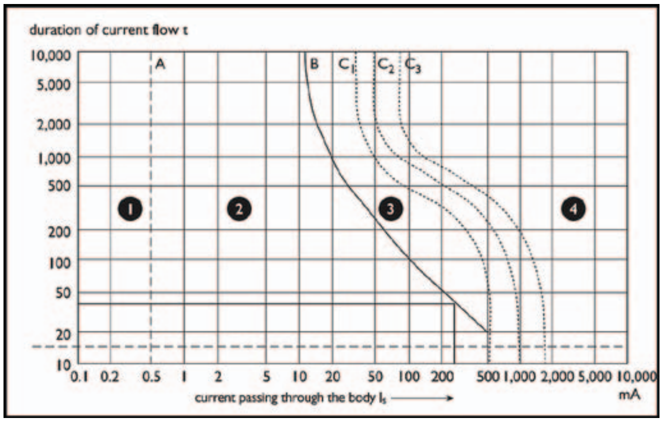

Figure 4 – Taken from *IEC TS 60479-1:2005, Effects of current on human beings and livestock – Part 1: General aspect*

seconds is permitted. The advantage of *UL 943*'s inverse trip curve is that it minimizes nuisance tripping from transient low-current faults while providing protection from ground-fault current.

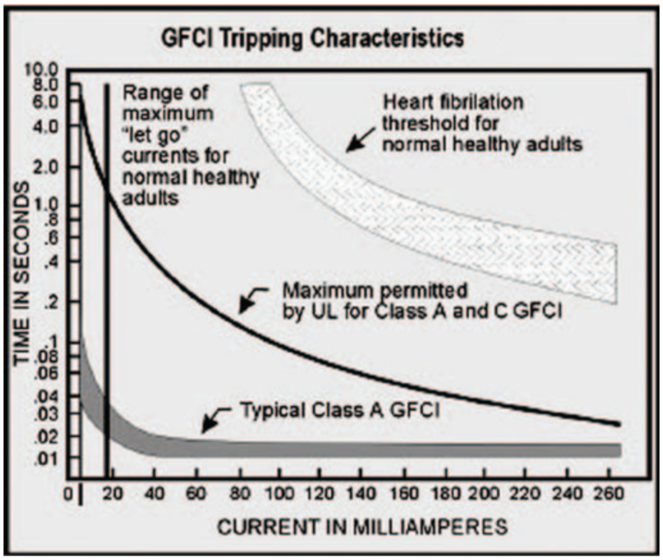

Figure 5 – Relationship of typical GFCI trip curve to the *UL 943* Curve (taken from "Now that industrial GFCIs are here…" by Nehad El-Sherif, Jan/Feb 2014 issue of the *IAEI Magazine*.)

Even though the *UL 943* inverse-time curve was meant to enable GFCIs to operate more reliably in real world conditions, manufacturers of lower-priced Class A devices do not implement the curve because it requires sophisticated micro-processors, which makes the design more complicated and more expensive. Instead they use a more aggressive response (like that illustrated in **Figure 5**) that is lower and faster than that required by *UL 943* (typically 250 ms at 6 mA where *UL 943* permits 5.59 seconds.) The more aggressive response of these GFCIs is permissible because the UL standard is the absolute highest current vs. time response accepted, but it is not mandatory. While this more aggressive trip curve does not generally pose a problem in one-tool per circuit applications for which they are meant, it has proven to be a problem in the more extensive distribution of multiple loads that characterizes motion picture production and event staging.

Part 2 of this multipart exploration of how to safely use small portable generators in motion picture and live event production will pick up with common sources of ground leakage and its accumulative effect on the GFCIs of portable generators. ■

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.