A LETHAL COMBINATION

Real-world examples of why electricity and water don't mix

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There's no doubt that more careful inspection and stringent maintenance/testing of bonding & grounding and ground fault protection systems near or in bodies of water are crucial for the everyday safety of swimmers and those working in environments around water that could become electrified. Corrosion and deteriorated bonding and grounding connections often expose swimmers to shock and electrocution hazards. Missing or damaged GFCI devices do the same. Many times, faulty connections can be traced back to the use and installation of non-listed connectors and poor workmanship, which ultimately lead to a breakdown in the overall protective system. So whether it's a pool repairman's electrocution, a town being forced to close its pools after shock incidents are reported, or unsuspecting boaters or homeowners receiving fatal electric shocks in or around water, the content in this e-book takes readers through codes and standards revisions that affect these type of scenarios, presents the electrical theory behind the requirements, and allows electrical professionals to make more informed decisions about whether they are doing enough to protect the public from harm.

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Pool Shock Peril Resurfaces

Push for low-voltage lighting and more careful inspection/maintenance of bonding and grounding systems follow electrocutions, shocking incidents.

By Tom Zind, Freelance Writer

A stew of knotty issues is sparking fresh debate over whether swimming pools adequately protect users from the menace of electric shock. Leading the way is a flurry of publicity about deadly and injurious encounters with stray electricity around the structures, rekindling a fear that seems to bubble to the surface with clocklike regularity.

Aging pools — and the risks they carry in the form of degraded or outdated infrastructures — compound those concerns. Add in lingering questions about the qualifications of installers and inspectors, calls for tighter regulations/new safety standards, and the rise of new technologies, and it's clear that pool electrical issues are getting more attention.

The core concern is whether more pool structures (existing and newly built) are slipping into the danger zone. The adequacy, functionality, and reliability of essential protections against the risks posed by an environment where water and electrical current must coexist in close proximity — chiefly equipotential bonding and grounding systems — are coming under increasing scrutiny.

Tragedy strikes again. Those persistent concerns were stoked by the electrocution of a seven-year-old Florida boy in the summer of 2014, which followed an incident the previous summer that saw a man electrocuted in a Houston hotel pool.

According to news reports, the boy was swimming in the pool at the family's Miami home when he was thrown from the pool and knocked unconscious. Investigators believe the pool water became electrically charged when current entered

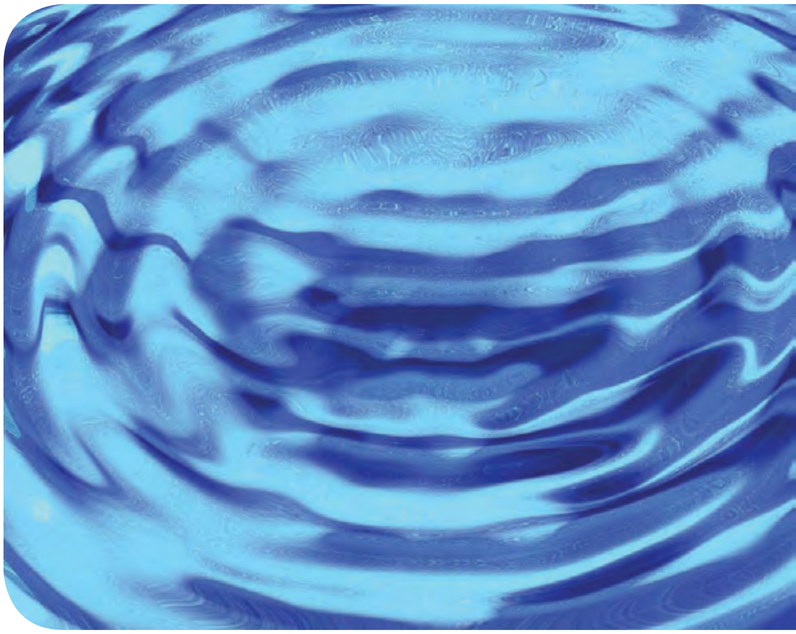

Photo 1. This aerial photo shows a pool being rebuilt and brought up to current Code requirements at the time. The equipotential bonding ring for the perimeter surface is located in the trenches encircling the pool. This ring is installed in the subgrade under the perimeter deck surface (in this case, pavers).

through a light fixture in the in-ground pool. They reportedly discovered that a ground wire wasn't attached to the transformer, opening the way for 120V to energize the light casing, allowing electricity into the pool water.

The boy's death spawned a wrongful death lawsuit that named, among others, a Miami electrical contractor reportedly hired soon before the incident to perform electrical maintenance on the pool. Brought by Colson Hicks Eidson, Coral Gables, Fla., the suit alleged Gary B Electric & Construction failed to "use reasonable care in the inspection, installation, and repair of the home's electrical components, including the installation of the new electrical panels and the pool pump's grounding rod and removal of the pool deck's pole light, to ensure the electrical system was properly grounded and bonded."

Electricians also were implicated in the Houston incident, in which a 27-year-old man was electrocuted while coming to the aid of a child who was struggling in water that had been delivering shocks to other swimmers moments before. According to media reports, two employees of Brown Electric, Inc., a Houston-area contractor that had been hired by the hotel to perform pool bonding and wiring work, were charged with criminally negligent homicide after an investigation found that wiring to the pool light lacked a GFCI device, setting up conditions for current to flow into the pool water. It was also alleged that the company did not secure a permit to perform the work.

Searching for answers. While the root causes of both electrocutions may prove to be different — and remain to be clarified within a legal framework — the incidents appear similar in one respect: They point to a likely blend of negligence, incompetence, and ignorance — a potentially lethal combination when working with a pool's electrical infrastructure. In a larger sense, the electrocutions serve as a reminder of what's at stake when pools are designed, installed, and maintained — not to mention the need for safe components, competent personnel, and routine maintenance.

That message has seemingly been heard in

Photo 2. This image shows an improper attachment of a bonding wire to a pump motor at a large competition pool. The bonding wire should be installed with a suitable connector.

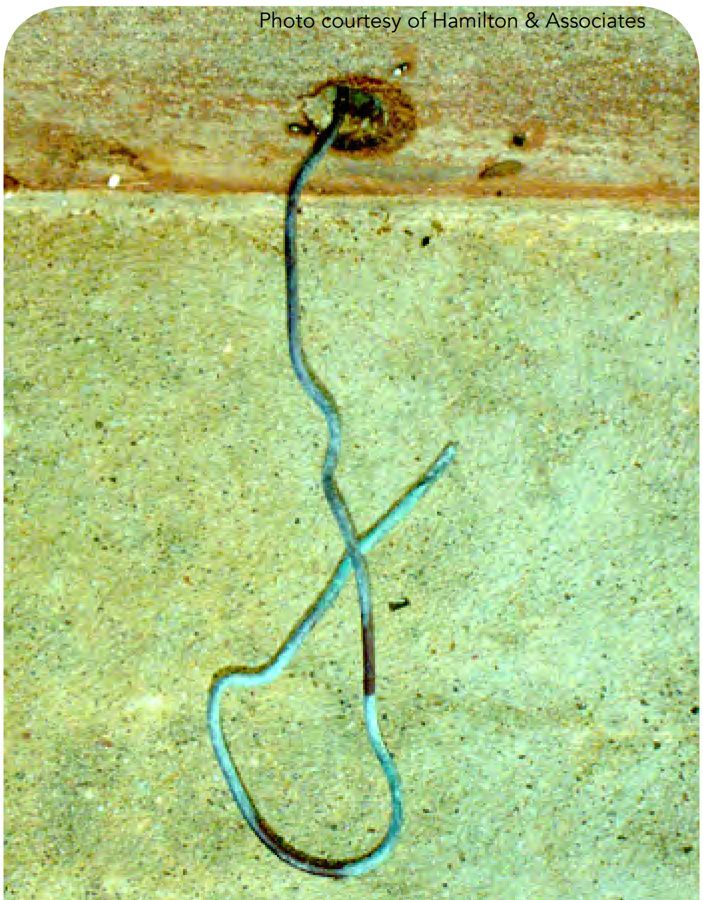

Photo 3. This bonding wire from an underwater pool light (seen from the back side of the pool structure) is not connected to the equipotential bonding grid.

Florida. The governing body of the county in which the seven-year-old boy died moved ahead with controversial legislation addressing one aspect of that tragedy.

The Miami-Dade Commission gave its early backing to a law that would require any lighting installed in and around newly installed or improved private swimming pools to be of the low-voltage/transformer variety, extending the scope of a requirement that exists for commercial pools in the county. Even though the Sloan pool apparently had such lighting — and the accident appears tied to human error and faulty wiring of the system that uses a transformer to step down 120V to a fraction of that to power lights — the incident reignited a long-simmering debate in the state over pool safety requirements and what can/should be done from a public policy perspective.

A tireless advocate of stronger regulations on pool lighting, Irv Chazen, owner of Custom Pools, a Miami pool installer, and an official with Associated Swimming Pool Industries of Florida, applauded the commission's action, saying the boy's death should offer an unequivocal answer to the question of "why have two standards; why not carry the same mandatory requirement to install low-voltage lighting and transformers to family pools?"

Caution urged. But other pool installer interests greeted the push for new regulation, which had expanded to Palm Beach County, Fla., with calls for caution. In light of the electrocution tragedies, The Association of Pool & Spa Professionals (APSP) instead emphasized the need for more vigilance in

Photo courtesy of Hamilton & Associates

Photo 4. Proper installation of a bonding conductor from the back of a metallic light niche to a listed clamp (not in photograph) attached to the pool structural steel. Because the conduit is non-metallic, a second No. 8 AWG wire must be run from the lug on the interior of the niche to the ground bus in the junction box, power supply, or transformer enclosure serving the light; the connection inside the niche must be potted with a suitable listed potting material.

inspecting and maintaining pools, stopping short of endorsing any kind of blanket requirement for low-voltage lighting.

Carvin DiGiovanni, the association's senior director, technical and standards, says the incidents point to a clear need for pool owners to better monitor and inspect aging pools and to ensure that maintenance is performed by competent professionals. However, he worries that more stringent lighting requirements, while appealing when framed as "low-voltage" solutions, could end up stifling the search for new solutions at a time of surging innovations in new pool lighting delivering better safety, performance, and aesthetics.

"I think we need to be careful that we don't lock into something on low-voltage that could minimize the chances for new lighting technologies that may require higher voltage, augmented with different processes that lead to safer lighting," says DiGiovanni. "There's still a school of thought that questions whether low-voltage will solve the safety problems."

But low-voltage lighting in and around pools is growing more popular, a trend progressively reflected in the National Electrical Code (NEC). The 2011 NEC established a "low-voltage contact limit," an acknowledgement of the surging popularity of pool lighting and the need to spell out safety parameters, product specifications and installation and configuration guidelines for emerging low-voltage alternatives. Restrictions on such lighting are relaxed in the 2014 NEC; low-voltage luminaires that don't require grounding no longer have to be

Photo courtesy of Hamilton & Associates

Photo 5. Pool ladder pockets must be bonded, but not this way. There is no assurance of electrical continuity because of the twisted connections. This was discovered upon excavation and illustrates the need for vigilance and frequent observations during the construction process.

placed a minimum of 5 feet from a pool's inside walls.

Beyond lighting. Even as forms of potentially safer lighting emerge, many aging pools remain tied to 120V lighting systems that themselves are aging, often in concert with GFCI protection and pool bonding systems essential to pool electrical safety. The condition and operability of those systems, according to Code experts and electrical contractors who install and maintain pools, is the real concern when it comes to pool safety. If compromised, that can neutralize any margin of safety offered by low-voltage lighting.

Underwater lighting systems do pose a clear threat because corroded and faulty fixtures can become electrodes for introducing current into water, says pool electrical systems expert Bill Hamilton, III, president of Hamilton Associates, a Pflugerville, Texas engineering services firm. But the root cause of most shocking incidents, says the member of NEC Code-Making Panel No. 17 (CMP 17) representing APSP that oversees Art. 680 covering

Low-Voltage Lighting Steps into the Limelight

In addition to traditional low-voltage incandescent lighting, new and improved lighting technologies are becoming acceptable options. Lighting, in turn, is poised to become safer and more functional, versatile, and dynamic.

"Because of changes in technology, consumers have more lighting choices than ever," says Carvin DiGiovanni, senior director, technical and standards, for the Association of Pool & Spa Professionals. "Options include LED, fiber optics, as well as different incandescent lighting."

While traditional 120V lighting is still the dominant and preferred type — both for its cost and performance — low-voltage is catching on because it's delivering a package of new solutions. New UL-listed products are coming to market that conform to low-voltage lighting standards in the NEC, and many don't require grounding because they're sealed in plastic.

"There's a lot of amazing, all solid-state stuff being manufactured now that would never have been allowed at 120V," says Bill Hamilton, III, a pool electrical expert and president of Hamilton Associates. "Some of it is microprocessor driven, allowing you to put on a real light show."

But new generations of safer and more functional lighting also incorporate new technologies that aren't yet fully understood in the field. Although the Code has evolved to address low-voltage, some low-voltage installations lie outside traditional interpretations.

"Some of this new high-tech lighting can have some very sophisticated power supplies," Hamilton says. "That was recognized in the 2011 Code cycle, and we're still working with authorities having jurisdiction to get them to bring local ordinances regulating low-voltage lighting into line with some of these new technologies.

"We don't want them red-tagging installations that would actually be desirable in terms of low-voltage alternatives. If you say you're not going to allow anything but a 15VAC light or below, you may be excluding a whole category of brand new solutions that may be very desirable and could be a lot safer."

The transition to these new technologies is being aided by new ways of defining acceptable pool lighting. Hamilton notes new pool and spa industry code language that sets a clearer, more objective standard for determining minimum pool illumination requirements. Along with an industry push to use a lumens rather than a wattage standard to categorize lighting and better guide how lighting is best deployed, the effort could further set the stage for the deployment of more low-voltage lighting in pools.

"Technology, because of a number of factors, is tending to move in a direction that's going to provide inherently safer devices just because they're getting away from 120V and getting into fairly low-voltage, reasonably low-current solutions, compared to incandescent lights," he says.

pool structures, often lies with systems that are supposed to form a barrier to electric current ever posing a lethal threat.

"Almost inevitably," he says, incidents he's investigated where shocks have been traceable to light fixtures "involve non-existent, faulty, or deteriorated grounding and bonding systems in concert with that."

Photo 6. All metallic fences within 5 ft of the inside wall of the pool must be connected to the equipotential bonding grid. In making these and other connections subject to direct burial, listed devices suitable for direct burial must be used, and it is important that attachment screws be made of stainless-steel or other corrosion-resistant material.

Photo 7. This photo shows an improper connection of the bonding ring to the pool's structural steel. Plated steel screws, even in listed devices, generally will not last in a corrosive pool environment.

Through the years, the Code has been revised to better define the proper design of pool equipotential bonding and grounding systems, which must remain operational over the course of many years. Following and maintaining those guidelines is essential, Hamilton says, both in the installation of new pools and the ongoing servicing required of pools as they age. Most critical is the equipotential bonding grid, consisting of copper-wire connections to metal components in and around the pool, which equalizes voltage and lowers the risk of electric shock.

CMP 17 addressed bonding again in the 2014 Edition of the Code. Concerned that wording referencing the "bonding of pool water," was confusing, the panel revised Sec. 680.26. The 2014 NEC states that "pool water must have an electrical connection" to specific bonded parts, or "the water must be in contact with a corrosion-resistant surface that's at least 9-square inches." A new requirement to ensure functionality is that the item making contact with the water must be "in an area where it won't be dislodged or damaged… ."

Knowledge and competence gap? Despite efforts to make pool bonding and other key elements of pool electrical systems more understandable, some see stubborn confusion about how it's actually done. That's putting not only newly installed pools at risk, but also older pools whose bonding grids can deteriorate over time and may require refurbishing or repairing. As the recent shocking and electrocution incidents suggest, there's no certainty that every pool installer or the electrical

Photo 8. The bonding system extends back from the pool to the equipment pad. This photo shows a proper bonding connection at the pump motor, prior to the wiring compartment cover being installed.

contractors they typically sub work out to fully understand the nuances of pool bonding or grounding — or that they can be trusted to perform the work by the book.

In his years as an electrical and building code enforcement officer for the town of Ithaca, N.Y., Chas Bruner has witnessed a less-than-ideal grasp of the bonding concept, in particular. That's compounded by installers who sometimes choose not to hire electrical specialists to do the work, a byproduct of comparatively loose state regulations on employing licensed electricians.

"Some people aren't trained, and, in a lot of cases, you have college kids doing the installations," he says. "So you end up counting on seeing some pretty flimsy bonds. Since there can be a lot of different pool designs, it can be hard to see if they've selected the right way of doing it."

Install jobs can be difficult to thoroughly inspect as well, he says, because the perimeter bonding is quickly covered with concrete in fast-paced jobs. "You have to get there quickly," he says. "I've had concrete trucks ready to pour, waiting for me to give the OK. In some cases, I've had to hold them up."

Time takes its toll. Even if they're installed properly — and that's hardly guaranteed if work is governed by outdated versions of the NEC — pool bonding and grounding systems are subject to wear and tear. Over time, these systems can corrode, and a host of variables can affect the pace of decline. That fact heightens the importance of, as the pool group APSP advises, "inspection, detection and correction" to address things like "aging electrical wiring, the use of sump pumps and vacuums that are not grounded, and lack of proper bonding."

Photo 9. This image shows a pool pump motor prior to attachment of the bonding conductor to the lug at the upper left. The wiring compartment cover is open and also must be installed to provide a safe and Code-compliant installation.

In the News and on the Web

EC&M has reported on several stories that relate to the hazards electricity presents in pool applications. Read these and other full news reports at ecmweb.com.

Pool Repairman Dies in Suspected Electrocution in Florida

This worker died from a suspected electrocution in Panama City Beach, Fla., when he and another coworker were repairing pool lights at a private residence. According to a report from the *News Herald*, one man was working at the breaker box while the other was in the pool when the accident occurred.
http://bit.ly/1v4u10u

EarkArk/iStock/Thinkstock

Pennsylvania Town Closes Pool After Shocks Reported

A town in Pennsylvania shut down its pool when a patron reported feeling electrical currents while sitting on the pool deck. The town council subsequently authorized $75,000 in emergency repairs after the incident. According to a report from *Lehigh Valley Live*, electrical engineers said the pool deck was improperly bonded.
http://bit.ly/1rZKDZ4

Children Shocked in Public Pool in Philadelphia

After three children were shocked in a public swimming pool in Philadelphia, local news sources said that area residents had been reporting for the past month a sensation of tingling or "pins and needles" when swimming. The pool was closed indefinitely, and the Philadelphia fire executive chief said an equipment malfunction could have caused the current.
http://bit.ly/1rtlkNc

Three Children Shocked at Florida Condo Pool

Three children were shocked at Florida condominium community pool as a result of shoddy electrical work. The children spent several nights in the hospital after being shocked at the Palm West Condo pool in Hialeah. According to a report on *Local10.com*, a green ground wire on the pool pump was disconnected. The building inspectors' report said that when the pump malfunctioned, the electricity wasn't directed into the ground. Instead, it energized the water the pump was pushing back into the pool. To see police photos, visit *http://bit.ly/1rlBZSJ.*
http://bit.ly/QERPZ7

Triec Electrical Services, Springfield, Ohio, has heeded that call. Motivated partly by news of pool electrocutions, Owner Scott Yeazell says he's recently begun offering complimentary inspection and testing of pool bonding. He suspects there are enough degraded systems in existence that repair work will provide the payback. He's eager to step in because he knows vigilance can be the difference between life and death.

"Bonding is your secure backup. If it's gone and you don't know it, you're at risk," he says. "But I don't see any program or commonly accepted practice of testing bonding to see if it's intact or not."

Hamilton, who senses that bonding still "mystifies" many pool owners and electrical contractors, says he's been an advocate of making inspections of both bonding and grounding systems a requirement. He has helped pioneer techniques and protocols to test systems, some of which have been referenced in a handful of states that have instituted mandatory commercial pool testing.


Photo courtesy of Hamilton & Associates

Photo 10. To verify the integrity of the bonding system, test it. Some states require periodic testing for commercial pools. This is basically a continuity test among items required to be bonded by the Code, and should be done so that the current being injected flows through the pool structural steel (concrete pools) and the perimeter bonding ring (non-conducting pools) such as fiberglass and vinyl liner pools. Plus, there are some things that old technology still does better, and this is one of them. Analog meters with large (C or D cell) batteries, an integral polarity reversal switch, and a "zero ohms" function allow the user to verify bond integrity over long distances and to detect if DC ground currents are affecting the measurement. More than 20 years of testing indicates that properly bonded equipment will exhibit resistances generally well less than 1 ohm, while ineffective bonds will measure substantially greater than 1 ohm. Equipment with current calibration (white label in the photo) should be used for these measurements.

Right the first time. While maintenance and testing is important, Hamilton says safety starts with the initial installation. Installers must adhere to the up-to-date Code, which should be incorporated into local ordinances. But bonding system design should be flexible to a degree, adapted to geographic variables like the water table and soil type, which can affect their functionality and longevity.

"Pools are only as safe as they get built," he says. "But then they need to be maintained, and today there are a lot of 50-year-old pools out there."

While the recent focus on pool lighting is well justified, it's important to remember, he adds, that the pool electrical safety issue is multi-faceted.

"If you make a statement that says were going to have safe pools if we convert everything to 12V lights, that's a highly oversimplified statement that doesn't reflect the physics of what goes on with electricity in a pool," he says. "If it were as simple as that, then NEC Art. 680 would be one sentence: 'Put a 12V light in your pool. Thank you.'"

Editor's Note. *This article was originally published in October 2014. All code references are based on the edition of the standard in effect at the time the article was written. Additional rules may now apply to new installations.*

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The Case of the Houseboat Electrocution

Damaged neutral on faulty light fixture and reverse polarity spell disaster for families' day of water fun at the lake.

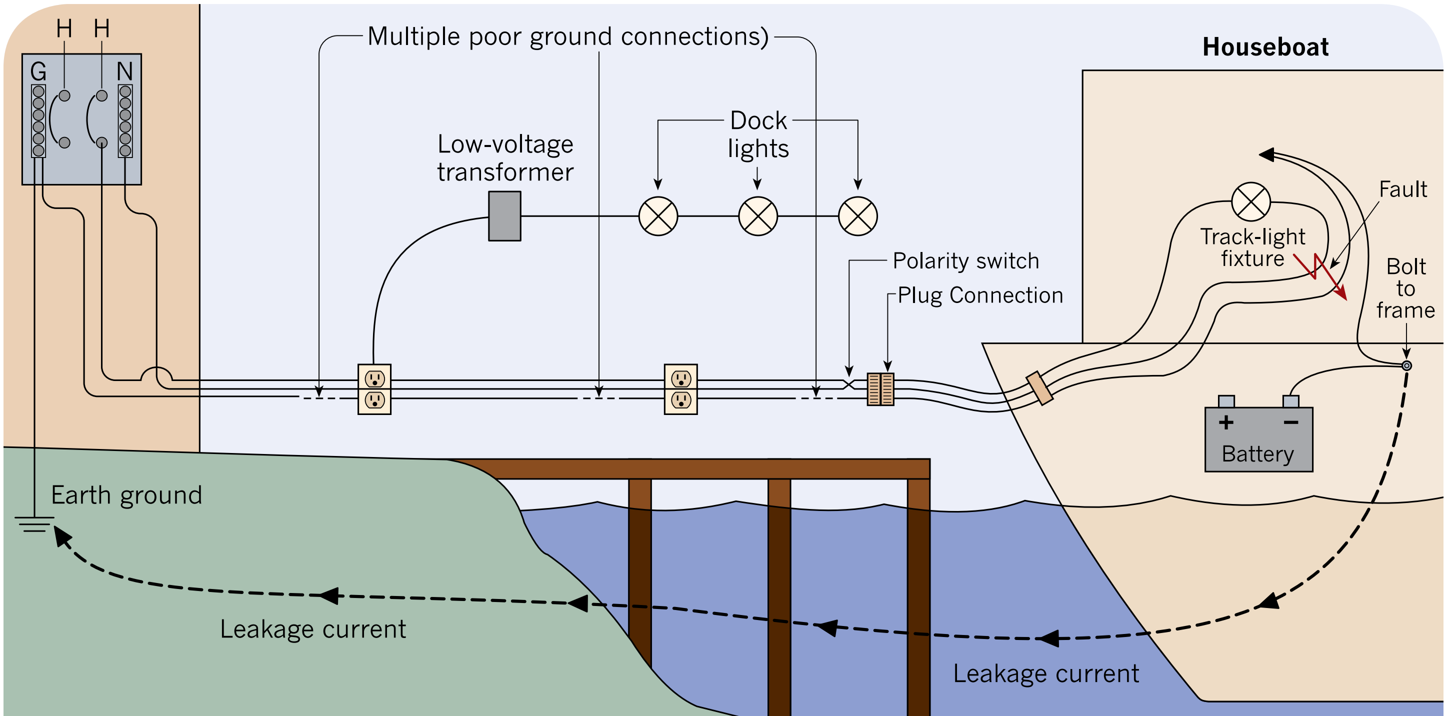
By Andrew Paris, P.E., Anderson Engineering

Soon after a young family purchased a vacation condominium on a local lake, they were anxious to entertain guests. One summer weekend, they invited another couple and their daughters to visit: Tim and his wife Liz, their older daughter Jenny (age 9), and younger daughter Laura (age 2). Toward the end of an eventful day at the lake, both families decided to take a walk along the docks down by the marina, which housed several boat slips.

Although the condo owners (Joe, Cindy, and infant son) did not own a boat, they were in the market for one. As they walked along, examining the different models, a large houseboat at the end of the dock immediately attracted their attention (**Photo 1**). They walked over and started chatting with the boat owner, Dave, and his girlfriend, Kim. While taking a tour of the cabin, Kim asked Jenny if she would be interested in going down the waterslide at the back of the houseboat. Like most girls her age, Jenny jumped at the chance to try out the slide. Unfortunately, the events that transpired would quickly turn a seemingly harmless bit of water fun into pure tragedy.

The accident. Dave turned on the water pump, and with the owners' approval, Jenny climbed up to the roof and slid down the slide. She quickly popped up from the water approximately 10 feet away and grabbed onto a life preserver Dave threw toward her. Holding it to her chest, she began paddling to the rear of the boat. As she got closer to the ladder, however, she began to feel numbness and tingling in her legs. When she was within 4 or 5 feet, she could no longer feel the lower half of her body at all. She screamed out in pain that something was stinging her. Thinking it might be a snake, Joe immediately jumped into the water to help, pushing Jenny toward the rear of the boat.

Photo 1. View of the subject houseboat docked in the marina.



Deficiencies in the wiring system serving this houseboat created a deadly situation.

At the same time, Tim, the girl's father, grabbed onto a metal railing and leaned out over the water to grab Jenny. As he was leaning forward, he slipped into the water but still kept hold of the railing. Quickly, he felt his body painfully tighten and found that he could not release his hands. He was left hanging to the side of the boat in obvious pain. Although Cindy and Liz pleaded with him to let go, Tim told them in slow, contorted speech that he simply could not. Realizing that it might be an electrical problem, Dave ran to the front of the boat and unplugged it from shore power. This immediately allowed Tim to free his grip, and the others helped him back onto the rear deck. Soon thereafter, Jenny also was able to make it to the rear ladder and climb out of the water.

As the chaos subsided, the group's attention soon turned back to Joe, who was nowhere to be found. Dave and another bystander dove into the water and found Joe near the bottom of the lake. They pulled him onto the rear deck and began to perform CPR while another bystander called 911. Unfortunately, Joe never regained full consciousness, and he later died at the hospital. An autopsy concluded that Joe had been electrocuted. In addition, the shock Tim received left him with lasting injuries. Fortunately, Jenny did not suffer any long-term harm.

Investigation and analysis. Based on the circumstances surrounding the accident, the sheriff's department hired a local electrician to assist in the investigation. He initially tested for voltage between the metal dock and the water. Finding none, he plugged the houseboat into shore power and measured the voltage between the water and various locations on the boat. The results were as follows:

- Portside stern (location of the ladder): 100.6VAC
- Starboard stern: 96.7VAC
- Starboard bow cleat: 112.3VAC

After unplugging the boat from shore power, no voltage potential was found at any of these points. Finally, the electrician performed a continuity test on the hot leg of the 120V shore power. A direct short was found between the hot leg and the hull of the boat. These initial tests showed that the water surrounding the boat was effectively energized to line voltage whenever the boat was plugged into shore power.

Anderson Engineering was hired on behalf of the plaintiff (victim's family) to investigate the accident and determine the particular failure mode that led to the accident. During our preliminary examination, we tracked the shore power connection, finding that 120VAC power originated from a metered disconnect located on the exterior wall of a nearby condo. Underground conductors traveled to a receptacle mounted on shore near the dock. A low-voltage lighting transformer powering several dock lights was plugged into the receptacle.

The circuit traveled onto the dock and powered a second duplex receptacle. The run continued on to a 30A female plug-in cord receptacle. A final extension cable traveled from there to a male receptacle on the side of the boat. Closer inspection of the extension cable revealed that the hot and neutral were reversed in the cable-to-cable connection.

Further examination of the houseboat's electrical system and components exposed a faulty interior track lighting fixture. As shown in **Photo 2**, the neutral fixture wire was damaged as it passed out of the covered wiring compartment. Unless the fixture wires were correctly routed during the manufacturing process, the edges of the grounded mounting plate would cut into the conductor insulation when the wiring compartment cover was installed. In this case, the neutral was effectively connected to electrical ground. The damaged "neutral," in combination with the reversed polarity, created a dangerous situation. Under normal circumstances on a land-based electrical system, the fault current would have traveled to earth ground. Then, depending on several factors, including the circuit load, the location of the ground fault, and the condition of the ground connection, the rise in current would most likely have tripped the overcurrent protection. However, this did not occur.

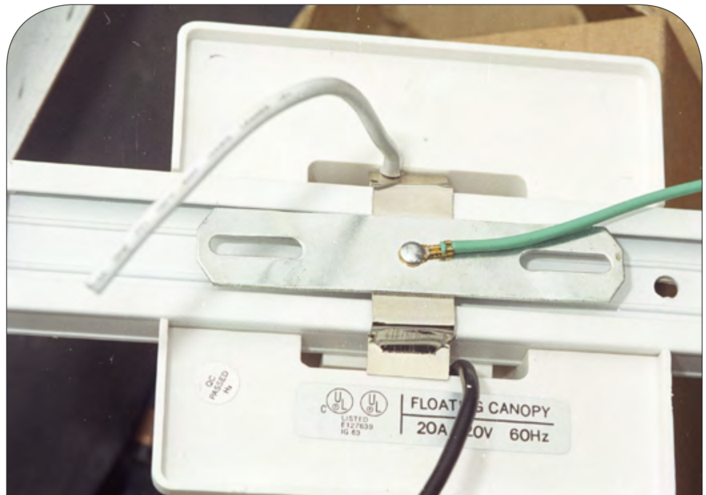


Photo 2. Light fixture wiring — neutral wire pinched between cover and grounding plate.

Rules and regulations. Rules regarding marina electrical systems are laid out in NFPA 70, (National Electrical Code) Article 555: Marinas and Boatyards. The Article bases all shore wiring systems against the electrical datum plane. The datum plane is a horizontal plane below which no electrical services, outlets, or connections are allowed. The Article further specifies rules regarding connections to boat AC power systems. The shore power system at the condo complex in question violated several provisions of the 2008 NEC, including:

1. The final cord-to-cord connection mentioned earlier was not at least 12 inches above the deck of the floating pier, which was a violation of 555.9 and 555.19.

2. The final receptacle was not housed in a listed marine power outlet and was not protected from the weather [555.19(A)(1)].

3. The shore power disconnecting means was at the circuit breaker panel on shore, and not within 30 inches of the boat receptacle, as specified in 555.17(B).

4. Wiring above the deck was not protected by rigid or nonmetallic conduit, as required by 555.13(B)(5).

5. The cable connection to the boat was routed through a rough hole cut in the side of the metal dock frame, violating several Code sections relating to workmanship and protection of conductors (110.8, 110.12, 110.27, etc.).

Shocking Stats

Even a small amount of electrical current can be extremely damaging. In general, 1mA is the threshold of human perception. A current of 5mA to 15mA will cause muscles to independently contract. The victim may be thrown away from the electrical source, or in other instances will not be able to let go. Higher current will result in larger contractions, which can severely tear muscles, ligaments, and possibly even break one's own bones due to the extreme force of the contraction. If slightly larger current (75mA to 100mA) passes through the heart, it can cause ventricular fibrillation, also known as a heart attack. It is only at higher currents (5A and above) that tissue will actually be burned.

NFPA 303: Fire Protection Standard for Marinas and Boatyards covers the design and construction of marinas and boatyards with respect to fire and life safety. NFPA 303 also contains a less well-known section on electrical equipment that complements the NEC. While much of NFPA 303 Chapter 5 restates or references the NEC, it also specifies additional warnings and safety measures, as well as presenting specific receptacle configurations approved for shore power connections.

In particular, NFPA 303 requires that insulation integrity of the electrical system shall be tested upon completion of the installation (5.18.10). All receptacles must be tested for ground integrity and polarity prior to use (5.18.2). Finally, 5.20 provides criteria for regular inspections (at least annually) of the entire shore power system for damage, improper additions, ground integrity and polarity, and several other safety hazards.

While the NEC and NFPA 303 cover shore-based electrical systems, they do not cover the internal electrical system of a boat itself. Safety standards for boat wiring are laid out in ABYC E-11, a publication produced by the American Boat and Yacht Council. Although that standard is beyond the scope of this article, one section plays a major role in cases of this type — the requirement that the boat's internal AC system ground be bonded to the DC ground. Normally, the DC ground/neutral is simply a connection from the negative battery terminal to the boat's hull.

When the boat is connected to shore power, the boat's AC system is bonded through the grounding conductor back to a grounding electrode on shore.

As long as the shore-to-boat grounding connection is solid, any ground-fault current will travel back to shore and trip the circuit's overcurrent protection. However, if the shore-to-boat grounding connection is severed, or even slightly weakened, fault current will travel through a parallel path created by the bonded AC/DC ground connection on the boat. As the AC/DC ground is basically a direct connection to the hull, fault current will energize the boat hull. Stray current then travels through the water in an attempt to reach shore, and the shore power grounding electrode.

In many cases, this parallel path is weak, as the voltage decreases with distance away from the hull. The current most likely will not be sufficient to trip the shore overcurrent protection, and the fault will continue indefinitely. That is why a strong, continuous grounding path back to shore is imperative.

Lessons learned. With this in mind, it may surprise you that ground-fault protection is not required for shore power circuits. It is only required for 15A and 20A circuits in marinas and boatyards that are not used for shore power. The reason for this is also beyond the scope of this article. However, it relates to the problem of nuisance tripping, because there often may be a small amount of current traveling through the parallel grounding path. Keep in mind that this does not prevent the use of GFCI protection on these circuits; it is just not required.

Severing the bond between the AC and DC systems on the boat would be another way to stop this problem, but the bond is there for good reason. For one, if there is an AC ground fault on the boat, and the shore ground connection is poor, it creates a shock hazard for those in the boat if they make contact between an energized AC source and the grounded boat hull. Secondly, a fault connection could create enough heat to ignite a fire before the overcurrent protection could trip.

Back to our case, the reversed polarity of the shore power system, and the faulty light fixture resulted in a direct connection to ground. The poor condition and distance of the shore power grounding conductor made for a weak grounding path, and a parallel path formed through the water surrounding the houseboat. The voltage decreased as the distance away from the boat increased, so the current could not break the skin until Jenny was closer to the boat. Once she was within sufficient distance, the fault current, although

Water and Electricity Don't Mix

As always, there is more to this saying than meets the eye. Pure H_2O is actually a poor conductor of electricity. Water becomes a better conductor as the amount of minerals and impurities increases. For instance, the conductivity of seawater is much better than normal lake water. Again, this plays a significant role in the cause of marine shocks and electrocutions.

When a ground fault situation occurs in the ocean, the conductivity of seawater is much higher than the conductivity of the human body, so the fault current would travel through the seawater and not through the relatively high-resistance path of the body. The situation in lake water is reversed. The salinity of the human body makes it a better conductor than the surrounding lake water, and much of the fault current is shunted through the body.

When Electricity and Water Must Mix

A bright sunny day, a clear cool lake, and a large well-equipped boat — combine them together and it sounds like a recipe for fun, right? From the smallest outboards to the largest cabin cruisers, today's boats are more powerful, efficient, and technologically advanced than ever. Larger vessels are often more like second homes, with kitchens, living areas, and bedrooms containing every modern convenience.

Many larger recreational boats have several 12VDC or 24VDC circuits powered by batteries or alternators. These circuits are typically used to power lights, radios, depth-finders and other DC-powered devices. Larger appliances, such as refrigerators and air conditioners, can also be found in DC-powered versions.

Larger cabin cruisers or houseboats may contain many items that operate on AC power, as these devices are typically more readily available and more powerful than their DC-powered counterparts. If necessary, power inverters or generators can then be used to power these 120/240VAC devices. Stable power is typically provided by a connection to AC shore power while the vessel is in port. A shore-power electrical connection is definitely convenient for the operator, but that convenience is coupled with unique hazards not found on land-based electrical systems.

small, was enough to paralyze the lower half of her body.

When Joe jumped in to save her, he was also shocked. Most likely, he was paralyzed by the fault current, causing him to sink below the surface — where he eventually drowned. Therefore, his death could be termed what is known in the industry as "electric shock drowning," rather than an electrocution. Tim also suffered a paralyzing shock, but in a surprising twist he was actually saved because the current was high enough to hold his grip on the boat and prevent him from sinking.

Notwithstanding the defective light fixture and reverse polarity condition, if all the provisions of the NEC, NFPA 303, and ABYC standards were followed, the tragic death of a young father may have been prevented. A strong shore power ground path, proper and regular inspections of the marina electrical system, and GFCI protection could have prevented fault current from energizing the water. Modern boats may also be equipped with isolation transformers to isolate the shore AC from the boat's internal AC system. Furthermore, electronic devices are also available that can check for low levels of ground-fault current and alert management of the danger.

A lawsuit was filed against several defendants in this case, including the houseboat owner, marina/condo management company, light fixture manufacturer, and houseboat manufacturer. An undisclosed settlement was reached prior to trial.

Editor's Note. *This article was originally published in October 2008. All code references are based on the edition of the standard in effect at the time the article was written. Additional rules may now apply to new installations.*

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The Case of the Do-it-Yourself Home Electrocution

By taking a home improvement project into his own hands, a homeowner set the stage for his pregnant wife's death.

By James Ruggieri, P.E., General Machine Corp.

When a Virginia man realized his pregnant wife was spending more than her usual amount of time in the shower one evening, he decided to see what was taking so long. His concern rose to panic when he entered the bathroom to look in on her. As the water continued to run and fill the shower pan, his wife sat unconscious and slumped over in the corner of the shower stall. She was unresponsive, and the husband's attempts to revive her were ultimately unsuccessful.

The woman's body showed no sign of trauma, but the possible cause of her death soon became apparent. Immersed in water next to her, the husband noticed the 120VAC portable hand lamp he had hung on a hook in the shower stall to provide light while he finished a home improvement project that involved installing a ceiling light fixture overhead (**Photo 1**). The hand lamp was plugged into a GFCI-protected bathroom receptacle via its attached 25-foot power cord, which was draped over the shower stall door.

At first, the woman's death appeared to be no more than the result of a series of unfortunate events, but seemingly contradictory facts uncovered in the initial investigation began to raise questions about why the GFCI didn't prevent the electrocution — and whether the husband had anything to do with the death.

Photo 1. The hand lamp was plugged into a GFCI-protected bathroom receptacle via its attached 25-foot power cord, which was draped over the shower stall door.

Assessing the scene. The fact that the husband had drastically altered the scene in his efforts to assist his wife before police and medical personnel arrived made it difficult for the investigative team to piece together exactly what had happened or determine the order of events. The lamp appliance switch was in the "ON" position, and the GFCI that supplied it had tripped, both of which suggested that the lamp was energized at the time of the incident. If the GFCI had tripped, though, how had the woman been electrocuted? And it was obvious that the lamp fell, but at what point and how?

The woman's body had blocked the shower drain, causing it to fill up, but there was no way to know when. Did she receive a lethal shock from the lamp itself and then fall and block the drain, or did she collapse for reasons unrelated to the appliance, only to be electrocuted when the lamp fell into the pool of water that accumulated when she blocked the drain?

Because of the suspicious nature of the death and the fact that the police were considering the husband a suspect, they retained me to evaluate the case. Using the actual lamp found at the scene and a replica of the shower, I conducted a battery of tests to better understand how she was electrocuted.

Testing and analysis. The governing UL standard, UL 298, Safety for Portable Electric Hand Lamps, requires a hand lamp like the one found in the shower to withstand 1,250V for one minute in a dielectric voltage withstand test, but the sample lamp broke down in five seconds at only 400V.

After disassembling the lamp, I made clearance

Photo 2. Not only was a screw missing that would have brought the guard assembly in connection with the grounding tab, deficient internal component spacing energized the entire lamp.

measurements between components and found why the lamp failed the test so quickly. The spacing between the integral receptacle's grounding lug and neutral attachment was less than 0.04-inch, significantly less than the 0.25-inch specified in UL 298 (**Photo 2**). To make matters worse, the grounding lug for the receptacle could move and rotate to some degree, serving to further reduce the spacing. Inspection proved the deficiency was a design defect rather than a condition caused by deterioration or use of the appliance.

In addition, a missing screw allowed for a slight separation between the two halves of the upper part of the handle, exposing the internal components to dust, dirt, debris, water, and water vapor.

Non-compliance with the leakage criteria quickly surfaced as the primary critical factor in this incident. In order to evaluate leakage current, I energized the lamp at 120VAC and monitored the resulting

current flow to the lamp's grounding tab.

High ambient humidity, which would be found in a steamy bathroom like the one in question, affects ground leakage performance since water vapor can collect or condense on energized electric components and parts, which generally causes increased leakage current between inadequately spaced electrical connections or components.

In a dry state, tests found the ground leakage current of the lamp to be 25 µA, which is an acceptable value. However, when the appliance was subjected to a humid environment of 90°F at 85% relative humidity for one-half hour — far less than the 88% relative humidity for 48 hours as specified by UL Standard 101 (incorporated by reference in UL 298) — leakage current measurements indicated the grounding circuit to be directly connected to one side of the AC line. In fact, even 40% to 50% humidity would have been enough to increase the leakage current to lethal levels.

I also tested for electric shock risk for an individual partially immersed in water with the 120VAC energized appliance immersed and in relative close proximity to the individual. With about 1 inch of water in the replica shower and with the appliance's guard in loose contact with its grounding tab, 125mA was recorded, and at 2 inches of depth, current quickly increased to about 500mA. I stopped the tests at 3 inches of depth, when current reached nearly 4,000mA. The deficient leakage performance discussed earlier confirms the high likelihood for electric shock injury to individuals coming into contact with either the appliance's metallic guard or grounding strip.

Additional tests showed with a reasonable degree of engineering certainty that although the lamp was hanging in a precarious position, the way in which the power cord was draped over the shower door would have prevented the lamp from falling into the shower pan without human intervention to either add tension or modify the tension angle enough to overcome frictional forces affecting the cord.

Conclusions. No one will ever know exactly what happened to precipitate the electrocution, but the results of the tests make it possible to offer a likely scenario. The woman's size at the time of the accident (5 feet, 2 inches tall and 220 pounds) and the relatively small size of the shower make it likely that in the course of showering she bumped the light and knocked it from its hook. The humidity in the shower would have caused water to condense in the lamp and bridge the already small gap between the grounding lug and the neutral, energizing the metallic lamp guard. Whether she caught it as it fell or tried to replace it after it did, the resultant leakage current she would have been exposed to when grasping the lamp was more than enough to send her heart into ventricular fibrillation. As she collapsed, she pulled the light with her to the floor of the shower, where it was eventually submerged as the water level rose. It wasn't until this point that the GFCI finally tripped.

Because of the likelihood that proper and timely operation of the GFCI device may have been hindered by the proximity of the grounding tab and the neutral attachment, it was likely that anyone in a running shower with the inappropriately located and defective appliance would be at a considerable risk of electric shock injury or electrocution.

The investigation showed that the electrocution was most likely an accident, and the husband was spared from criminal prosecution. However, he wasn't completely relieved of responsibility. Not only did he fail to secure a permit for the work in his shower or have it inspected, thereby violating state and local laws, he had no formal training in electrical system construction. Although he wasn't directly involved with the electrocution, his disregard for electrical safety and proper installation rules no doubt played an indirect role in his wife's death.

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Electricity and Water: A Volatile Mix

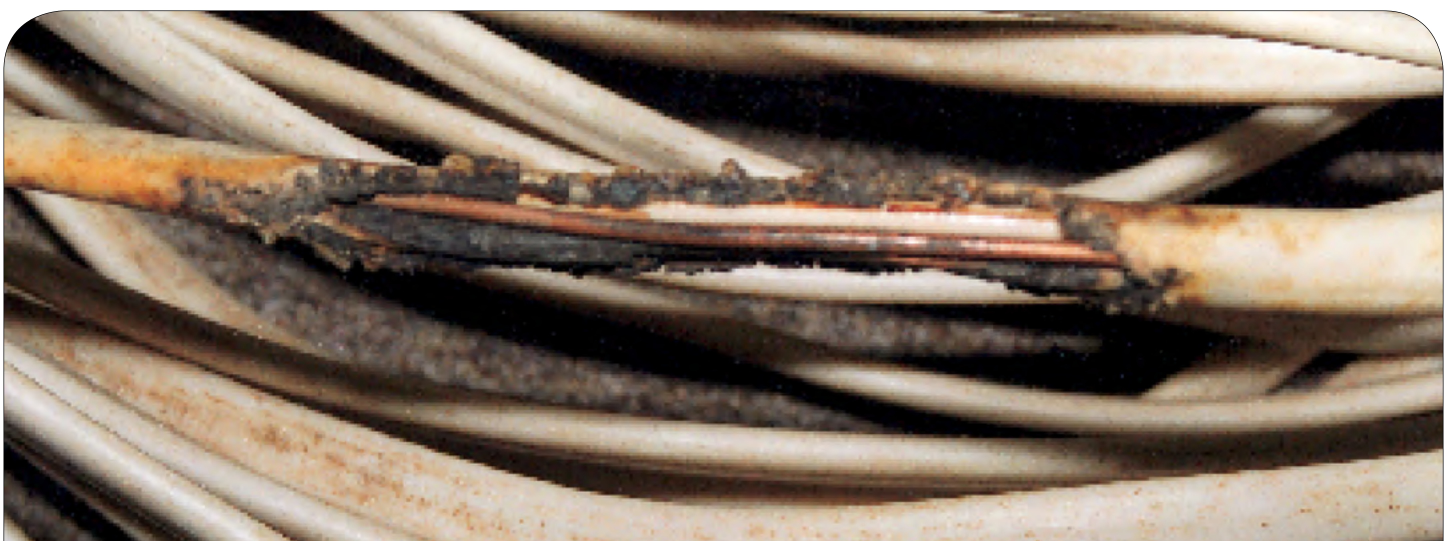
Improper wiring, a lack of GFCI protection, and standing water spell disaster.

By Michael Foley, President, Technical Consultants Group, Ltd.

When a father and son carpenter team took on a construction project to make improvements to a drainage canal, their first concern was supplying power to their equipment. They immediately installed a temporary electrical panel, fed from a nearby home garage electrical sub-panel.

In the beginning, they placed two portable submersible pumps in front of a temporary dam in the canal to pump water to a diversion channel. At first, the carpenters used an extension cord to supply electric power to the pumps. However, as the project progressed, they had to move the pumps farther away from the temporary service. Instead of using approved power cords, they used a 250-ft-long 2-conductor, No. 10 AWG (with ground), type NM-B cable to connect the panel and pumps. Since this cable crossed an area with heavy truck traffic, they decided to bury it.

Two weeks into the project, the son went down



The damaged NM-B cable shows where the energized conductor came into contact with the grounding conductor.

to the canal to help the other construction workers. At the time, the canal held a few inches of standing water. As one coworker recalled, the son went into the water to move a pump to another location. As he bent over to pick up the pump, he suddenly yelled, jerked violently, and fell over face down into the mud and water. Workers ran to his aid, raising his head out of the water. One worker ran to inform the father of the accident. The father called 911 from his cellular phone as he ran to the canal where his son lay unconscious and not breathing. Emergency medical personnel responded and immediately administered resuscitation efforts. They took him to a nearby emergency room where he was pronounced dead.

Emergency medical personnel responded immediately, but were not able to resuscitate the victim.

Within hours of the accident, investigators from the local police and fire departments, as well as representatives from OSHA, arrived on the scene.

OSHA investigators identified several deficiencies in the installation of the temporary electrical system contributing to the accident, including:

- A non-permitted connection to a residential electrical system;
- The neutral conductor of the single-phase service conductors feeding the temporary service was a separate cable from the phase conductors;
- Improper use and wiring connections of a single-phase, 4-wire, 50A receptacle at the temporary panel;
- Improper installation and connection of a 125V, 3-wire, 15A duplex receptacle used for general construction power;
- Improper installation of type NM-B cable in a direct-burial application;
- Absence of an OSHA-approved GFCI device or an assured equipment-grounding conductor system; and
- Inadequately trained employees.

As a result of this investigation, OSHA fined the construction company $52,000.

Forensic evaluation. The attorney representing the construction company called us to review the accident. In response, we assigned an engineer to investigate the case. Through his own on-site investigation, our engineer confirmed the deficiencies noted by the OSHA investigators.

However, he also revealed the following

problems: Temporary construction panel. The carpenters set up the temporary panel about 150 ft from the house garage sub-panel. They also tied the panel (equipped with a 2-pole, 50A circuit breaker; a 3-phase, 50A receptacle; and 15A duplex receptacles) with baling wire to metal posts driven only 8 in. into the ground. There was no grounding conductor to the construction panel, nor was there a grounding electrode conductor. The engineer found neither the 50A, 3-phase receptacle nor the 15A duplex receptacles equipped with a grounding conductor. He found the duplex receptacle mounting screws stripped; therefore, they didn't have a reliable metal-to-metal connection between the yoke and panel enclosure.

Buried cable. The carpenters buried the NM-B, 10/2 cable, with ground conductor, about 6 in. below crushed rock, which workers spread over the area to accommodate heavy construction-related truck traffic. Laboratory examination of the cable found the outer sheath torn and the insulation of the energized conductor damaged. Analysts also found localized heating at one location on the cable.

The engineer concluded the crushed rock most likely damaged the conductor insulation after its installation. Once this occurred, the energized conductor contacted the bare grounding conductor, which, in turn, energized the outer case of the pump. The pump case became energized because the carpenters did not effectively ground the grounding conductor at the construction panel receptacle.

Accident prevention. Several factors contributed to this accident. However, most (if not all) were avoidable. Poor electrical work practices caused this tragedy. A qualified, competent electrician would have installed the temporary service panel in accordance with NEC and OSHA requirements. Had the son received training in the use of GFCI devices or daily testing of the grounding integrity of electrical equipment, he would have detected and removed the damaged cable. Lastly, had the workers known and used proper first aid (CPR), this story might have had a happier ending.

Foley is President of Technical Consultants Group, Ltd. in Denver. His firm specializes in electro-forensic engineering investigations.

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