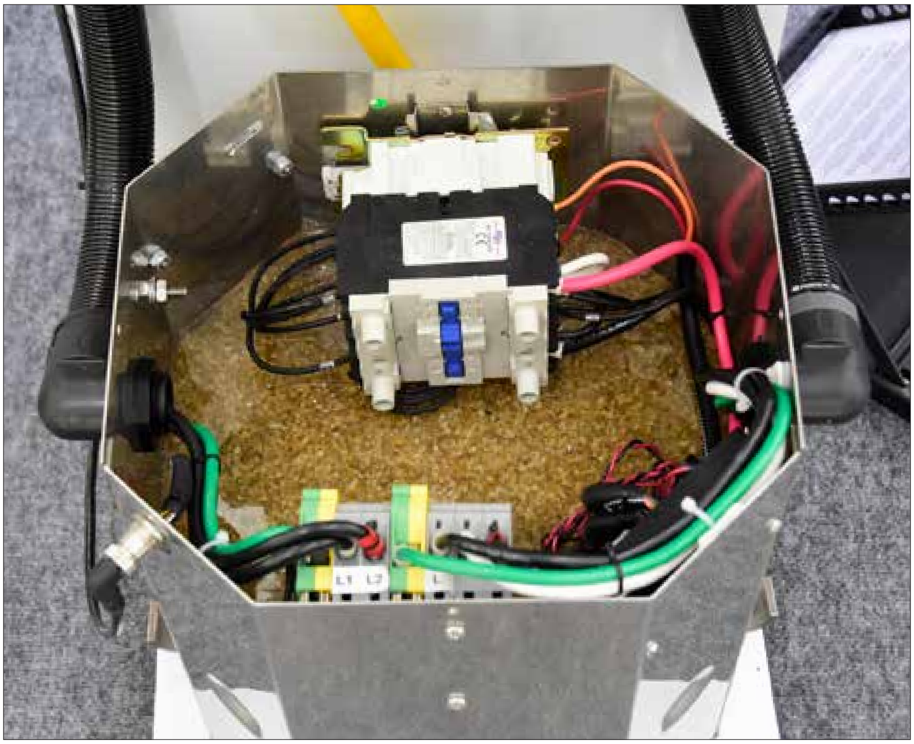


The Complexity of PLUGGING IN

Theory, standards, and best practices behind installing and maintaining shore-power transformers.

Text and photographs by Steve D'Antonio

Not long ago, I sat with a client hunched in the lazarette of his newly acquired boat. Looking over the humming shore-power transformer, he said, "I've heard these are useful, but I have no idea why. Can you explain it?" The boat's builder, struggling to articulate a response, finally said, "Trust me, they are good to have."

Many professionals in the industry stumble on the transformer question. These units are indeed beneficial in many ways, and those who decide whether to use, install, advocate for, or sell them should thoroughly understand why.

Shore-power transformers can be wired in one of two configurations—for isolation or for polarization (see pages 105 and 106). In either case, their greatest attribute is saving lives by reducing the risk of shock, electrocution, and electric shock drowning, or ESD (see **sidebar** on page 112). When wired in isolation mode, a transformer is also a deterrent against galvanic corrosion, which results when nearby submerged, grounded metallic objects interact via the shore-cord-grounding conductor.

Above—*Looking inside a new Hubbell auto-boosting shore-power transformer, note that the winding is potted in a sand/resin mixture, increasing its durability, moisture resistance, and weight.*

Installation

While the operating principle of a shore-power transformer is simple, there are peculiarities to be aware of to ensure a safe, reliable, and effective installation.

In many ways a transformer behaves much like a power source, a generator, an inverter, or the utility company's transformer at the head of the dock. The most important safety characteristic is the path electricity takes after it leaves the transformer. Like all electricity, it seeks a return to its origin and not necessarily to ground. Electricity "returns" to earth ground only when the power source is referenced to earth ground. In the case of the transformer at the head of the dock or in a marina parking lot, this is accomplished with a ground rod bonded to the transformer's neutral output and the green grounding conductor for the system (known as a grounded neutral). The importance of this safety feature cannot be overemphasized. Shore-power electricity, once it passes through the vessel's transformer, will "return" only to *that transformer*, either through the white neutral conductor or the green safety-grounding conductor. (These two are typically bonded or connected either at the transformer output or at the electrical panel, but not both.) On transformer-equipped vessels, it's important that there be only one connection location. (For more on neutral-to-ground connections, see the ProBoat online resource at https://www.proboat.com/2011/10/demystifying-the-neutral-to-ground-connection/.) Put simply, if the grounding/bonding system is intact, electricity that originates at an onboard transformer will not travel through seawater to reach a utility company transformer at the head of the dock or elsewhere ashore. Instead, it will return to the vessel's onboard transformer, thereby protecting persons in the water. Note that even if operators know their boats are appropriately grounded/bonded, they should *never* swim around vessels or docks energized with power originating ashore.

Left—Some transformers are located near an electrical panel to minimize cable runs, but they all must have plenty of ventilation to remove the heat they generate, and away from bunks, where the hum of operation would disturb sleeping crew.

Below left—A true shore-power transformer—the one at the head of the dock—is the source that shore power will strive to return to. Sometimes its path runs dangerously through the water.

As well as protecting swimmers from electrocution, a transformer eliminates the possibility of reverse polarity. That's why boats with 120V onboard transformers are exempt from ABYC's reverse polarity indicator and double-pole branch circuit breaker requirements.

The benefits of transformers are tempered by their size, weight, and cost: The average 30-amp unit may measure a little less than a cubic foot ($0.03m^3$) and weigh 60 lbs (27.2 kg), while a 50-amp, 240V unit measures half again as large and more than 200 lbs (90.7 kg). Transformers, especially ABYC/UL-compliant boosting versions, can cost in excess of $5,000 (4,442€).

They also generate and radiate considerable heat and need appropriate ventilation and air circulation. In addition, they produce a noticeable hum, which means you wouldn't want one under a berth or opposite a headboard. If installed in accommodation spaces, under a helm or behind an electrical panel, for instance, they should rest on flexible mounts. Some transformers are mounted amidships, near an electrical panel and between bow and stern inlets, to minimize wire runs. Ideally, shore-power transformers should carry a *marine* UL listing (while most industrial transformers are UL listed, few carry the "Marine" prefix), and adhere to ABYC's standards.

Be aware that not all transformers are created equal. While they all have the potential to be a fire hazard, the better options for onboard installation are UL listed, and the best are UL Marine listed.

Inner Workings

Through the principle of inductance, a transformer can achieve either polarization or isolation in the case of an isolation transformer. In brief, shore power travels from the dock's wiring, through the shore-power cable(s) to the boat's power inlet. (Note: One onboard transformer is required for each shore-power inlet that may be in use.) Instead of going from there to the vessel's circuit breaker panel, the isolation transformer is inserted into the circuit first. The incoming AC power travels through the primary (or input) winding of the transformer and back to shore. That's as close as the actual dockside current ever gets to the boat's electrical system. Because electricity is electromagnetically induced on the transformer's secondary (output, or boatside) winding from the nearby primary winding, no direct connection between the two is required.

The specification tag for a transformer will tell you a lot, including primary and secondary voltage and whether it's rated to operate at 50 Hz, 60 Hz, or both. The latter is particularly important for vessels likely to cross oceans on their own bottoms or to be shipped overseas, where standard electrical service varies.

One aspect of UL Marine compliance for shore-power transformers is the electrostatic shield between the primary and secondary windings, which prevents arcing between the two. The shield (though *not* rated for lightning strikes) must be capable of enduring surges of 4,000V for only one minute to comply with ABYC E-11. Unlike ordinary transformers, the windings for marine-rated units are typically potted in a mixture of sand and resin, a process that improves shock resistance and prevents water absorption. The shield is usually referenced to the shoreside ground; however, that measure is required only when wiring in the isolation mode.

No connections should be made to the AC safety ground wire located between the transformer and the inlet.

The inner workings and wire windings of an unpotted transformer are more likely to suffer moisture issues over their lifetime compared to a potted transformer.

No mention of transformer function would be complete without noting there is a high-frequency switching version. Instead of using hundreds of feet of heavy wire and iron cores, high-frequency switching transformers use electronic circuitry, in much the same way inverters do, to achieve isolation. They *may* (depending on the specifications), therefore, be smaller and lighter than traditional transformers of equal capacity. The units I've seen rely on fan cooling, while most conventional transformers do not. That means if the fan fails, the unit may shut down, and the vessel may, as a result, be without shore power. For applications where every pound counts, and cost is not a factor, they may make sense. Otherwise, the anvil-like ruggedness of traditional transformers would have greater appeal.

ABYC Transformer Guidelines

ABYC guidelines for transformer installations are predictably detailed and specific, including sections on overcurrent protection. The relevant sections are available as part of complete ABYC standards or, for the purposes of this article, on ProBoat's website at www.proboat.com. Follow them!

A few details are worth more expansive consideration. For instance, if a transformer is located within 10′/3m (a measurement of the wire, not as the crow flies) or less from a shore inlet, although a conventional circuit breaker is required, an ELCI (equipment leakage circuit interrupter) device is not. While that satisfies the

Overcurrent protection for transformers can be tricky. Read and fully understand the requirements spelled out in E-11. Err on the side of caution, and if in doubt, remember that it's safest to install a breaker, including an ELCI.

letter of the ABYC "law," bear in mind that for overcurrent protection, every foot (30.5cm) of wire between the inlet and the transformer relies on the dock-mounted circuit breaker, one that may be deteriorated, inadvertently oversized, not ELCI-equipped, and whose condition is unknown. Regardless of where the transformer is located, I recommend that my clients install a primary ELCI circuit breaker, as close as possible to the shore inlet.

One ABYC standard I often see violated is the need for a circuit breaker for the secondary, or output, of a transformer if it's providing split-phase 120V/240V service. This circuit breaker must be two pole, i.e., it opens both ungrounded or "hot" conductors, and it must be placed within 7″/178mm (again, a measurement of actual wire length) of the transformer. That distance may be extended to 40″ (1m), provided the conductors are supplementally sheathed or enclosed within a conduit.

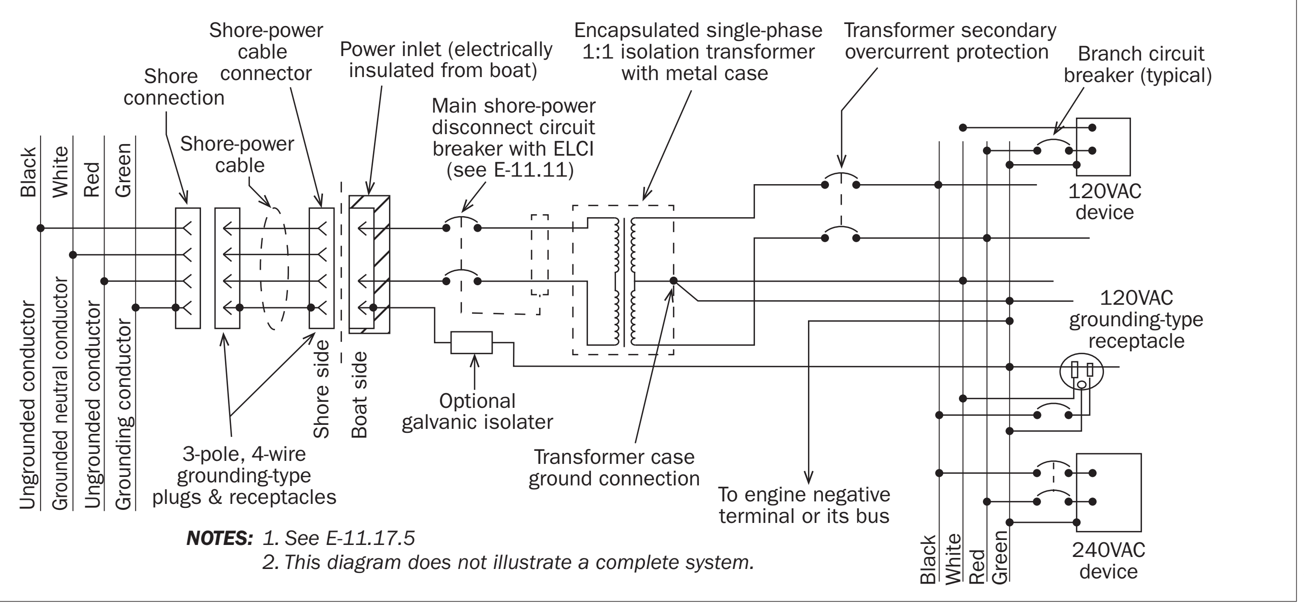
Polarization vs. Isolation

There are few but important distinctions between wiring a transformer for polarization or for isolation.

The primary difference is in its means of grounding. The *polarization* transformer's primary and secondary ground are connected, i.e., the vessel's onboard AC safety ground, bonding, and DC negative are common with the dock/shore AC safety ground (**Figure 1**). This affords the vessel a safe path for fault mitigation but no galvanic isolation, the type required to prevent corrosion induced from nearby vessels. So, a polarization transformer must include another device known as a galvanic isolator to deter corrosion (see the **sidebar** on page 109).

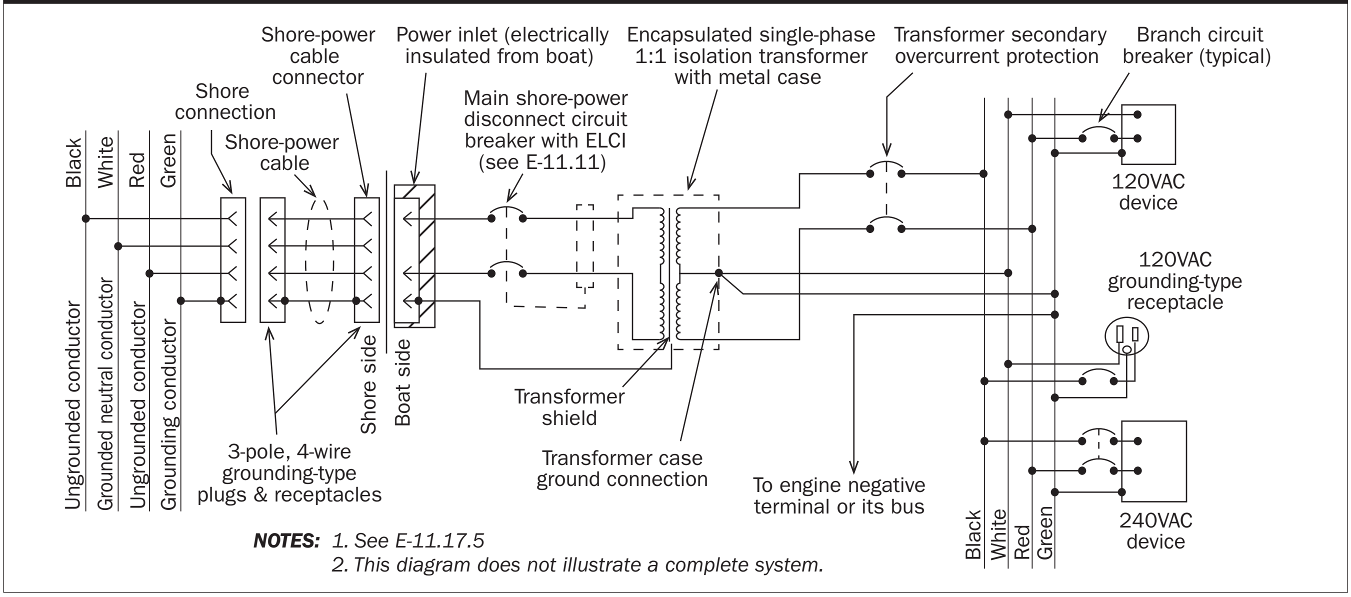
Conversely, in the *isolation* wiring configuration, potentially damaging galvanic current that normally would be allowed to come aboard, via the green grounding conductor in the

Figure 1. Polarization Transformer System with a Single-Phase 240V Input, 120/240V Output, and Shore-Grounded Secondary



Example of a shore-power installation using a 240V primary transformer wired for polarization. Note the presence of a galvanic isolator. This is required, as transformers wired for polarization do not provide galvanic corrosion protection. All grounded and grounding connections remain the same as that of the isolation configuration, with two exceptions: a grounded shield is not required, and the shore and vessel ground are common. The secondary neutral and the case are still referenced to ground.

Figure 2. Isolation Transformer System with Single-Phase 240V Input, 120/240V Output with Boat-Grounded Secondary, Transformer Shield Grounded on Shore, Transformer Metal Case Grounded on Boat



Example of a shore-power installation using a 240V primary transformer wired for isolation. Note the presence of an ELCI primary circuit breaker. This should be installed as close to the shore inlet as possible. Note also the locations of the shield and case grounds, as well as the secondary neutral, which is also grounded to the case and to the vessel's AC safety ground.

shore-power cable, is thwarted, because there is no longer *any* direct connection to shore-side ground or current-carrying conductors (**Figure 2**). The transformer's secondary is, in effect, the source of power, and thus the ground reference.

Either approach to wiring, if carried out in accordance with ABYC standards, offers the required level of safety, with a few caveats.

It is impossible to determine by casual visual inspection whether a transformer is wired in polarization or isolation mode. The identical, fully ABYC-compliant transformer may be wired either way following manufacturer guidelines during installation. Only by carefully inspecting the actual wiring connections and/or by using a multimeter can the mode be determined for certain.

The distinction between polarization and isolation also represents a marked difference between the isolation transformer and the galvanic isolator. Where the galvanic isolator blocks DC voltage (nearly all galvanic corrosion is DC in nature) from coming aboard up to a given threshold of about 1.4V, the isolation transformer severs this connection altogether, with no limitation. It's the most thorough electrical separation that can be achieved under these circumstances.

The onboard AC green safety grounding conductor originates at the secondary winding of the isolation transformer. As a result, primary and secondary ground—i.e., the shore-side ground and the boat's ground—have nothing in common. That eliminates the potential for "foreign" (originating *off* the boat) galvanic- and stray-current corrosion. Stray- and galvanic-current corrosion that originate *aboard* a transformer-equipped vessel remain potentially destructive and are not prevented or reduced by the isolation transformer, galvanic isolator, or any other device except a proper bonding system and general ABYC-compliant wiring procedures.

With the installation of the isolation transformer, all onboard bonding, DC grounds, and AC safety grounds remain unchanged. Also, because the transformer's enclosure cannot be connected to both primary and secondary grounds (doing so would eliminate its isolation and corrosion effectiveness), absolute attention to detail is a must when installing AC wiring through the transformer's metallic case—usually mild or stainless steel, for ABYC compliance. Accidentally connecting primary and secondary grounds could result in the case becoming energized without tripping a circuit breaker. Because the case cannot be referenced to both shore and boat ground, it's typically referenced to

Left—*One of the most common transformer installation faults involves inadequate chafe protection and strain relief where wires pass through the metal housing.* ***Right***—*This approach, using nonmetallic compression fittings, is ideal.*

the vessel, thereby presenting an electrocution hazard. Correctly configured, proprietary, and preferably nonmetallic strain-relief fittings must be used to eliminate the possibility of chafe or contact between an energized conductor and the unit's metal housing. In my experience, chafe protection alone is wholly inadequate for transformer-enclosure wire pass-through locations.

In accordance with ABYC recommendations, primary input cabling must be equipped with overcurrent protection—with few exceptions (see below), a circuit breaker that embodies ground-fault protection and is commonly referred to as an ELCI. This amalgamation of a circuit breaker and a GFCI-like receptacle offers ground-fault and overcurrent protection to the

Galvanic Isolators

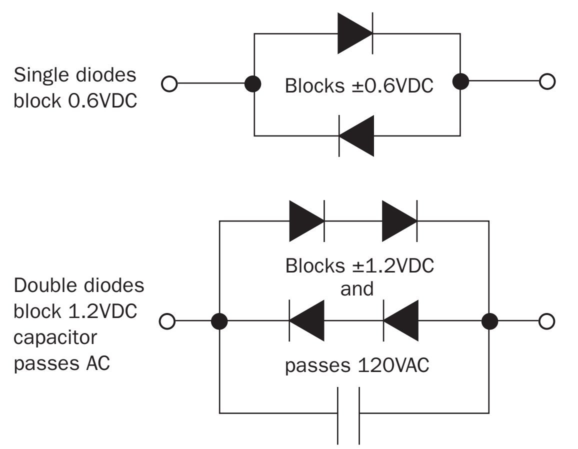
Select a galvanic isolator that meets the current ABYC standard for a fail-safe design, which continues to provide a safe path to ground for fault current even if it fails.

For boats fitted with polarization transformers (which afford no galvanic isolation), or for those that have no transformer at all, a galvanic isolator must be installed to deter corrosion caused by adjacent vessels, steel pilings, bulkheads, etc.

Among the most common corrosion-related misunderstandings is the role shore-power plays in this phenomenon. With rare exceptions, 120VAC and 240VAC shore power does not cause corrosion or rapid consumption of zinc anodes or underwater metals. Corrosion is primarily a DC phenomenon. The shore-power cord and the green safety ground wire it contains, however, often are an accessory in the process.

The moment a non-isolation transformer or a boat without a galvanic isolator is connected to a dock pedestal via a shore cord, and before the dock or vessel circuit breakers are turned on, a connection has been established between the boat—including all of its grounded underwater metals, zinc anodes, seacocks, shaft, strut, etc.—and the dock's AC safety ground, and thence, in theory, to every other boat in the marina and their underwater metals. Such an arrangement can wreak havoc with anode consumption rates and corrosion of underwater metals. If, for instance, the owner of the vessel in slip number one hasn't replaced his or her anodes in a year, but the owner of the vessel in slip number three has regularly inspected and replaced the anodes, they

Galvanic Isolators



The most effective galvanic isolators are fitted with a capacitor.

will protect both vessels, or several vessels, for a time, until they are depleted, which can happen rapidly.

Many boat owners, and some professionals, have asked, "Can't I just do away with the green wire and its connection to all the other boats?" The short answer is an emphatic No. That connection must exist to carry fault current back to its source, typically a transformer at the head of the dock. It's worth repeating: The green safety ground connection between the vessel and the dock and on to the transformer must not only remain in place, it must be sound and free of corrosion and excess resistance. Without it, there's no reliable, safe, low-resistance path for fault current to take back to its source, which in turn will, hopefully, trip a circuit breaker.

There is, however, an alternative: a galvanic isolator. This device is inserted in line with the green safety ground as it enters a vessel, typically between the shore-power inlet and the electrical panel. (Much like an isolation transformer, it's critically important that no connections be made to the AC safety ground between the galvanic isolator and the shore inlet, as doing so will negate its effectiveness.) The isolator's role is simple: allow low-level AC fault current to pass unimpeded, while blocking, to a point, DC voltage up to about 1.4V. With this approach, small AC faults are safely conveyed back to their source, while destructive galvanic DC current is blocked. With a galvanic isolator in place, anodes now protect only the underwater metals of their own vessel and not those of other vessels, and "hot marinas" are of little concern.

Be sure the galvanic isolator you choose is designed to be fail-safe, which means if it fails, it continues to provide a safe path to ground for fault current, and is compliant with the latest (July 2008) revision of ABYC Standard A-28. It's important to recognize that if a fail-safe galvanic isolator fails safe, as advertised, the device no longer provides corrosion protection, so test these devices at least annually.

—Steve D'Antonio

transformer's *primary* circuit installation—albeit with a significantly higher 30-mA trip threshold when compared to that of a common 5-mA GFCI receptacle. This device also serves to prevent electrocution and ESD in the event of a ground fault *between* the transformer and the shore inlet, where no protection is provided by the transformer.

ELCIs, also known as residual current devices, add a measure of safety to a transformer installation, particularly for the wiring between the shore inlet and the transformer itself, which is afforded no protection by the transformer.

Because the transformer behaves much like a power source, units wired for split-phase 120V/240V three-wire service must include overcurrent protection for the secondary, or output, wiring as well, and it must be installed within 40″ (1m) of the transformer, the closer the better.

Polarization transformers, on the other hand, maintain the shore-side ground connection. While these

Electrocution and Electric Shock Drowning

Unlike conventional electric shock, which causes the victim's heart to stop or to go into ventricular fibrillation as a result of exposure to a sufficiently high level of electric current, electric shock drowning (ESD) simply paralyzes the muscles so the victim can't swim.

In one well-known fatality from 1999, a nine-year-old boy was electrocuted as he swam adjacent to a marina dock in fresh water. He was wearing a life jacket, and his face never touched the water. His mother jumped in to save him and as she did so, her limbs and extremities went numb in an early stage of ESD. Had she been unable to swim away from the electric current field, she may have drowned. She was able to pull her son to the dock, where others helped pull them from the water, but it was too late.

The ensuing investigation determined that this tragedy occurred because of an electrical fault in a nearby unbounded/ungrounded boat. An improperly overcurrent-protected DC wire had melted into an AC wire and, in turn, allowed AC-shore-power current to leak into the DC system and from there into the water around the boat and the nearby dock where the boy was swimming. Because this was fresh water, the current made its way in a narrowly focused field back to its source ashore, and the boy entered its path.

As a result of the saline content of the human body, it is a much better conductor than fresh water—a comparatively poor conductor—and offers the leaking current a lower-resistance path.

Had the vessel with the electrical fault been properly bonded, it's likely this fatality would never have occurred, as the fault current would have passed safely ashore over the green safety grounding wire, where it would most likely have tripped the dockside circuit breaker. Similarly, if the vessel had been equipped with a shore-power transformer, leaking current would have returned to it rather than through the water, which also would have saved the boy. If no other lesson is learned, let it be this: *Never swim in a marina or adjacent to docks where shore power is present.*

—S.D'A.

transformers ensure correct onboard polarity in the event of a dockside fault, as well as reducing the likelihood of electrocution and ESD, they will do little if anything to prevent corrosion, because the connection between shore-side and vessel ground remains intact.

Advocates for polarization transformers point out that the units are safer than isolation transformers: Because their metal enclosures are connected to shore and to the vessel's grounding system, an unresolved ground fault to the case is nearly impossible. When used with a galvanic isolator, they too provide *a measure* of shore-induced corrosion protection (up to 1.4V of blocking voltage versus the infinite blocking ability of the isolation transformer).

Most shore-power transformers can be installed in either the isolation or polarization mode, depending entirely upon the ground-connection method. In either case, the installation must meet current ABYC guidelines and manufacturer-recommended installation schematics, which offer several options.

Take the Boost

Standard shore-power transformers offer what's known as a 1:1 power ratio, i.e., identical input and output. Optionally, transformers may be designed

For vessels equipped with polarization transformers, an associated non-ABYC-compliant galvanic isolator does not meet fail-safe requirements and should be replaced with an up-to-date model.

Manual transformer primary selection for shore inlet voltage is an option, but the onus is on the user to make the correct selection.

for either manual or automatic boosting capability. With this design, low dockside voltage can be boosted to a degree, reducing the detrimental effects, particularly for motors, and refrigeration and air-conditioning compressors. Thus, a standardized voltage of 208V (or less) on many docks, particularly in older marinas, could be boosted to 220V or more.

Most off-the-shelf boosting transformers are automatic. The user simply plugs the vessel in, and the transformer's circuitry senses the available power and controls internal switches to select the correct winding "tap" to achieve the needed boost, if any.

On manual boosting transformers, the user typically moves a rotary switch to select the known input voltage. Both work well; however, the manual version is fraught with the potential for sending damaging overvoltage into the vessel's electrical system if, for instance, the user forgets to switch from 208V to 240V input when moving to a dock that provides 240V. While electrically savvy do-it-yourselfers are free to take the manual approach, my advice is to avoid offering or agreeing to install this option. It's simply too risky.

Common 240V, 50-amp (often expressed as 12 kVA or 15 kVA, or kilovolt-amperes) transformers are typically wired for a 240V input or primary alone, from which they provide "split phase," i.e., 120V/240V from the secondary. For 1:1 nonboosting transformers, this can present a problem. If the primary voltage is 208V (and often less when voltage drop occurs on long docks, or in summer, when every vessel's HVAC is running), the split-phase output voltage will be no more than 208V/104V, which is below the voltage specified by most equipment manufacturers—for motors, and air-conditioning and refrigeration compressors. By contrast, a non-transformer-equipped, dockside split-phase circuit will yield 208V/120V. In some cases, a 1:1 transformer may in fact yield low voltage, and potentially lead to equipment malfunctions and failures. Lower operating voltage for motor and compressor circuits yields higher current, more heat, tripped circuit breakers, and potential damage to armatures. My advice to electricians, yards, and builders is to install only boosting transformers.

With more and more docks being equipped with pedestal RCDs, soft-start devices are becoming a necessity for transformer installations. This one can be added to any installation.

More Options

For transformers with a primary input of 240VAC, a useful option is to also include a 120V primary input. With this configuration, the transformer can be used when only a 120V, 30-amp or 50-amp shore-power supply is available, albeit at a diminished capacity of 3.6 kW or 6 kW. The beauty of this arrangement is the judicious use of 120V *and* 240V gear, even when no 240V power is available on the dock.

For transformers that have this 120V primary, the installer must include some external switchgear—a

Some transformers are available with a remote readout and controls, which can be mounted for more convenient monitoring and operation.

rotary switch, slide-lock circuit breakers, or automatic shore-power relays—to prevent inadvertently supplying 120V and 240V simultaneously to the transformer.

For vessels that use a transformer with a 240V primary and a permanently installed shore-power cord-reel system, yet another benefit is available: Standard shore cords used without transformers in split-phase applications have four wires—two hot legs, one neutral leg, and a safety ground. However, because 240V shore-power transformers require no neutral at the primary, this wire can be safely eliminated, making the cord smaller, lighter, and less expensive. However, for a standalone non-cord-reel shore-power cord, this three-wire approach could be disastrous: If this cord were inadvertently used to supply power to a vessel *without* a transformer, the result would be the equivalent of a "dropped neutral"—a dangerous scenario potentially leading to excessively high voltage, damaged equipment, and fire.

A limited number of transformer manufacturers produce units appropriate for either recreational or commercial vessels. While there are many industrial manufacturers of terrestrial transformers, none that I know of offers automatic boosting, and few produce units compliant with current UL Marine and/or ABYC standards. I recommend sticking with marine-industry-specific manufacturers, because they offer considerably better support.

Yet another option involves a soft-start device. With the advent of dockside residual-current devices (RCDs), it's not unheard of for a transformer-equipped vessel to trip the RCD if the power is engaged at just the wrong moment in the AC waveform. A soft-start device, available from some manufacturers as a built-in option or as an add-on, will typically solve this problem.

Many marine-specific transformer manufacturers also offer remote controls. They can be as simple as a series of visible lights in the cabin, so no one has to crawl down to where the transformer is installed. Alternatively, remote control and monitoring can also be handled by a smartphone or tablet via Bluetooth connection. For new builds and refits alike, remote control/monitoring makes good sense.

Finally, make sure your installations comply with transformer manufacturer instructions *and* ABYC standards. When you complete an isolation transformer installation, test its isolation function with a multimeter and/or inductive leakage meter. *Isolation*-transformer-equipped vessels should exhibit no leakage current when measured at a shore cord. If leakage is present, a bonding or ground connection might have been made between the transformer and shore inlet—a scenario that demands immediate investigation, as it would negate the transformer's isolation properties.

I also recommend photographing correct installations upon completion—especially wiring and cord grips—to establish a record in case a failure results from third-party modifications. PBB

About the Author: *A former full-service yard manager, Steve works with boatbuilders and owners and others in the industry as Steve D'Antonio Marine Consulting. An ABYC-certified Master Technician, he sits on that organization's Hull and Piping and Engine and Powertrain Project Technical Committees, and is also* Professional BoatBuilder's *technical editor.*

PBB Resources

(Not all transformer and galvanic isolator manufacturers offer ABYC-compliant and/or boosting models.)

Transformers

ANG: atlasmarinesystems.com

Charles: charlesindustries.com

Hubbell: hubbell.com/wiring device-kellems/en

Olsun: olsun.com

Ward's Marine Electric: wardsmarine.com

Nauti Tech (boosting transformers and rebuild kits): nauti-tech.com

Galvanic Isolators

DEI: dairyland.com

Newmar: newmarpower.com

Professional Mariner: promariner.com