Grounding and Bonding in Boats and Marinas

A Vital Link to Safety

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The September issue of Exchange featured an article that posed some questions regarding the practice of grounding and bonding on boats and in marinas. The writer solicited an invitation to provide a "non-technical, plain English reason for connecting the AC green wire to the DC Ground". We'll go one step further in this article and also include the technical details necessary to understand the current standards being used in the industry.

This article will deal with grounding and bonding as it applies to boats and marinas. References will be made to NFPA 70 (National Electric Code), NFPA 303 (Fire Protection Standard for Marinas and Boatyards, 2000 Edition), and American Boat and Yacht Council Standard E-11 (AC and DC Electrical Systems on Boats).

As we begin, a couple of accepted definitions are appropriate.

"Grounding" is defined as a common connection to Earth for the purpose of:
- Lightning discharge
- System voltage stabilization
- Reducing static and RF interference

"Bonding" refers to a common connection joining metal components to:
- Provide a low impedance ground fault path to trip a circuit protection device
- Prevent dangerous voltages from appearing on metal objects
- Provide a path for galvanic and DC stray currents

Keep in mind that these terms are often used interchangeably in the current lexicon. We will be focusing primarily on "Bonding" in its classic sense but may also refer to some aspects of this as "Grounding" (e.g. the green wire is called the ground wire, but it's actually a bonding wire by definition in most cases).

A recent incident should set the stage for our discussion. A quiet Memorial Day weekend turned tragic when a houseboat owner decided to install a new female plug on his shore cord so it would be compatible with his inlet receptacle. His boat was wired for 120vac but the cord was set up to supply 240vac. Please examine the result of his handiwork in the below pictures. Note that the green ground wire in first picture is taped back and not connected to the plug. In the second picture you can see that he inserted the red wire (the hot, ungrounded conductor) into the hole for the ground wire effectively electrifying the aluminum hull (and water surrounding the boat) *while eliminating the ground wire fault current return path.*

His wife and daughter were sunning themselves on the boat when they decided to go for a swim to cool off. After entering the water adjacent to the boat, they were both overcome by electric shock and drowned by the electric field established in the water.

This tragedy was the result of a ground fault and a loss of ground connection at the same time. This combination is what has resulted in numerous deaths in freshwater marinas nationwide. AC ground faults, along with ground system problems also result in boat fires each year. Faults in the bonding system of a boat, coupled with DC ground faults, contribute to significant cases of underwater metal corrosion.

So, there are 3 areas we are focused on: personal injury and death, fires, and corrosion of underwater metals. To put them in perspective, personal injuries and deaths occur less frequently but the consequences are catastrophic. On the other hand, underwater corrosion is far more widespread but the consequences pale in significance to personal injury. This analysis gives us a glimpse into what the priorities were in developing standards for the industry. ***Personal protection is the number one priority, hands down.***

With personal protection as the premise, let's examine exactly how grounding and bonding protect us from personal injury and fire in the marine environment. First, the green-wire ground system in the marina (really a bonding system) is designed to carry AC fault currents back the source (the transformer which supplies power in the marina). The impedance (or resistance) of this system must be low enough to cause a circuit protective device to trip without delay in the event of a fault on one of the loads supplied. When you have an AC ground fault on a boat, fault current will attempt to flow back to its source on the green ground wire. If the impedance of the ground wire run is too high (more than about a half an ohm), not enough current will be able to flow, meaning that the circuit breaker could take minutes, or even hours, to trip. This could result in excessive heat generation at the fault location, which can start fires in boats.

Also, by carrying off enough of the fault current (again depending on the impedance of the wiring) the ground system will keep the voltage potentials (touch potentials) on exposed metal components on docks and boats to a low enough level to prevent personal injury.

Key Summary Point #1: We must have a low impedance path to carry fault currents back to the source. This will keep the touch potentials of exposed metal components low enough to provide personal protection, and minimize the likelihood of fires by ensuring circuit protective devices operate without delay.

Now, let's look again at that situation mentioned in the September article. First, the only way a metal object connected to the grounding/bonding system on a boat can rise in potential is if the ground impedance back to the source is too high or the ground connection is missing. And this may not be too unlikely given the harsh environment the ground system lives in. In examining marina electrical dock systems, we routinely find receptacles with missing grounds, and ground systems with excessive impedance.

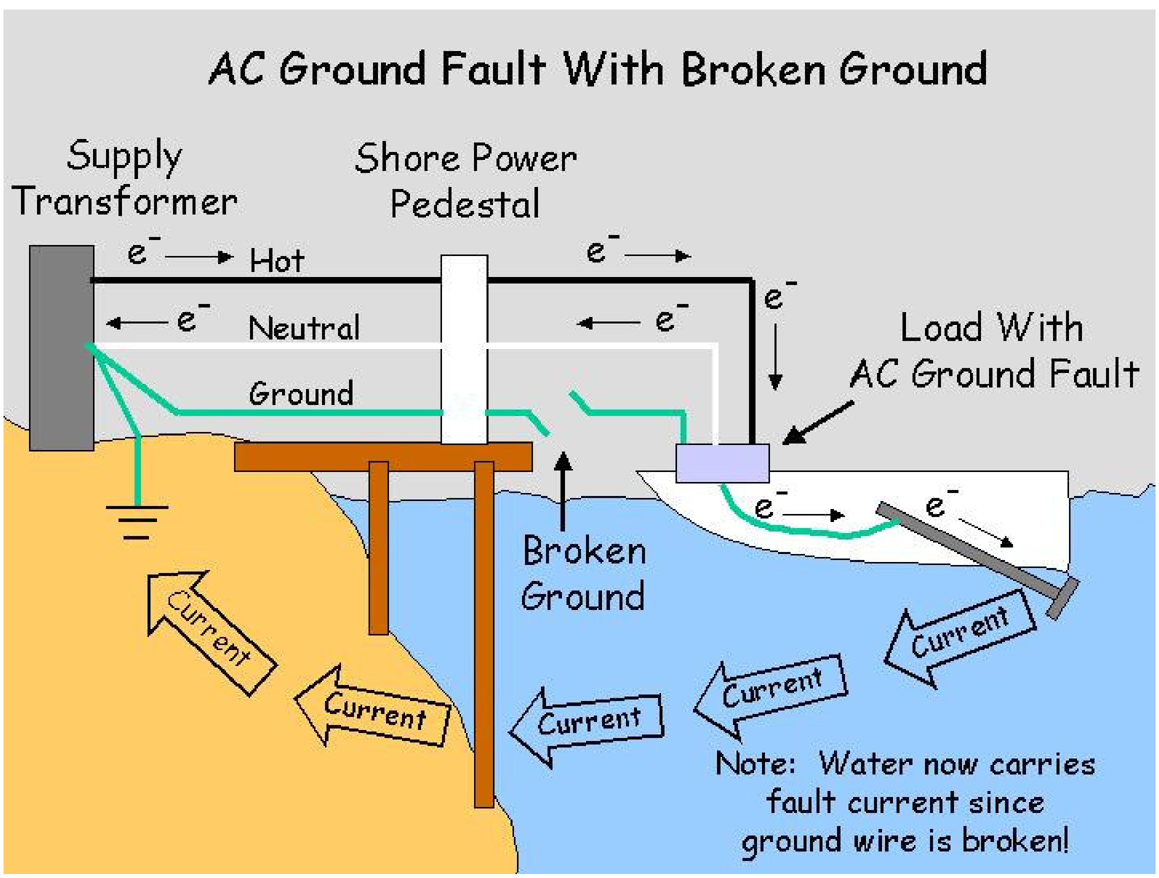
If a ground fault causes a metal or metal-cased component to rise to dangerous potentials (again, from loss or poor green ground wire), and a person touches this object along with another object at a lower potential, the person bridges the gap and receives a shock from the *difference* in the 2 potentials. NFPA 70 (National Electric Code) considers that potentials as low as 30vac are considered dangerous. This situation can produce lethal currents in the body. See the chart below for the effects of various current levels.

AC Ground Fault Effects

1 ma	Tingle
15 ma	Paralysis /Drowning
60 ma	Heart Failure
300 ma	Combustion
10 ma	= .01 Amps

The path for current flow in the above situation may not be all that obvious. Here goes: AC current originating from the source reaches the load on the boat and 'sees' the possible fault path due to the ground fault. Since current takes all possible paths back to the source (proportioned based on the resistance of each path), and in this case the ground connection is poor or missing, the current can pass through a person touching this object and another object which is in electrical contact with the water (like an engine block, strainer, shaft, etc.). Once in the water, the current will find its way back to the source because where the green ground wire is attached to the source at the transformer, it is also staked into the Earth as a *ground* connection required by NFPA 70. In the case of a marina, this fault current can get back to the source through the water and soil until it reaches the ground stake, or, it can also get back through the underwater fittings of other boats connected directly to the green ground wire ashore.

From the above discussion we have revealed another source of personal injury; the electric field in the water caused by AC ground faults. The good news is that this is of little consequence in saltwater since the water is so conductive that the human body does not represent a lower resistance path for current to flow. However in freshwater, AC ground faults are a real threat, and in fact are killers. Remember that as long as the green ground wire back to the source is of low enough impedance, water currents will be low and create little voltage gradient. NFPA 303 (reference by NFPA 70) specifically addresses this situation by requiring that the ground systems in all marinas be checked for integrity at least annually, along with visual inspections of marina wiring for compliance with code requirements. It also forbids personnel from entering the water in any marina where shore power is provided. Complying with NFPA 303 substantially reduces the likelihood of electric shock drowning. Please see the diagram below.



However, if all the metal cases of electrical equipment, along with all metal objects with a connection to the water, are connected (bonded) together, then if a ground fault occurs along with a faulty ground path, all these metals will rise in potential together. If you touch 2 objects that are at 120vac, you will not be shocked since there is no potential difference and no current will flow. This is what provides personal protection on the boat. This is the exact reason the ABYC standard recommends connecting the AC ground system to the DC ground system.

Key Summary Point #2: Connecting the AC and DC ground systems together, and bonding all metal components together provides personal protection from electric shock injury or death inside the boat. Personal protection in the water is provided by completing all required inspections and by prohibiting swimming in and around marinas.

Let's turn our attention to the last issue related to grounding and bonding on boats and in marinas. Again, keep in mind that the fundamental reason for grounding and bonding is to prevent personal injury and fire. Since it's not a perfect world, we must accept some of the corrosion-related concerns that stem from providing for a safe marine environment. Accepting this, there are many options out there for addressing these concerns to protect a boat from underwater corrosion.

The most significant form of electrically-induced corrosion we deal with is stray current corrosion. It's primarily a DC current phenomenon although recent research suggests that AC current can contribute to underwater metal loss (however its damage occurs much slower compared to DC). Simply put, stray current corrosion occurs when there are underwater metals at different potentials connected by an external means. This situation allows a current to flow (electrons in metals, ions in water) from and back to a fault source. This current flow is what causes the damage to these metals.

It follows by reason, that the way to prevent stray current corrosion is to ensure that all underwater metals are always at the same potential (same exact situation discussed earlier for exposed metal objects within the boat). No current will flow between metals at the same potential. The way this is accomplished in most applications is to connect all the underwater metals together, and preferably to a singe point. This single point is then connected to the negative of the battery ensuring all underwater metals are at the boat's ground potential.

Similar to the AC case it takes 2 faults to create a stray current situation. First, there has to be an electrical fault that attempts to drive the potential of an underwater metal component or bilge water in the positive direction. Then there has to be a fault in the bonding system. Typically this fault would be a poor or open connection in the bonding system that allows one or more underwater metals to become more positive with respect to others.

The interesting thing about stray DC current faults is that they not only can adversely affect neighboring boats plugged into shore power but can also cause corrosion in boats disconnected. These disconnected boats might just happen to be in the path for some DC waterborne current seeking to get back to its source. This will cause corrosion of the metal at the point of entry of this current.

A knowledgeable corrosion surveyor can detect stray current problems in a routine corrosion survey, after which action can be taken to correct the problems. A well-maintained bonding system will go a long way in preventing damage from stray current corrosion. It also serves as a conduit for providing cathodic protection to underwater metals on the boat, as well as a component of the "grounding" system for lightning dissipation.

Key Summary Point #3: Good bonding serves to minimize the likelihood of developing a stray current problem in a boat. It does, however, increase vulnerability to neighboring boats, whether plugged in or not, should a stray current situation develop nearby.

Finally, with the above in mind, we'll address some of the points brought up in the September article. The author states that he does not understand the difference in personal protection between using an isolation transformer (which does not use a direct connection to the shore green ground wire) and cutting the green wire in a boat directly connected to shore power (no transformer). As explained in this article, on a boat without a transformer, the fault current will travel in the water to get back to its source ashore. This water path is what completes the circuit allowing for the possibility of electric shock. With an isolation transformer, there is no water path back to the source (since the source is the secondary of the transformer on the boat!), so people on the boat cannot be part of a circuit for current flow.

Regarding hastening the demise of engine zincs as a result of an AC-DC connection and bonding on the boat, this can't happen. The water inside the engine cooling system is its own little "ocean". Any water current path is blocked by the rubber impeller of the water pump at one end, and by the voids in the exhaust system where the cooling water exits the boat at the other. In addition, all components on the engine block are at the same potential, since they are connected together. Thus, with no potential differences within the block, there is no force available to cause stray current flow within an engine that could in any way damage internal zincs.

Regarding the use of shaft savers, this is part of another highly specialized strategy that at least one manufacturer is using to provide for personal protection (both inside and outside the boat) while minimizing corrosion concerns. The rest of the strategy involves ensuring that there are no underwater metals in contact with the water that protrude into the inside of the boat. Non-conductive hull fittings are used in this application. But the need for a bonding system remains since the builder cannot control the actions of maintenance personnel and boat owners. What if the yard forgets to but the shaft savers back in? What if the owner installs a ground plate and connects it to the DC ground? Without a bonding system, if an unauthorized modification is made, an AC ground fault could once again cause personal injury.

Regarding RF activity causing corrosion, we could find nothing in the current literature to support this claim.

Regarding the use of 3-wire grounded plugs, they are still very much required by NFPA 70 and ABYC standards whenever an appliance is not double insulated and appropriately UL approved. There are numerous pieces of equipment used in boats that are typically not insulated (having exposed metal cases). These include hot water heaters, windlasses, battery chargers, water makers, inverters, along with myriad portable power tools available for maintenance. These items all have a ground wire or 3-prong grounded plug to ensure they are grounded in accordance with the standards to provide for personal safety.

Regarding the claim that Volvo has placed stickers on their engines indicating no connection to ground, we have contacted senior management at Volvo Penta and we are awaiting a response from the their technical staff. In the meantime we can offer that all Volvo engines on boats that we have analyzed in the field, including current year models, have had grounded engine blocks.

Summary:

The current industry standards define the grounding and bonding requirements that are essential for personal safety and to prevent fires. Deviating from these standards places personnel at increased risk in the marine environment.

Even when the standards are followed to the letter of the law, there are effective strategies to prevent or reduce the impact of electrically induced corrosion.

We appreciate the opportunity to address the marine professionals who subscribe to the Exchange and hope we have provided an understandable technical basis for appreciation of the vital need for grounding and bonding in the marine environment.

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