

# Understanding the Neutral-to-Ground Connection

## *It's Meaning and Consequences*

By Capt. David Rifkin, (USN-Ret)

An often misunderstood and misdiagnosed fault in the AC electrical system on a boat occurs when there is an improper connection between the neutral and ground systems. This fault represents a safety hazard and is not uncommon, especially in older boats. In this article we will examine how this fault occurs, the safety-related consequences of having this fault, and how it can be detected.

First, a little background is in order. The ABYC standards and the National Electric Code are consistent when they require that the neutral and ground only be connected at a “newly derived source.” In our case, this means that the connection is made at the marina’s electrical service entrance (which is a transformer ashore) and at the output of an operating generator, operating inverter (invert mode), or isolation transformer aboard the boat. When the operating source of power is aboard the boat (a generator), this neutral-ground connection is required to be aboard the boat. And when shore power is the boat’s power source, there must be no neutral-ground connections on the boat.

You ask, “why do we have to have any neutral-ground connections”? Seems like getting rid of all of them would eliminate a lot of confusion about when to have them and when they are illegal. Well, having this bond at the source provides a means for having an effective path to carry ground fault currents safely back to the source. For example, if a hot-to-case fault occurs on the boat, the green grounding (or “bonding”) wire in the shore cord and throughout a properly wired boat will provide an effective path for any fault current to return to the neutral-ground connection back at the source. This serves two purposes; first, it keeps the touch voltage low on metal-cased equipment, and second, it can cause enough additional current to flow in a short time to cause a protective action to occur (circuit breaker trip or blown fuse) and clear the fault. Normally, there is supposed to be no current flowing in the green grounding (or “bonding”) wiring in the boat’s system. (See diagrams on page 4).

### The Problem

Going back to our boat situation, when shore power is being used on the boat, those neutral-ground connections, which are required for generators and inverters, must be broken. Remember that for isolation transformers, the neutral (white wire) and ground (green wire) are permanently joined on the boat on the secondary side only of the transformer since it’s considered a newly derived source.

For generators, this connection is normally broken by an additional pole on the shore-genset selector switch. In the case of inverters, it is normally broken automatically inside the case when the inverter operates in the pass-through mode (i.e. when the actual power is coming from shore power and not from the batteries).

So, how does this fault occur on boats? There are numerous ways a neutral-ground connection is inadvertently established, which explains why it occurs on boats, especially those with modern appliances and older boats that have been “tinkered” with by unqualified electricians. Here’s how it can happen:

- *Improper load wiring in the panel.* When loads are wired into the AC panel, the installer may mistakenly attach a green grounding wire to a neutral terminal (white wires), or vice versa.

- *Improperly configured power source selector switch.* Use of a shore-genset selector switch without a dedicated pole to break the neutral connection when the “shore” position is selected causes the required genset neutral-ground bond to remain active when receiving shore power.

- *Improperly wired 240v appliances.* Many 240v appliances (clothes dryers, ranges and cook tops) use 120v to power lights, clocks and audible alarms. These devices often come from the factory with an internal neutral-ground bond so they can be used with older-style three-conductor re-

ceptacles. When these appliances are connected to a newer four-conductor receptacle, a neutral-ground bond occurs on the boat. The bond can also occur when using the older-style receptacles, depending on how the receptacle is wired. Most instructions explain when the internal bond should be removed.

### The Consequences

Now let’s examine the consequences of an improper neutral-ground bond aboard. In a properly wired and configured system, all of the supply current will return to the source via the neutral connection for 120v service, or a combination of the neutral and ungrounded (hot) conductors for a 240v service.

However, since the neutral is grounded at the source ashore, a neutral-ground bond on the boat establishes a new path back to the source that directly parallels the neutral conductor (since the neutral and grounding wires are now connected to each other at each end).

Effectively, we now have a second path for normal load currents to return to the source, this second path being the green grounding (or “bonding”) wire. The current flowing in this grounding wire raises the voltage potential of any grounded metal items on the dock to something above earth potential. This elevated potential creates a shock hazard to anyone touching anything grounded on the dock (like shore power pedestals, rails, metal docks, faucets, etc.).

But this dockside shock hazard is only one of the consequences. If the boat is wired to ABYC standards, the AC grounding system is connected to the DC grounding system by a grounding (or “bonding”) wire. This creates yet another parallel path for normal load current to travel back to the source: the water path.

Since the DC grounding system is connected to underwater equipment, and since the AC grounding system is staked to earth

ground ashore (at the same point where the required neutral-ground connection at the service entrance is made), there is a path for normal return current to flow through the water and earth back to the source ashore. This current can also jump back into a lower-resistance grounding wire system on the dock by using the underwater metal of other boats as the pathway!

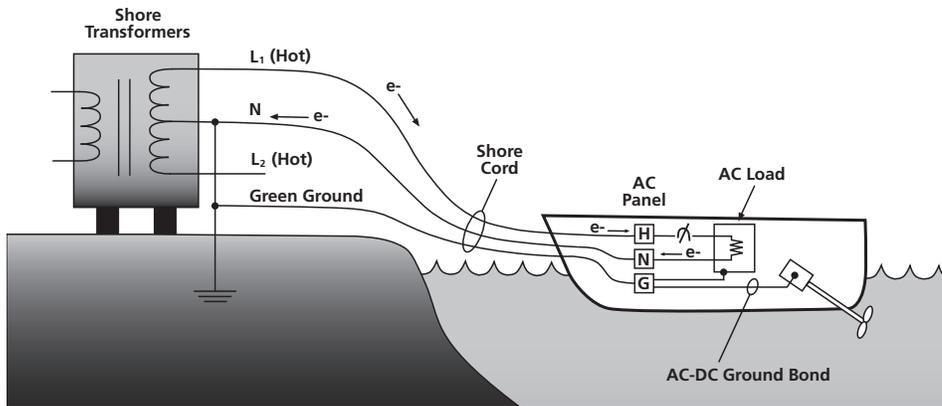
If the resistances of the conductors and connections in the neutral and grounding wires of the dock system and shore cords are low, most all of the load current will be carried by these conductors, and little will enter the water. However, considering the poor condition of wiring systems in many older marinas and boats, along with the condition of the many decrepit shore cord sets you see on the docks, you could have a recipe for disaster.

If the water return path becomes the lowest resistance of the three paths (neutral, ground, and water), then the water path can see a majority of the return current. Note that current doesn't take the least resistance path back to the source, it takes all paths. The most current will flow, however, in the path with the lowest resistance.

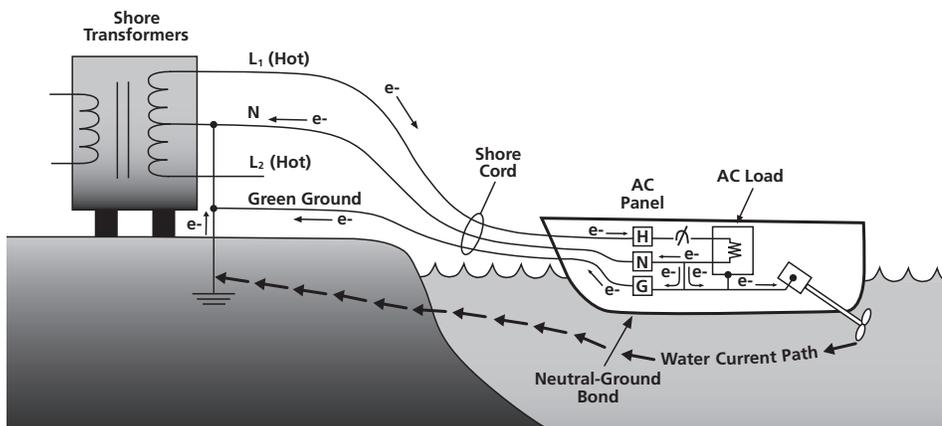
Current flow in freshwater means that the voltage potential on underwater equipment has risen significantly. The electric fields established can be strong enough to paralyze (which causes drowning) or even electrocute someone in the water near the boat. In saltwater, the high conductivity of the water will keep the voltage potential on underwater metals relatively low (saltwater is a good conductor) therefore the personnel hazard is not as acute as in freshwater. But be assured, a diver receiving a "tingle" while

circuit. (Reverse polarity indicators are not required for 240v shorepower systems.) Since the neutral is not provided with overcurrent protection at the main breaker on boats powered by 240v, there is no overcurrent protection available to disconnect the source. Conductors will burn, and fires are likely to start very quickly. This situation occurred a couple years ago at a local marina in NE Florida, starting fires and destroying several boats (predictably, they were all older boats, and neutral-ground connections were detected on those that still had a relatively intact electrical system).

A similar issue exists with 120v systems. If a boat without a double-pole main supply breaker onboard (required by ABYC standards) also has an improper neutral-ground connection and is then plugged into shore power with reverse polarity, the same direct short as discussed above occurs. In this case, until a dock circuit breaker trips, wiring in the boat's ground system is likely to burn and possibly cause a fire.



**Proper boat:** "This illustration shows a properly wired boat receiving 120volt service. There are no ground faults, or neutral-ground connections therefore no current is flowing in the green grounding wire. Note that the required bond between the AC-DC ground systems is intact on this boat."



**Improper boat:** "This boat has an improper connection between the neutral and ground systems on the boat. This not only creates a second parallel path for current to flow back to the source in the green grounding wire, but also a third parallel path back to the source via the water."

changing anodes in saltwater, could be seriously injured or even killed working on the same boat in freshwater.

The last potential consequence of a neutral-ground connection on a boat is fire. This

can happen during maintenance on the marina electrical system. If a maintenance error is made that inadvertently connects an ungrounded (hot) conductor to the neutral system ashore, the neutral-ground connection on the boat represents a direct short

## The Survey: Does a Fault Exist?

Determining if a neutral-ground fault exists on the boat you are working on or surveying is a matter of making a simple test with a digital multimeter. With the boat unplugged from shore power (see safety note below), measure the resistance between the neutral and ground buses in the panel, or access these two points at any convenient AC receptacle on the boat (the large slot on the receptacle is the neutral). This reading should be greater than 25kohm. Typically the reading will be close to zero ohms if a neutral-ground connection exists.

*Important safety note:* If the boat has an inverter, make sure the fuse is removed from the DC supply conductor before proclaiming the boat's AC system is deenergized. Inverters can sleep through meter voltage checks on receptacles and come to life when your ohm meter, or you offer a lower resistance and put a load on the system!

In summary, neutral-ground connections represent a safety hazard in the marine environment. Wiring errors usually create this situation. These faults are relatively easy to detect and correction should be made on a priority basis. Adhering to the ABYC electrical standards during maintenance and installation, and inspecting to these standards during surveys will provide the safest possible environment for your clients while enjoying their pastime. I can be reached at [QualityMarineSvc@comcast.net](mailto:QualityMarineSvc@comcast.net) for more information.