Electric Shock Drowning

By Alan Hosler

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What is Electric Shock Drowning ESD?

(ESD) is the result of the passage of low level a-c current through the human body causing skeletal muscular paralysis rendering even good swimmers unable to help themselves. The majority of ESD near-misses and deaths have been associated with marinas and public and private docks. ESD is a risk only in fresh water.

ESD is usually caused by an undetected ground fault (i.e., a short between the 120 v a-c hot side [black wire] and a grounded component) that results in a submerged metal part of a boat or dock (e.g. the boat prop and shaft or the dock ladder) being energized. This ground fault will produce a voltage gradient in the water. For a gradient of 2 volts/foot the resulting current flow through a swimmer will be about 12 ma. This much current may lead to loss of muscle control or ventricular fibrillation making it difficult for the individual to swim or even call for help. The condition is referred to as electric shock drowning and not electrocution because there is no physical injury and the individual usually drowns. There has been at least one event where the voltage gradient was so severe that the individual was electrocuted and he was left floating in the water wearing a personal floatation device (PFD) (Ritz 2009).

A typical ESD scenario is:

- Victim enters fresh water with an a-c voltage gradient.
- Victim may become disabled and/or can't call for help.
- Victim may make the situation worse by seeking a safe haven if that effort brings the swimmer closer to the source of the electric current.
- Victim, not being able to swim and not wearing a PFD, goes under.
- The event may be documented as a simple drowning if there are no witnesses (i.e. the electrical aspect is missed).

How much of a risk is ESD?

The American Boat & Yacht Council (ABYC) categorized 21 fatalities and 28 near misses that occurred over a seven-year period. Not included were events that were the result of faults with the dock electrical system that have also resulted in several ESD deaths. Because ESD is usually only be identified as a cause if there was a witness, it is believed there have been many more cases of ESD that were attributed only to drowning.

What can go wrong on my boat that would increase the probability of an ESD?

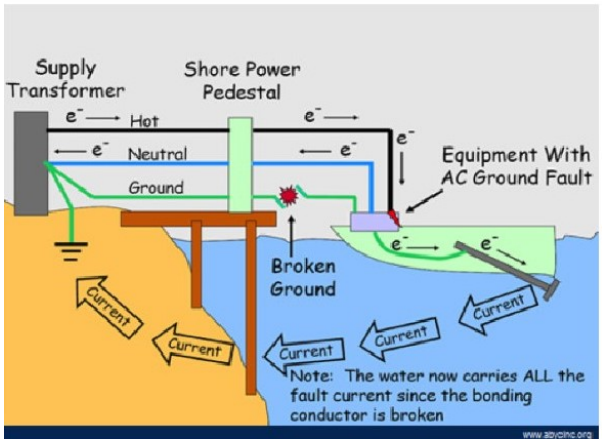
First it must be understood that a-c current follows all available paths to return to its source. It does not simply follow the path of least resistance. For a dock or marina, the source is usually an on-shore transformer where the neutral and ground are connected. When things are working as they should, this return path is through the a-c neutral (white wire).

For a boat to impose an a-c voltage gradient in the water, two conditions must occur:

1. There is a ground fault (i.e., a short between the 120 volt a-c hot side and a grounded component).
2. The a-c safety ground has failed.

When these two conditions exist, a current path will be present from the energized submerged component, through the water (and maybe a swimmer) and then through earth back to the on-shore transformer.

The a-c safety ground system is designed to cause circuit protective action, or reduce touch voltages to non-lethal levels, in the event of a ground fault. For fresh water, if a ground fault condition is present but the safety ground is functional, then about 95% of the leakage current will be routed back to the on-shore transformer through the safety ground. For this case there will be no consequences to the swimmer. But if there are both the presence of a ground fault and the failure of the safety ground, then the return path will be though the water. This condition is shown in the drawing to the right (approval to include this drawing provided to the author by Capt. David Rifkin). If there is a swimmer in the water, then most of the electric current will pass through the body of the swimmer because the electrical resistance of the human body is less than that of the fresh water.



How can ground faults be produced on my boat?

- Wire insulation failure(s) between the 120 volt a-c hot side (black) wire and ground.
- Failures internal to equipment, such as hot water heaters, battery chargers and inverters.
- Direct contact between an exposed shore power conductor and the water.
- Wiring error such as connecting the a-c hot side to the d-c ground or connecting the a-c neutral to ground.
- Other conditions such as reverse polarity on the dockside.
- Problems with the dock electrical system.

If you are in the water and suspect an ESD condition:

- Don't swim towards the dock.
- Try to stay upright with limbs close to your body (to reduce the voltage gradient).
- Swim back out the way you came in and exit water at least 150 ft away.
- Warn others who are in the water.

If you Witness an ESD condition:

- Call for help, 911 and/or Channel 16.
- Don't pull the person toward the dock.

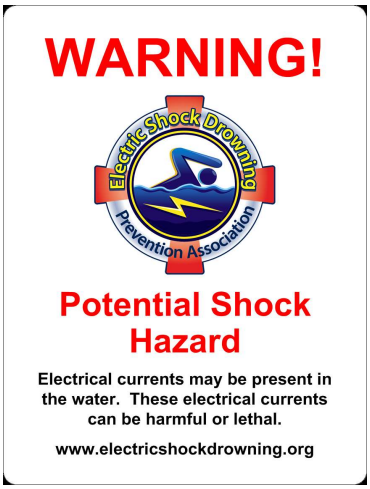
- Don't enter the water; use a boat to get to the victim if necessary.
- Turn off shore power and/or unplug shore power cords.
- Perform CPR if necessary.

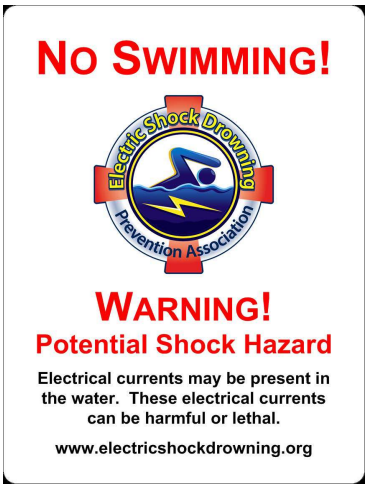
The 2017 Edition of the National Electrical Code (NEC), Article 555, "Marinas, Boatyards, and Commercial and Noncommercial Docking Facilities" requires a sign that states;

"Warning - Potential Shock Hazard. Electrical currents may be present in the water".

Article 555 applies to docks associated with one-family dwellings, two-family dwellings, multifamily dwellings, and residential condominiums; any multiple docking facility or similar occupancies; and facilities that are used, or intended for use, for the purpose of repair, berthing, launching, storage, or fueling of small craft and the moorage of floating buildings. A link to excerpts from Article 555 can be found at;
http://www.electricshockdrowningmn.com/2017_NEC.html

The following are two versions of signs that satisfy Article 555. The graphics for the signs can be obtained at http://www.electricshockdrowning.org/esd--faq.html (under "ESD Resources".)





Interesting Aspects of ESD

1. **Not a saltwater concern** – Lethal voltage gradients are not normally achieved in salt water. Because salt water is a relatively good conductor of electricity, most of the current will flow around the human body rather than flow through it. Of the 21 fatalities and 28 near-miss ESD events mentioned above, none occurred in salt water.

2. **More of a concern for wood and fiberglass hulls than metal hulls** - The voltage gradient typically varies inversely to the surface area of the energized metal. It takes a much higher level of a-c leakage current to cause dangerous conditions as the

surface area of the energized metals increases. Thus, a small fiberglass runabout is of greater risk than a large metal-hulled houseboat.

3. **Not a concern for a boat away from shore** - The ESD hazard exists for shore-derived a-c power. It is not present away from the marina or dock because a-c current always flows back to its source, and for a boat away from shore, the source is on the boat (the boat's inverter or generator) so there is no significant current flow though the water.

4. **Not a concern for d-c leakage.** The cyclic nature of alternating current disrupts the minute electrical signals used by our nerves and muscles much more than continuous flow of d-c. There have been no recorded ESD events from 12 or 24-volt d-c systems.

What near-term actions can be taken by marinas and private dock and boat owners to reduce the probability of ESD?

Awareness. Inform those using marinas and docks of the threat of ESD via presentations and printed material.

Prohibit swimming in marinas and near docks with a-c power. Signs could be installed that state "No Swimming, Warning! Potential Shock Hazard. Electrical currents may be present in the water. These currents can be harmful or lethal." As discussed above, such a sign (minus the" No Swimming") is required by the 2017 Edition of the NEC.

Periodically test boats for a-c leakage into the water. This can be done by testing boats for unbalanced current flow in the shore power cables using a clamp-on ammeter. The meter should be one that indicates current flow to two decimal places. Both a Blue Sea Systems 8110 and a Hioki 3280 are good for this purpose. When the electric power system on the boat is functioning properly, the a-c current going to and from the boat will be equal, and the ammeter clamped around the power cable will indicate zero current. However, if current is leaking into the water, then the current returning from the boat will be less than the supply current, and a non-zero reading will be obtained. While any reading is an indication of something wrong on the boat that needs correction, a reading of 100 ma or greater creates a risk of ESD. This testing should be performed with as many a-c loads connected as practical. In particular, space heaters and water heaters should powered with a demand for heat. Also, battery chargers and inventers should be connected. If the boat has two shore power feeds, then the meter should be clamped around both.

Periodically confirm the integrity of the boat's bonding (grounding) system. As discussed above, in addition to a short to ground, a boat must have a failure of its grounding system to present an ESD risk. This testing could reveal those boats with bonding system faults such as broken bonding conductors, failed open circuited galvanic isolators and corroded or damaged receptacle connections. For more information on grounding and bonding see Rifkin and Shafer.

Inspect shore cords for compliance with NFPA 302, NFPA 303 and ABYC E-11. These codes collectively require that shore power cords have molded and locking connectors at the shore end. Such a connector is also required at the boat end unless the shore power cable is permanently connected to the boat. NFPA 303, Section 50.2.4 also states "The use of tape to repair broken or cracked insulation of jackets on flexible cables or cords shall be prohibited." These codes also require that the cords be rated for 30 or 50 amp service.

Install Ground Fault Protection. Install Ground-Fault Interrupter (GFI) devices that provide ground fault protection not exceeding 30ma. This is a requirement of the 2017 Edition of the NEC, Article 555, "Marinas, Boatyards, and Commercial and Noncommercial Docking Facilities." This is a change from the 100ma requirement of the 2014 edition of the code.

Install isolation transformers. Boat owners could install isolation transformers. As explained above a-c current will follow all available paths to return to its source. With isolation transformer, the source is internal to the boat (the technical term is “a newly derived power source”). Thus, if there is a short to ground on the boat, the current will return to the transformer and not through the water to the on-shore transformer.

References:

Rifkin 2005 - *Understanding the Neutral-to-Ground Connection*, *Its Meaning and Consequences,* Capt. David Rifkin, (USN-Ret).

Rifkin and Shafer – *Grounding and Bonding in Boats and Marina, A Vital Link to Safety*, Capt. David E Rifkin and James D. Shafer.

Ritz 2009, *A Preventable Dockside Tragedy*, http://www.boatus.com/seaworthy/magazine/SeaOct09.pdf