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Electric Shock Drowning

Electric Shock Drowning Phenomenon

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Swimmers or other persons in the water may be at risk from a phenomenon commonly referred to as "electric shock drowning" (ESD) when in the vicinity of a boat plugged into shore-side electricity (shore power) and on which an electrical fault has occurred, creating electrical current in the water.

ESD is typically the result of low-level alternating current (AC) passing through the body while immersed in fresh water. It only takes a very low level of electricity when a person is in the water to cause muscular paralysis or cardiac arrest. The victim usually ends up drowning. ESD can happen in any water but is far more dangerous in fresh water due to the lower electrical conductivity of fresh water than salt water. Higher levels of AC current leakage in the water are equally or correspondingly more dangerous but not as common since high level ground faults are more likely to trip a circuit breaker, thereby shutting off the electricity.

Many drownings caused by ESD are not properly diagnosed or investigated. ESD generally reveals no evidence as cause of death during an autopsy, so the actual cause of death – AC electricity in the water – goes undetected. Many people are unaware that swimming from an energized dock or from a boat plugged into shore power is dangerous. In some cases, individuals who entered the water to help a victim have themselves become a victim of ESD.

How ESD can happen

In a properly installed and functioning electrical system on a boat, all of the AC current that goes into the boat through the shore power cord also returns to its source of ground potential through the shore power cord. (The source of electricity being the transformer located on the dock or on shore where it originated.) For any AC current to wind up in the water, three things must occur:

1. An electrical fault (a "ground fault") must be present on board the boat: AC current that finds its way out of its proper circuit and into the water will try to return to its source (the dock- or shore-side transformer). An electrical fault may be referred to as a "short" or "short circuit", a "ground fault", an "AC fault", "fault current", "residual current", "stray current", a "non-zero sum" current, or other term meaning AC current is returning to ground potential along an unintended or alternate pathway.
2. An AC safety grounding circuit fault: A defective AC safety grounding circuit results in fault current that cannot easily return to ground through the grounding circuit (commonly referred to as the "green safety ground" conductor). The safety grounding circuit includes the grounding conductor in the boat's AC wiring circuits as well as the grounding conductor in the shore

power cord. The green safety grounding conductor does not normally carry any AC current, but is installed as an alternative path back to ground potential in the event of a ground fault. Without an effective, low resistance grounding circuit, any stray electricity then has only one path back to its source – through the water.

3. The boat is not equipped with a ground fault protection device: Any ground fault current returning to its source through the water will create a detectable difference (unbalance) between the amount of current supplied to the boat and returning from the boat through the shore power cord. A ground-fault-protecting device (a ground fault circuit breaker, a ground fault circuit interrupting outlet, a residual current device, an electrical leakage circuit interrupter, etc.) can detect differences measured in milliamps and shut down the electricity within a fraction of a second. If the circuit does not have ground fault protection, then electricity will continue to flow into the water unless a conventional circuit breaker trips.

If the conditions noted above exist (and a circuit breaker doesn't trip), then underwater metal objects will be energized, including propellers, outdrives, drive shafts, rudders, struts and more. It is not uncommon in this case for metal handrails, fuel fill and other deck fittings and other metal objects – both above and below the water – to become energized. Electricity in the water will radiate out from any energized metal object. The "radius of influence" or span of influence of electricity in the water might be 20 feet or farther from the boat or other source depending on the electrical conductivity of the water and the amount of current.

Discussion of shore power and on board electrical systems

As a simplified discussion, dock side AC shore power leaves its source (from the dock- or shore-side transformer) on the hot black wire (the ungrounded conductor) and it normally returns to the source of ground potential on the white neutral wire (the grounded conductor); the third wire in a common AC circuit is the green safety ground wire (the grounding conductor that is intended to take any stray or fault current back to its source). At the source of power – the transformer – ground potential is established by connecting both the neutral conductor and the safety grounding conductor to a metal rod (a grounding rod) installed or driven into the earth. Remember this point: For dock-side shore power, the neutral and the safety ground are connected together – but only at the source of power – never on board a boat or at any on board appliance.

To understand how AC current can energize underwater metal objects on a boat in the case of a ground fault, one must note that the grounds for both the AC and DC electrical systems on board should be connected. The AC green safety grounding conductor and the DC black or yellow negative conductor are connected at the common grounding bus or engine block. The reason both systems are tied together is, in the case of a short circuit between the AC and the DC systems, most of the electricity will try to return to its source of ground potential through the AC green safety grounding conductor while hopefully tripping the circuit breaker and shutting off electricity to the boat. Without the AC and DC system grounds tied together in the event of a short circuit between the two, the only path back to ground potential is through the water.

To function properly, the AC green safety grounding conductor needs to offer near zero resistance back to the source of electricity (back to the transformer grounding rod) so that any electrical leakage returns via the conductor and not through the water.

Domestic electrical appliances often have grounding straps that connect the white, neutral (grounded) conductor to the green safety (grounding) terminal for home use. If such an appliance is used on board a boat, this connection must be removed – but often isn't. The prohibited neutral-to-ground connection is sometimes found as both conductors connected together on the appliance itself under one terminal screw or a connecting strap on the appliance between the two conductors.

As mentioned above, the white neutral and green grounding conductors of an AC shore power circuit are connected together only at the source of power (the dock- or shore-side transformer ground rod). With other sources of on board power, the neutral-to-ground connection is, again, only made at the source – for onboard generators and inverters it is at the generator or inverter; with an isolation transformer it is at the secondary winding of the transformer. There must never be any connection between the neutral and grounding wires at any other point on board.

When plugged into shore power, if the neutral conductor is (inappropriately) grounded on board and the boat is then connected with reverse polarity (either through improper wiring dock-side, or through an improperly wired shore power cord, wired improperly on board or somehow plugged into the wrong type shore power receptacle) any neutral-to-ground connection on board will cause the AC grounding circuit to become energized. If this circuit is connected to the DC negative (as it should be as described above), the entire DC negative circuit will become energized, creating an electrical shock hazard both on board and in the water. If this happens, on board circuit breakers will probably not trip since the resistance of the water may not allow sufficient current flow to trip a circuit breaker. The resultant ground fault current into the water can be more than enough to kill someone in the water.

If a boat has two shore-power inputs, the two AC neutral circuits on board must always be isolated from each other. If the neutral conductors are connected on board and one of the shore-power connections is plugged in with reverse polarity, all conductors on the other shore power connection would be energized.

Differences in electrical standards and practices on shore and on board a boat can lead to ground fault currents in other ways including:

- An individual not qualified to work on marine electrical systems may inadvertently connect neutral to ground on board as they do on shore. Because the AC green safety conductor is connected to the DC negative conductor on the boat, the water may become energized in the event of a ground fault.
- A neutral-to-ground connection may exist on household appliances used on board. If this type connection is not removed, any fault in the grounding system will allow ground fault current to pass to the DC electrical system and out through underwater metal objects into the water.
- When using an onboard generator, inverter or isolation transformer as the source of power, a qualified marine electrician should verify that the neutral-to-ground connection is made only at the source of power. In the case of an on board power source installed correctly, any ground fault current trying to return to the source will stay on the boat and not enter the water unless another boat (with an electrical fault) is plugged into the boat supplying the power (via another shore power cord or extension cord).
- If AC and DC electrical conductors are mixed on the same panel, the potential exists for AC current to be introduced into the DC system through a short circuit or ground fault, which could then energize metal objects on board – both underwater and above water.

- An unqualified individual might not realize that a black conductor could be either an AC ungrounded wire (the AC "hot" wire) or a DC negative wire. Connecting the two in any way will energize metal objects and the surrounding water.
- Be aware of boats which may not have been built to current safety standards or that have had electrical work performed by unqualified people.

Residual current leakage

Residual current is sometimes referred to as a "non-zero sum". This is in reference to the current balance between an AC hot, or ungrounded conductor, and an AC neutral, or grounded conductor. If all is well, the current differential between the two should be zero; that is, they balance perfectly. In the case of a ground fault or electrical leakage within an AC device or circuit, then some of the current will be carried by an alternate path to ground potential (via the green safety grounding conductor, the water, etc.) indicating a non-zero sum between the hot and neutral. This condition is commonly referred to as residual current leakage. This type of current leakage is frequently not enough to trip a circuit breaker. Residual current leakage can occur while every electrical device or system on board still appears to operate normally. However, cumulative residual current leakage, if not carried away by the AC green safety conductor, can energize underwater metal objects to the extent it can cause ESD.

- Sources of residual current leakage on board a vessel can be almost any, or most, AC electrical appliance- electric ranges, air conditioners, freezers, refrigerators, hot-water heaters, battery chargers, inverters, fans, etc. As items age, residual current leakage becomes more probable.
- Houseboats in particular typically have many circuits and many appliances; cumulative residual current leakage frequently exceeds 30mA.

Effects of electricity on a swimmer in fresh water

The human body has a saline content similar to saltwater and is a comparably good conductor of electricity. Swimmers in fresh water present a much lower resistance to AC fault current than the fresh water itself; the human body will conduct the majority of whatever current is available in the water. Due to the resistance offered by fresh water to fault currents trying to return to ground potential, the fault current takes a "shortcut" through the human body.

Dipping one's hand or foot into fresh water that is energized by an AC fault current may result in an uncomfortable tingle (or worse). But when the human body is immersed wholly in fresh water, AC current can be extremely dangerous because of the whole-body conductivity to electricity and disruption to the nervous system. The following table illustrates how dangerous even very small amounts of current can be.

- Current (milliamp / mA): 1 mA = 0.001 ampere (amp);
- Based on the table below, 1/10th of one amp exposure to AC can cause cardiac arrest.
- Consider that the lowest standard for shore power is 30 amps = 30,000 m/A

Electric Shock Effect on a Swimmer:

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Effect:	Alternating Current (AC)- Milliamp (m/A)	
	Male	Female
Slight Sensation	0.4	0.3
Perception threshold	1.1	0.7
Perception level, slight tingling sensation.	1.0 m/A	
Shock, not painful, no loss of motor control	1.8	1.2
Slight shock felt; not painful but disturbing. An average individual can let go.	5 m/A	
Shock, painful, still no loss of muscular control	9	6
Shock, painful, voluntary ability to “let go” threshold	16	10.5
Painful shock, threshold of the “freezing” current or the ability to let go.	6 – 16 m/A	
Shock, painful and severe, uncontrolled muscular contraction, great difficulty breathing	23	15
Extreme pain, respiratory arrest, severe muscular contractions. Individual cannot let go of an electrified object. Death is possible and even likely.	17 – 99 m/A	
Shock, probable ventricular fibrillation of the heart following 3 seconds exposure	100	100
Ventricular fibrillation, cardiac arrest, internal organ and nerve damage. Death is likely and even probable.	100 – 2,000+ m/A	

Mitigations to ESD

Some methods and strategies to mitigate ESD are noted below:

- Do not swim in a marina or around a dock equipped with shore power; don’t allow children to swim in a marina.
- Never dive or swim from your boat when it is plugged into shore power to change a propeller, untangle a mooring line, to retrieve a lost item or for any other reason. If you must enter the water, turn off or unplug all shore power to your boat and all others in the area.
- Do not enter the water to help a swimmer if electrical leakage or ESD is suspected.
- A person in the water experiencing a tingling or sensation of shock should swim AWAY from the dock and boats that are plugged into shore power.
- Frequently inspect your shore power cords for damage, signs of excessive heat, fraying or split insulation, electrical arcing or burned connectors. Never use “homemade” shore power cords.
- Do not allow work to be performed on your boat’s electrical system by anyone not a qualified marine electrician.
- Always make sure the shore power receptacle is the same configuration and rating as the shore power cord. Do not force a shore power cord into a questionable or unlabeled shore power outlet.
- Inquire if your marina’s electrical systems are inspected at least annually by a qualified marine electrician in conformance with National Fire Protection Association (NFPA) standards.

- Have the electrical system on your boat inspected annually by a qualified marine electrician. Promptly have a qualified marine electrician correct any deficiencies noted.
- Completely isolate the AC shore power system from the AC system on the boat by equipping the boat with an isolation transformer. An isolation transformer is a transformer used to transfer shore power to a boat while isolating the boat from the power source. An isolation transformer also provides galvanic isolation and is used to ensure a boat cannot leak AC electrical current into the water.
- Inquire and insist that the marina shore power system features ground fault protection as required by the NFPA for current dock construction. Older docks may not feature ground fault protection. One method for achieving ground fault protection of the shore side electrical supply is to ensure each shore power pedestal is equipped with a ground fault protection device with a 100 m/A trip level.
- Ensure your boat is equipped with an "Equipment Leakage Circuit Interrupter" (ELCI) or Type A "Residual Current Device" (RCD). An ELCI or RCD is installed on board at the main shore power inlet for whole boat protection against AC current leakage. In the event of an AC ground fault, these devices trip at a maximum of 30 m/A.
- If using a household type extension cord around the water or on board your boat, make sure it is plugged into a convenience outlet featuring "Ground Fault Circuit Interrupter" (GFCI) protection. GFCI-protected outlets generally trip around 6-10 m/A in the event of a ground fault.
- Ensure appliances on board are "marine rated" or designed for marine use. If they are not, ensure a qualified electrician inspects each appliance to ensure there are no neutral-to-ground connections at the appliance.
- Use only electrical devices and electrical cords on board which are "polarized"; that is, the male plug features one blade which is broader than the other blade which aligns the device (load) with the correct polarity of the electrical receptacle.

While not the only reason to not swim in a marina, the risk of ESD is by itself a compelling reason not to swim in a marina.

Do Not Swim Near Docks
Water And Electricity Do Not Mix!

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