Assessment of Hazardous Voltage/Current in Marinas, Boatyards and Floating Buildings

Final Report

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FOREWORD

The safety of electrical equipment installed and used in the vicinity of marinas, boatyards and floating buildings is a challenge. This typically requires designing, installing, operating and maintaining electrical equipment that balances inherently safe levels of equipment operation against nuisance interruptions of the applicable electrical infrastructure.

This electrical equipment is typically subjected to harsh environmental conditions that can result in deterioration and other long term maintenance concerns. Reports in the mainstream media of drowning in the vicinity of marinas, boatyards and floating buildings has raised question on possible shock hazards from nearby electrical equipment, and thus credible data is needed that clarifies the problem and provides guidance towards the most appropriate mitigation measures.

The goal of this project is to identify and summarize available information that clarifies the problem of hazardous voltage/current in marinas, boatyards and floating buildings, and to develop a mitigation strategy to address identified hazards.

The Research Foundation expresses gratitude to the report authors John Adey with ABYC Foundation, Inc., and Bill Daley and Ryan Kelly both with CED Technologies, Inc. Likewise, appreciation is expressed to the Project Technical Panelists and all others who contributed to this research effort for their on-going guidance. Special thanks are expressed to the following project sponsors: Attwood Marine; Eaton Corporation; Hubbell; Intertek; Leviton Manufacturing Company; NEMA Electrical Connector Section; and Underwriters Laboratories.

The content, opinions and conclusions contained in this report are solely those of the author.

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November 5, 2014

American Boat & Yacht Council, Inc.

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Overview

The American Boat & Yacht Council (ABYC) responded to a proposal from the National Fire Protection Association's (NFPA) National Research Foundation to study the phenomenon of electric shock drowning (ESD) and agreed to recommend a technology based solution to the land-based side of electrical installations in marinas, boatyards and floating buildings. ABYC became aware of ESD around 2000. Initial studies of ESD lead to a United States Coast Guard Office of Boating Safety grant where ABYC gathered data, mapped electrical fields and recreated accident scenarios in order to find a series of solutions to ESD. Following the grant work, ABYC proposed a ground-fault protection system onboard boats called Equipment Leakage Circuit Interrupters (ELCI), and such devices were made mandatory for boats built after December 31, 2012. However, a large population of boats exists that are not covered by the mandatory inclusion of ELCI technology.

Peoples' understanding of ESD is not pervasive across the spectrum of marinas, boatyards and floating buildings. ESD has been principally seen in fresh water environments. ESD begins with an electric fault on the dock or onboard a boat when a voltage source comes into contact with the body of water. The voltage radiates throughout the water in a hemispherical field. As a swimmer approaches the electric field, electric current begins to flow through the swimmer's body. The human body has a much lower resistance than fresh water so it acts as the better conductor of electricity. In the presence of an electric field, the human body, not the surrounding fresh water, conducts the majority of electric current. As little as 10 mA of current through the human body can cause loss of muscular control which may result in drowning. ESD can be fairly insidious since the victim may not be exposed to the stray voltage field upon initially entering the water. This leads the victim to believe that the water is safe for swimming until he unintentionally enters the voltage field and becomes shocked. Further, the voltage source may be intermittent as a function of when a particular AC device is automatically or manually cycled on or off, or a when a fault is intermittent in nature. Although ESD has been mostly observed in fresh water, the incidence of ESD in brackish water cannot be ignored since the conductivity of brackish water can vary based on numerous environmental conditions.

The recommendations in this report are not intended to encourage marina owners to allow swimming in their facilities. Many hazards exist in the water around marina properties, ESD is only one of many. ABYC recommends that no recreational swimming at any time take place in a marina environment. Part of an effective plan against ESD will include a no swimming policy and "NO SWIMMING" signs posted throughout the facility. This will also prevent possible injury due to boat traffic, harmful marine life, etc.

Electronic devices that may mitigate ESD were researched for their application to land-based protective systems. These devices can be categorized by their function as either: (1) monitoring or (2) sense and trip. Within these broad categories, equipment can be installed at the power feed to the marina, at the head of a pier or group of piers, or at individual slips. In general, these devices can be configured for a variable response time in milliseconds (ms) and to a variable level of stray current measured in milliamps (mA). ABYC Standards recommend a device that interrupts the source of power feeding a fault within 100 ms from the moment stray current exceeds 30 mA. While 30 mA through the body is more than enough to kill a swimmer it is not sufficient to assume that all of the 30 mA leaking into the water will actually go through the swimmer. Rather, U. S. Coast Guard studies have shown that due to the hemispherical 'spreading' of the electric field, only a portion of leakage current will go through the swimmer. The main exception to this occurs when the swimmer comes into direct contact with the voltage source itself, for example by grabbing a metallic ladder that has become energized. 30 mA represents an acceptable level that ABYC expects to prevent a majority of ESD incidents while remaining practical enough to minimize unnecessary tripping.

Results

The appeal of any particular product cannot be realized unless there is a common means by which to evaluate an individual product relative to the population of potential products available on the market. In short, a grading system needs to be established in order to evaluate one product relative to another. The grading system should consider a number of product features to assist and guide the customer as to the product's usefulness.

This study considered 10 broad grading criteria to construct a final grade for each product that was reviewed. These criteria were: accuracy, availability, cost per protected circuit, customer acceptance, effectiveness, environment, installation, maintenance, regulatory and standards, and usability. Some of these criteria consisted of additional sub-criteria which are mentioned in the discussion section of this report. Finally, the grades for each of the broad criteria were averaged to determine a device's final grade. The overall goal is to answer the single question: "What is the best product to provide the most protection for a swimmer in the water?"

Since the immediate danger to a swimmer in the water is a function of electric current through the body over a measureable time, monitoring systems offered little or no protection in fresh water environments since the potential health effect could have already occurred before any human response was possible. Moreover, a monitoring system only alerts that a threshold has been reached when in fact the actual stray current could be well above the acceptable limit for a sense and trip system. It is worth noting that monitoring systems might be better than nothing for significantly brackish and/or salt water locations. One must consider, however, that water salinity may not be equally distributed or easily predicted. Wind driven currents and run-off are some of the factors that can influence salinity. It is important to remember that the risk of ESD increases as water salinity decreases.

Table 1, below contains the grades awarded to each of the 12 researched sense and trip technologies currently available on the market. Each system is identified by a device identifier. The scoring system was based upon a survey of available literature for each of the 12 devices. For each criteria, 0 means the device meets the criteria poorly; 1 means the device is good compared to its peers; 2 means the device is better than several of its peers, and 3 means the device is among the best. The 10 grading criteria across the top of the table were averaged to produce the final grade for each particular system. As discussed earlier, several of the grading criteria were broken down into sub-criteria to better differentiate between the 12 systems. If a search through a device's literature did not yield data for a particular grading criteria, then a score of NP was awarded, for 'not published'. In this case that criteria (or sub-criteria) was omitted from that device's final score average.

Table 1: Comparison of Surveyed Sense and Trip Devices

	Device Identifier	Accuracy	Availability	Cost per protected circuit	Customer Acceptance	Effectiveness	Environment	Installation	Maintenance	Regulatory and Standards	Usability	Total Score
Pedestals	A	2.25	3	1	2.5	3	3	2	3	3	2.5	**2.53**
	B	2.25	3	1	2.5	3	3	2	3	3	2.5	**2.53**
	C	1.33	3	3	2	2.8	3	3	2	3	2	**2.51**
	D	1.33	3	3	1.5	2.8	3	3	2	3	2	**2.46**
Ground fault monitors (Integral sensor)	E	2	2	2	0.5	2.5	2	1	1	2	1.5	**1.65**
	F	2.67	2	1	0.5	2.8	2	1	2	2	2	**1.80**
	G	2	0	NP	0.5	2	1	1	2	2	2	**1.25**
	H	1.33	3	2	2	2.8	3	2	3	3	1.5	**2.36**
Ground fault monitors (Separate sensor)	I	2.67	2	1	0.5	2.8	2	1	2	2	2	**1.80**
	J	2.25	3	2	2.5	2.33	2	1	2.5	2	2.5	**2.21**
	K	2.75	2	1	1	2.6	1	1	2	2	2.5	**1.79**
	L	3	3	2	1.5	3	3	1	2	3	3	**2.45**

Grade Scale: 0 = Poor; 1 = Good; 2 = Better; 3 = Best

Discussion

In this section the device grades from Table 1 are discussed and overall trends are analyzed. Each of the 10 grading criteria is expanded below to include sub-criteria (as applicable).

Accuracy (subcategories)

- **Minimum sensing**: What is the lowest detectable fault current? The surveyed devices ranged from 3 to 30 mA. In the context of fault current sensitivity a device that can detect as little as 3 mA scores higher than a device that can only begin sensing at 30 mA.
- **Accuracy of leakage current**: What is the device's error in terms of detected leakage current versus actual leakage current? This was published by a percentage of a device's trip set-point and ranged from 1% to 5%. Several devices lacked published accuracy figures.
- **Step size**: How many leakage level set-points did the device offer? Set-points ranged from none (or fixed) in the case of GFCI circuit breakers, to multi-set-point dip switches, to finely adjustable analog control knobs in other devices.
- **Precision of output**: How precise was the fault current given by the device to the user? The devices ranged from binary reporting (GFCI tripped or not tripped, fault LED illuminated or not illuminated) to several digits of fault current displayed on analog and digital accessories.

Availability (subcategories)

- **How to purchase**: How easily can a device be researched, ordered, and obtained? Some devices were difficult to locate in stock online and were primarily found in third-party electronics stores, while others were offered directly from the manufacturer along with complimentary consulting services.

- **Customer support**: How easy is it to obtain help for a device (general questions, installation, pricing, etc.)? This category varied greatly. At the high scoring end, devices had user-friendly phone, email, and website support in an easy to find location, often on the main page. On the other hand, other device manufacturer's websites required significant searching to find the proper resource for assistance, if it was discovered at all.
- **Cost per protected circuit:** What is the average cost of a protected circuit, when taking into account the cost for the protection device itself, major accessories, and the number of circuits it can sense and trip? Some of the devices were capable of protecting dozens of circuits, while many others could only protect one. Costs per circuit ranged from over $2,000 to under $400. Labor rates were not included in device cost. Rates vary greatly by geographic region and marinas have different existing infrastructure which makes installation cost situation dependent.

Customer Acceptance (subcategories):

- **Number of circuits or outlets**: How many outlets or circuits can each device be equipped with? While this factors in to the cost per circuit (discussed earlier) it also contributes to customer acceptance because more circuits per devices means fewer devices that need to be purchased, installed, configured, and maintained.
- **Bonus features**: Do the devices offer any additional services or protections independent of ground fault leakage? The surveyed devices ranged from no additional features, to features such as surge protection, over-current protection, harmonic filtering to minimize unnecessary tripping, lighting, and even water connections and metering.

Effectiveness (subcategories):

- **Monitor or sense & trip**: Can the device interrupt a circuit or just monitor fault current levels? For the device to be considered a protective device for ESD it must be able to interrupt a faulty circuit. Each of the 12 devices on Table 1 are capable of interrupting a circuit by some means such as through a GFCI circuit breaker or a shunt-trip breaker.
- **Failure mode**: If control power is lost to the device, will the device allow the circuit to remain energized (not fail safe) or will the device fail in a conservative manner and interrupt the circuit because it can no longer sense a fault (fail safe)? On the other hand, some of the circuit transformer (CT) enabled devices were fail safe selectable while others did not have this information published in their literature.
- **Response time**: How quickly does a device interrupt a circuit once the threshold fault current is detected? The CT powered devices researched are selectable to as low as 20 ms while GFCI's have can have a variable response time of up to 2 seconds.
- **Reset mode**: Once a fault has caused a device to interrupt a circuit, how does one reset the device? All of the devices require the circuit breaker (either GFCI or electronically driven shunt-trip) to be manually reset. Some devices also necessitate that a reset pushbutton be pressed either remotely or on the sensing unit itself. The remote-only reset option was awarded a lower score than units which had both remote and manual reset options.
- **Tamper resistance**: How easy is it for a boater or marina operator to defeat a device's protection by tampering with its configuration or disabling the device? Some devices are minimally tamper-resistant, having completely exposed controls while others are shipped from the manufacturer in lockable outdoor enclosures. One cannot discount the possibility of mis-use of a

product. As an example, using a non-GFCI protected adapter that permits the use of a 15A receptacle to power a 30A boat.

Environment

How suitable is the device for the marina environment, when considering exposure to temperature extremes, humidity, rain, and salt spray? Devices range from fully ruggedized to vulnerable to the marina environment. Conformal coatings, and IP and NEMA rated enclosures were represented.

Installation

How involved is the installation process? Is the device marina-ready out of the box or will it require additional accessories? What is the installation footprint? Some devices are ready to bolt-down to the dock in place of existing outlets while others require installation indoors with additional signal cables to communicate with sensors and control shunt-trip breakers. To obtain the graded functionality, some of the devices also required a base-station computer with special software installation.

Maintenance (sub categories):

- **Warranty**: For how long is the device warranted and what is covered? The warranties, where published, ranged from 5 to 7 years and covered a mix of electronic components and exterior housing.
- **Built in test features**: How does the device report that it is having a problem? Options ranged from automatic continual built-in tests to user initiated tests. Some devices required a remote to initiate the test cycle, while other had the functionality built in via a push-button on the device itself.

Regulatory and Standards

Does the device literature advertise compliance with marina regulations or standards? Most notable were devices that met NFPA 303 and NEC 70 Articles 555 and 553. Some of the device literature did not mention these marina-specific standards but did advertise UL1053 for ground fault sensing.

Usability (sub-categories):

- Intuitive: Will the marina operator readily understand how to configure and maintain the device by looking at it, or will it require significant training and reference materials? Some of the devices look intimidating and high-tech with markings, contacts, and switches unfamiliar to the layman. Other devices have simple interfaces that lend themselves to enhanced usability.
- Alerting method: How does the device inform the marina operator that a fault has occurred? Some surveyed devices give no notification (i.e. nothing more than the breaker tripping), while others activate an integrated alarm mechanism, while others are advanced enough to trigger a text message to a technician's cellular phone.

The following trends are noted:

Pedestals

The highest scored devices were pedestals. Pedestals, by nature, are ready to bolt to the dock, connect to the branch circuit, and put into marina use quickly. The pedestals evaluated in this report represent a complete solution if the customer wishes to add new electrical service at the slip or replace existing pedestals with a newer product.

Results Summary

Devices A and B were the overall best scored devices and are made by the same company. They use a CT to sense fault current, and all electronics were contained within the pedestal. Each of these two pedestals was capable of monitoring three branch circuits, and could report their status to a base station computer wirelessly. They excelled most in the criteria of availability, effectiveness, suitability for the marina environment, maintenance, and advertised regulatory and standard compliance. These high scores came at the expense of cost per circuit as devices A and B were the most expensive pedestals surveyed.

Devices C and D were made by a different company from A and B, and these used GFCI circuit breakers to protect the swimmer from fault current. A GFCI is a less accurate technology compared to a CT-enabled device, but the cost can be significantly less. Devices C and D were economical pedestals that had power outlets with few other bonus features, but could be purchased for only a few hundred dollars. With only two outlets each and few frills, customer acceptance was slightly lower than Devices A and B but still above the "good" range. Usability for C and D was below that of A and B primarily due to the lack of a reporting method when their GFCI circuit breaker tripped.

Integral Sensors Ground Fault Monitors

The integral sensor ground fault monitor is a device that can be used to protect branch circuits that feed existing shore power outlets. Devices E, F, and G were relatively expensive microprocessor based devices with CT sensors built into the packaging capable of monitoring one circuit each. Price range on these devices was approximately $500 to over $2,000. The higher price pays for the most customizable surveyed device with regards to trip levels, delay time, and factory configurable settings. Devices E, F, and G were not designed with the marina environment in mind and scored lower than the pedestals overall. This was due in part to the increased burden in installation to meet marina environment and standards demands, as well as to prevent tampering. Customer acceptance was especially low since one device only monitors one branch circuit, and it offers no bonus features to the boater or marina operator. All three of these devices interrupt a faulty circuitry by sending a command to a shunt-trip breaker. This command necessitates wiring between the device itself and the interrupt breaker.

Device E reports a fault by virtue of a LED on the unit itself, whereas device F and G have an LED as well as additional output contacts that can drive any number of external alarm options.

Device F was one of the only three surveyed devices that had the capability to display fault current on a wired remote display (the others were Device I and K). This option adds to cost but presents a solution to provide real-time fault information to the marina operator in a central location.

Device G was the most difficult device surveyed to find information with minimal information on its data sheet and unintuitive website support.

Device H is a power substation capable of monitoring up to 36 GFCI protected branch circuits from one location. It has a mid-range cost per circuit around $1,000 assuming all 36 circuits are used, and also affords the benefit of simplified maintenance. The branch circuits from Device H could be fed directly into existing shore power outlets, assuming there exists an additional means to de-energize the outlet within reach of the boater.

Separate Sensor Ground Fault Monitors

Device I was the same as Device F but had a separately attached CT vice using the integrated one built into its packaging. A separate CT is useful if the branch circuit is in a different location from the device itself, or if the branch circuit wiring is bulky and does not fit through the integrated sensor. The addition of an external CT did not affect the score for Device I, but it does add to the cost and installation complexity (which were both already a 1 for Device I).

Device J is the same CT sensor and control hardware used by pedestals A and B. It may be used to upgrade existing shore power boxes or pedestals. It comes with three CTs to monitor three branch circuits and has the option of communicating wirelessly with a base station. This adds the benefit of a marina operator being able to receive notifications off site of his marina's power status. The company selling device J intended it for marina use and offers complimentary consulting with its purchase. The device itself is inexpensive at under $400 per circuit plus nominal cost for the necessary shunt-trip breaker, but the feature-rich computer software costs several thousand dollars. However, with each additional device J installed, the impact of the software cost would lessen per circuit. Device J requires installation in an existing pedestal or other enclosed panel-mounted location to protect it from the marina environment and potential tampering.

Device K was the only other sensor (besides F & I) that allowed a wired remote display to show real-time fault current. This device was a high-tech, highly accurate ground fault monitor not necessarily intended for the marina environment. It is quite expensive at over $1,600 for one protected circuit and was difficult to locate for purchase online. Device K protects a maximum of one circuit with a required external CT. One bonus feature it provides that is unique to the other devices surveyed is harmonic current filtering which reduces the likelihood of unnecessary trips caused by the modern power electronics aboard today's boats. Installation of Device K is complex due to the need to protect the device from tampering and weather, as well as the need to run signal cable from the device to the shunt-trip breaker and remote fault-current display.

Device L is manufactured by a company with the marina in mind. It is a CT driven control capable of monitoring up to 12 branch circuits, each with their own connected CTs. The device is highly configurable with respect to trip levels, response time, and alerting methods. It alerts to a fault using a strobe light by default but can also communicate to a base station computer or cell phone via text message. Installation is made more complex than single-circuit devices due to the need to run communication wire between the control unit and each of the 12 branch circuit CTs. However, the device enclosure comes out of the box ready for the marina environment and is lockable to prevent unauthorized access to its configuration settings. Fault current is indicated on a digital display on the device itself. The manufacturer provides a list of local sales representatives on its website along with several customer service options to include web based, email, and telephone.

Conclusions

The devices that scored best overall are those that are designed with the following things in mind:

1. The customer is a marina, and the highest scoring devices are ready to bolt down to the dock and use with the least amount of effort.
2. The device is designed to protect at the individual slip.

3. The device is ready for the outdoor environment.
4. A device with additional convenient features beyond just interrupting a circuit may cost more, but there may be a customer who is willing to pay this cost for enhanced capabilities (i.e., wireless reporting).

In making an informed decision it is important to empower the customer with relevant information. Several grading criteria were used to evaluate the devices against one another, but not all of the necessary information was provided by each device's literature or website. In particular, pricing information required significant effort and was not always solicited easily from the manufacturers.

It could be argued that more intense research will yield all of the missed information, but such additional effort should not be placed upon those individuals who want to quickly compare several technologies. If device information is not readily available to the customer, it is less likely that the customer will be inclined to purchase the device. Standardizing relevant device characteristics will help the manufacturer in marketing the product to the right customer, help the customer (marina, dockyard, etc.) purchase the most appropriate device for the needs and budget, and most importantly help save the lives of those in the water by ensuring the standard of safety is indeed met.

Discussion time was spent on protection of the main marina feeder. NFPA 70 Article 555 already requires 100mA protection for the main marina feeder. The justification for the recommendation on the 30mA protection in this report relies on the research found in the USCG Grant titled In-Water shock Hazard Mitigation Strategies, 2008, ABYC. A number of all the accidents researched for the purpose of this report occurred based on a fault in the marina wiring itself, rather than on a boat connected to the marina service. There is not a body of research surrounding faults in the marina feeder, therefore the ABYC recommends a study similar to the 2008 USCG study that would document marina feeder based faults, and the effects of cumulative lower level faults on this type of protection. While there is no debate among the experts that in addition to the pedestal protection a main feeder protection must be required; in the absence of such a study, the ABYC is reluctant to make a recommendation on the parameters of this type of protection.

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