Connecting Berthing Ships to Shore Power to Minimize Air Pollution IEC/IEEE 80005-1

2019 UPDATES TO ADDRESS PRACTICAL ISSUES WITH INSTALLATIONS

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Digital Object Identifier 10.1109/MIAS.2023.3325107
Date of current version: 31 October 2023

THE AUTHORS ARE EXPERIENCED IN THE DESIGN, INSTALLATION, testing, safety of personnel, and commissioning of shore power projects, "connection/disconnection of ships to shore power during berthing at ports." Herein, the authors provide their views of some of the issues that may require first-hand input to the industry professionals involved in these types of projects. Technical references and recommendations included in the article should enhance the reader's knowledge of shore

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power projects mandated in numerous regions around the world at larger ports to enhance safety of operators, minimize air pollution in the vicinity of ports for health benefits, and produce a cleaner environment for the public.

Introduction

The objective of this article is to provide a synopsis of changes in the International Electrotechnical Commission (IEC)/IEEE 80005-1:2019 [1] to address practical issues that may be faced at the installation port to comply with the standard. IEC/IEEE Joint Working Group (WG) members from 20 countries under the leadership and guidance of the convener, put forward a tremendous effort to compose the standard. Many meetings took place for consensus resolutions of the review comments. The authors of this article are IEEE officers and WG members of this standard from the first issue through the present revised version and have knowledge of the history of comments, and their resolution made a great effort to technical changes listed on pages 7 and 8 [1].

Automatic restart and synchronization alternatives are enhancing flexibility towards reducing the time to make shore-to-ship connections without sacrificing safety.

The authors provide their views of some of the issues that may require first-hand input to the industry professionals involved in these types of projects. The word *safety* has been used in this article, which means safety from electrical current through the human body. Refer to Figure 20 from IEC 60479-1:2010 0 for permissible body current versus duration curve.

This article will first provide some rationale for these changes for industry benefit in general. As we know, every change in a standard is with the consensus of the WG. Then the article will provide some discussion on other safety and technical statements where WG members and some other industry professionals may benefit from the input contained in this article based upon the consensus opinion of this article's authors. Such an article then can be a source of further improvements in the next revision of this standard.

Shore-to-ship power supply is matched with the power supply of the onboard ship power supply system. In general, nearly all ships around the world today use 460/480 V, 6.6 kV, or 11 kV ac at 60 Hz. This power is generated by onboard generators, which are either ungrounded or grounded by individual high-resistance grounding (HRG) resistors or by a common homopolar grounding system [12]. When a ship berths at a port in preparation of receiving shore power, the first task by the ship operators is to turn off all generators (per the written instructions for shore power operation) with the exception of one generator, which will continue to run to keep all essential loads of the berthing ship in operation. The main purpose of the shore-to-ship power supply is to meet air pollution standards. The intent is to reduce air pollution by minimizing the use of the ship's onboard generators that typically use low-grade fuel. This is becoming less of a factor since most modern ships now use electric propulsion systems, which are more efficient, thereby helping to meet mandatory air pollution requirements set forth by the International Maritime Agency when ships are in the ocean away from ports [9]. The procedure to connect to shore power involves the person in charge of the berthing ship communicating with the port operators to perform the task of making shore-to-ship power connections, the interface of power plug and receptacle assemblies. The procedure to make these connections takes great care to maintain safety and insure that the work is performed under de-energized conditions. Upon completion of this task, the shore operator informs the ship operator to remove the grounding switch from the shore power supply circuit at the ship so that the breaker can be closed. Upon closing this breaker, the ship operator informs the shore operator that the breaker is closed. Then, shore power is received inside the ship-receiving switchboard, where the ship operator synchronizes shore power with ship power [11].

The title of this standard [1] uses the phrase "high-voltage shore connection" (HVSC) to describe the shore power which is, in fact, either 6.6 kV or 11 kV, typically. This is in accordance with the definition per National Electric Code (NEC) NFPA 70 [7]. However, per IEEE definition, shore power at these supply voltage levels should be referred to as *medium voltage* (MV). This article uses the IEEE definition throughout the remainder of the text.

Technical staff from several ports have reached out to these authors for interpretation and clarification of some requirements of the first 2012 edition of this standard. Based upon the lessons learned, the authors provide clarifications to some of the most controversial and confusing clauses in the standard. The clarifications listed below are opinions of the authors of this article and will require meetings for consensus agreement of all WG members from 20 countries participating in this standard. All cited pages and paragraphs (Par.) used in the text below are from this revised standard [1]:

1) Significant technical revisions are on pages 7 and 8
2) Equipotential bonding
    a) Equipotential bonding, Par.4.2.2
    b) Compatibility assessment before connection; Par. 4.4.r, consideration of electrochemical corrosion due to equipotential bonding

    c) Equipotential bond monitoring, Par.7.2.5
    d) Connectors, Par. 7.3
    e) Earthing bonding connections, Par.11.3
3) Shore power system grounding
    a) Neutral earthing resistor, Par. 6.2.3
    b) Roll on/roll off (Ro-Ro) cargo ships and Ro-Ro passenger ships, Par. B.6.2.3
    c) Cruise ships, Par. C.6.2.3
    d) Container ships, Par. D.6.2.3
    e) Liquefied natural gas carriers (LNGC), Par. E.6.2.3
    f) Additional requirements for tankers, F.6.2.3
4) Shore power transformer
    a) Voltages and frequencies, Par. 5.1
    b) HV supply voltage, automatic control, Par. 6.2.2
    c) Transformer primary protection by fuses, Par. 6.2.2
    d) Neutral earthing resistor shall be continuously monitoring, in the event of loss of continuity, the shore-side circuit breaker shall be tripped, Par. 6.2.3
5) Shore and ship frequency shall match
    a) Operating frequencies of shore and ship shall match; otherwise, frequency converters shall be utilized on shore.
6) Other clarifications

The article ends with technical references used in this document to enhance the reader's full understanding of the technical information included in the article.

Significant Technical Revisions

The last of the significant technical changes are as follows:

1) Removing the earthing switches inside the ship will reduce the number of incidents, such as those that happened at a western U.S. port described in the "Compatibility Assessment" section. For this reason, the earthing switch shown in Figure 1 [1] has been deleted.

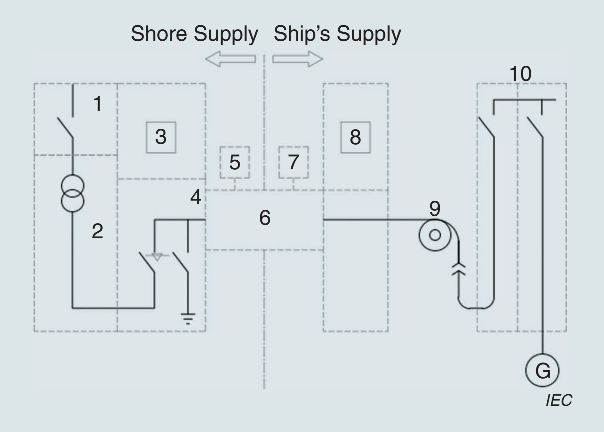

FIGURE 1. Block diagram of a typical described HVSC system arrangement Par. 4.1 [1], with ship onboard cable reel and without galvanic isolation transformer onboard. Key numbered items include: 1: shore supply system; 2: shore-side transformer; 3: shore-side protection relaying; 4: shore-side circuit breaker and earth switch; 5: control shore; 6: shore-to-ship connection and interface equipment; 7: control ship; 8: onboard protection relaying; 9: cable reel; and 10: onboard receiving switchboard.

2) Adding testing of ground conductor bonding at both the ship and shore will not require mandatory equipotential conductor continuous monitoring.
3) Adding safety circuits minimum current of 50 mA provides definite criteria. Adding safety circuits that must open the circuit breaker in 200 ms is within the capability of a five-cycle standard circuit breaker and provides definite criteria.
4) Since the onshore power supply grid is seeing increasingly more harmonics pollution, adding a number as a harmonic content limit establishes a minimum harmonic quality standard for the power being supplied from the grid.
5) Adding an earthing HRG enclosure (on transformer secondary winding neutral) for bonding to earth, while the power supply to the transformer primary winding is in delta configuration.
6) Safety circuits are important and their addition to all figures in the Annexes will improve safety.
7) The addition of metallic cores on the power cables and a common semiconducting layer on pilot wires helps the integrity of the cable from the ship, per Annex A [1].
8) The addition of a safety circuit for Ro-Ro ships is a safety improvement.
9) Having the option of shore power being fixed or movable solves the problem of berthing ships not being able to connect to shore power receptacles at fixed locations.
10) Improvement of the one-line diagrams for cruise ships provides clarity.
11) Shore power connector pin assignment is updated to match with industry available pins.
12) Pilot wire voltage of 25 V ac and 60 V dc is a step forward for electrical safety using pilot wire circuits.
13) Automatic restart and synchronization alternatives are enhancing flexibility towards reducing the time to make shore-to-ship connections without sacrificing safety.

Equipotential Bonding Conductor

Equipotential grounding of the ship and the shore is achieved through the pin E inside the plug and receptacle assemblies [Figure 2(b)]. The most challenging subject related to this is the requirement of continuous monitoring of this ground conductor (CMGC). Those who feel that it is not possible to continuously monitor this ground conductor using the monitoring circuit shown in Figure 2(a) insist that the shore and the ship have a parallel conductive path outside the plug and receptacle assembly, which remain continuous when the ground conductor path upon separation of ground conductor at pin E breaks the continuity. One such parallel path is the earth (ground) itself between the shore and due to very low impedance of damp moist soil at the ports [Figure 2(c)]. Another parallel path is the MV cable shield connected inside shore and ship switchboards ground bus. This shield also gets grounded inside underground metallic vault from both ends of the plug and receptacle assembly. Thus, the continuous monitoring circuit in Figure 2(a) may not operate due to reduced current flowthrough the circuit. In other words, if the external parallel ground circuits, as explained by Figures 2 and 3, remain in operation upon separation of the E pin, then the circuit may not work.

The need of this continuous monitoring of the ground conductor can be challenged based upon the following technical considerations: 1) electrical safety from maximum ground fault current flow though this grounding conductor when phase-ground fault occurs on the ship and 2) HV long cable shield/sheath grounding at multiple locations.

Electrical Safety From Maximum Ground Fault Current Flow Through This Grounding Conductor When Phase-Ground Fault Occurs on the Ship

All shore power systems are HRG-grounded: 25-A resistor limiting touch voltage to 30 V, LNGC ships Annex E and tankers Annex F [1] may be ungrounded or grounded in such a manner as to minimize ground fault current in a hazardous area and, therefore, in such cases ground fault current through this ground conductor will be practically zero, and thus there is no safety concern as operators are not subjected to touch and step potentials for the ground fault hazards [14], [15].

All other shore power systems described for various ships in the Annexes [1] are HRG-grounded with a maximum fault current flowthrough CMGC less than 25 A and the maximum voltage across this ground conductor less than 30 V. This voltage is much safer from a human body touch voltage hazard point of view [13]. If the ground conductor through pin E becomes an open circuit, even then the touch voltage for a person touching the ship hull and standing on the shore will not be subjected to more than 30 V. See the missing technical

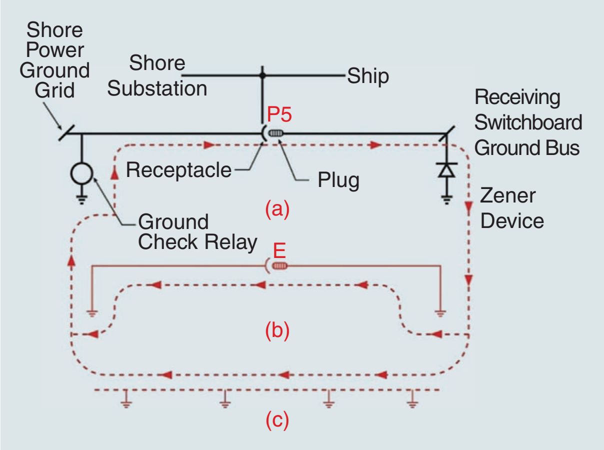

FIGURE 2. (a)–(c) Continuous ground conductor loop monitoring circuit.

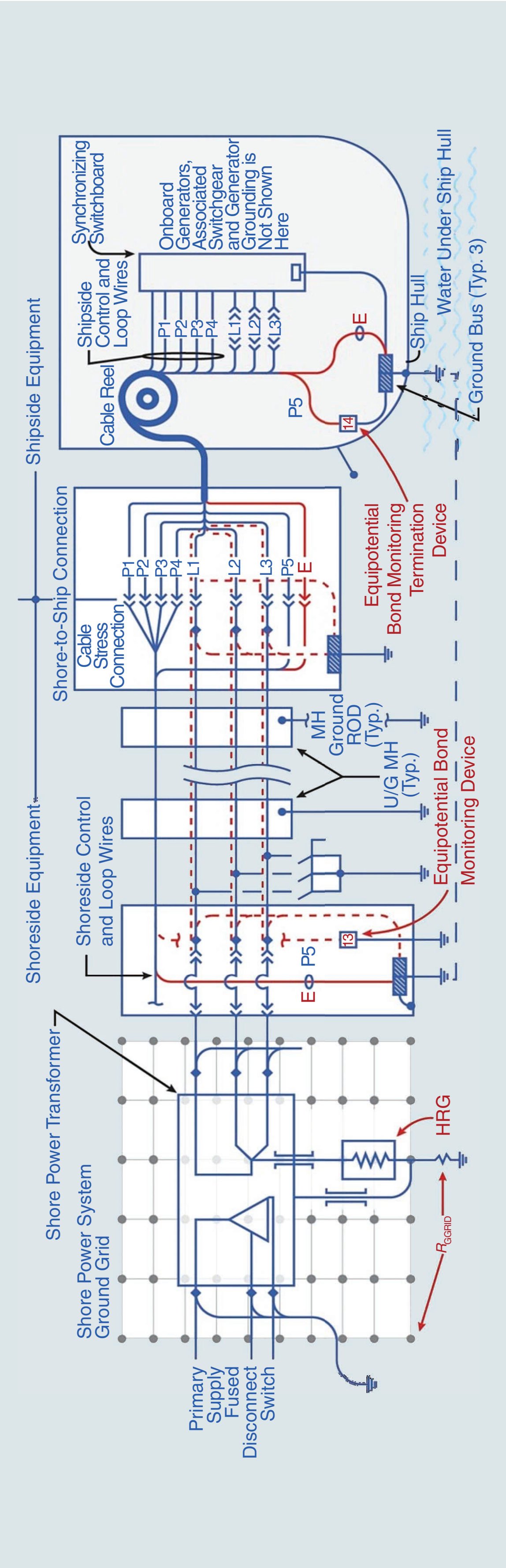

FIGURE 3. Shore power system block diagram.

requirement of verifying ground grid resistance of shore-to-ship substation grounding grid to remote earth not to be more than 1.2 Ω resistance for 30 V (30 V/25 A), as shown in (1) in the "Shore Power System Grounding" section. Therefore, there is no concern of ground fault current hazard resulting in maximum voltage drop across the CMGC of 30 V [13].

When a ground fault occurs on an HRG-grounded shore power system, the ground fault current relays on shore and on ship will activate to trip their respective circuit breakers on the shore and the ship to clear the fault within 200 ms (12 cycles). Even if the breakers do not clear the ground fault, there is no safety issue at 30 V.

Based upon the above discussion, it seems to be clear, that a continuous monitoring of ground conductor (through pin E) and then upon loss of this continuity, the tripping of the shore breaker, which will cause interruption of shore-to-ship operation may not be absolutely required, as long as the shore power system grounding included in the "Shore Power System Grounding" section is applied.

For these reasons, in lieu of CMGC, the revised standard has added testing of ground conductor bonds every 12 months on shore and every six months on the ship to ensure that the measured resistance will not be more than 1 Ω. The reason for selecting the 1-Ω value was based upon the thought that it will provide a voltage of 25 V, less than 30 V, obtained by multiplying the 25-A rating of HRG with 1 Ω resistor (25 A × 1 Ω). The authors believe that the bond-measured resistance should not be 1 Ω, but very low in milliohms to ensure the integrity of the bond to avoid possible bond arcing in case the bond becomes loose and a ground fault current passes through the bond location. Irrespective of the authors' thoughts that the measured bond resistance should be lower, this bond-measuring resistance is a great idea for safety improvement and to possibly eliminate the need of a continuous monitoring of the equipotential ground conductor between the shore and the ship.

Table 1. HR rating per IEEE Standard 32

Serial No.	Annex No. [1]	HRG Ohm Rating [1]	Recommended HRG Ampere Rating
1	Par. B.6.2.3 for 11 kV	335 Ω	20 A, 10 s
2	Par. B.6.2.3 for 6.6 kV	200 Ω	20 A, 10 s
3	Par. C.6.2.3 for 11 kV	540 Ω	15 A, 10 s
4	Annex D for 6.6 kV	200 Ω	20 A, 10 s
5	Annex E	HRG[1]	HRG[1]

HRG[1] Rating should follow the same method as shown for Annexes B, C, and D.

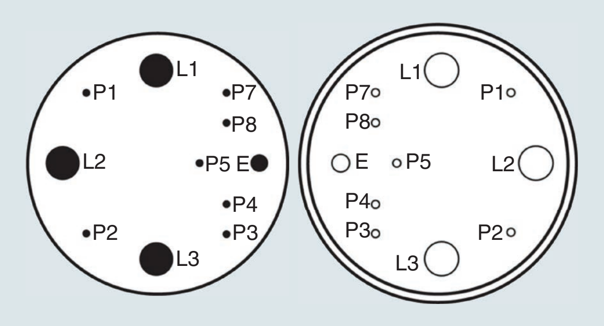

FIGURE 4. Plug and receptacle assembly.

Today, in the mining industry, 100 V safe-touch voltage is used for grounding of movable HV equipment, as per NEC 2017 Article 250. In the shore power supply system, we used the same touch voltage as 30 V, which provides enhanced safety. This is based upon the reasons that a ship moves with tidal ways, it is therefore recommended to keep this requirement of CMGC in the standard. Much safety concern is covered in the safety loops where CMGC is part of this safety, as seen in all five Annexes [1]. All five types of ships use E contact as a part of the plug and socket assemblies, although the number of pilot contacts (designated by P1, P2, etc.) used for safety loops is different for five types of ships with different HRG ratings, as shown in Table 1.

Figure 3 depicts a block diagram of shore-to-ship power supply showing an interface at the plug and receptacle assembly inside an underground vault near the wharf. Long underground shielded power cables, along with all other safety loop circuits, including CMGC and E conductors, are shown between the shore and ship via plug and receptacle assembly.

Each man hole (MH) ground rod shown in Figure 3 should be bonded to all metallic components, such as metallic ladder, metallic cable supports, and even MH cover with grounding conductors for safety of persons inside the MH.

For clarification of all types of conductor connections between shore and ship, Figure 4 is included. This plug and receptacle assembly in Figure 4 is located inside the shore-to-ship connection box shown in Figure 3. This plug and receptacle interface shows three-phase power contacts, safety loop contacts, as well as continuous ground conductor loop monitoring circuit contacts included in Figure 2. The monitoring circuit included in Figure 2 is to further enhance the shore power safety provided by two safety loops developed by use of two separate control power circuits, the shore-side control power circuit and the ship-side control power circuit, using P1, P2, and P3, P4 pins, respectively (see Figure B.2 in [1]).

As described earlier, in the case of shore power projects, the ground fault at any location during cold ironing is controlled by a transformer neutral grounding resistor (NGR) to be 25 A or less (Table 1). This NGR is enclosed in its own enclosure insulated from the earth, connected to transformer neutral using insulated conduits to assure the NGR is not shorted by parallel metallic conduits. Measured ground grid resistance to remote earth shall not exceed resistance values determined by (1) in in the "Shore Power System Grounding" section.

This bond-measuring resistance is a great idea for safety improvement and to possibly eliminate the need of a continuous monitoring of the equipotential ground conductor between the shore and the ship.

HV Long Cables Shield Grounding

It is a common practice to ground HV-shielded cables at both ends. It appears that this shield-grounding practice of very long HV underground cables between the shore power switchgear (close to shore power transformer) and underground vaults (near the wharf for ship cold ironing operation) is the actual installation in many large ports. It is known [8] that a continuous flow of current occurs through the cable shield and earth when both ends of the cable shield are connected to the ground. The flow of current in the cable core acts as the transformer primary winding current, whereas the grounded shield connected to earth at both ends acts as a transformer secondary. This shield current flow during shore-to-ship operation causes power losses. Such power losses and resulting energy losses can be avoided by installing surge limiters to ground the cable shield at one end. These surge limiters act as an open circuit-to-cable shield ground under normal operation. Surge limiters can be enclosed inside the link box to be installed inside the shore power switchgear. Standing voltage across the surge limiters will appear based upon the length of the cable and the current flowthrough shield (due to load current flowthrough cables) during shore-to-ship operation [8]. During switching surge propagation, if the standing voltage across surge limiters becomes higher than the surge limiters' rating, then surge limiters will conduct the surge current to ground for a short duration and achieve their original state to provide an open circuit to shield to avoid a circulating current. This grounding practice of HV cables to use surge limiters should be evaluated for possible implementation in the next revision of the standard [1].

The authors would like to present a future technical paper on cable shield grounding practice for port facility electrical power distribution infrastructure for the benefit of marine industry, including shore power connection to ships.

Compatibility Assessment

Very useful and practical information to enhance the safety of personnel and to minimize shore power connection equipment hazards during shore power operation is included in Par. 4.3 of the standard [1], based upon two hazardous accidents that occurred at a western U.S. port reported by Kor Yen, an electrical engineer. One incident occurred during installation and the other during shore power operations.

Ground Fault at the Plug Attached to Cable Coming Down From the Berthing Ship

The power receptacle and matching plug are installed inside the underground vaults at a certain spacing to cover the entire length of the wharf where berthing ship connections can be made. The cable reel rolls down the cable with the plug to reach the underground vault with the cover removed. Operators inside the vault manually make cable plug connections to fixed receptacles. The plug at the end of the cable uses weatherproof covers to ensure water and moisture are not present when caps from the plug are removed. Likewise, much care is used with the receptacle to ensure there is no moisture or water when its cap is removed to make the connection to the plug. The plug is relatively heavy, and thus carne is used to slowly position the plug close to the receptacle, guided by the operator. See Figures B.3, C.4, D.3, E.2, and F.2 in the standard [1].

After performing a compatibility assessment of the berthing ship, the plug and receptacle assemblies were connected. When a power connection was established for power flow from shore to ship, the plug had a ground fault that tripped the shore power circuit breaker to clear the fault. Later investigation of the incident by port and ship technical staff, including the plug manufacturer's technical staff, concluded that the plug cap was left open from the previous port before arriving at the port. Ship operators should have made it clear to shore operators to clean the plug thoroughly to remove any dust or moisture inside the plug, as it was left open along the way from the previous port. Since no plug cleaning task was performed at the port to check for moisture or other contamination, it went unnoticed that a layer of sea salt had compromised the insulation level of the plug resulting in a ground fault trip. Had this task been included in the compatibility list, Par. 4.3 [1], this incident could have been avoided.

The sensitive ground fault relay cleared the fault in fewer than 10 cycles to avoid major damage to the cable connected to the plug.

Berthing Ship Electrical Interlocks Between the Shore Power Circuit Breaker and Associated Cable Capacitive Voltage Discharging Disconnect Switch

A berthing ship made connection inside the shore power switchgear located at the ship. During synchronizing, the shore power switchgear breaker was closed while the earthing switch was in a closed position. This led to a three-phase bolted fault with fault current of 4,000 A at 6.6 kV. Sensitive phase overcurrent 50/51 relays set at 3.2-A secondary current cleared the fault by tripping the shore power in fewer than 10 cycles. Investigation of this fault condition revealed that the ship wiring had a technical error in the electrical interlock circuit preventing the earthing switch from opening before the breaker closed. The berthing ship had made ship modifications without disclosing the changes to the western U.S. port. The port never required the berthing ship to show evidence or provide a complete report that all components were in the operating condition. It is worth stating that the current standard in Figure 1 (which is the synchronizing location, onboard receiving switchboard) now has no earthing switches to cause the short circuit reported here.

Shore Power System Grounding

The criteria of the NGR to make it as an HRG is given in Par. 6.2.3 [1]. This criteria of determining a neutral HRG resistor rating of 25 A is based upon another technical insight, as follows:

a) Transient overvoltage on the system will not be more than 2.5 PU peak voltage, where 1 PU is 1.4 × ELN voltage, where ELN stands for line-neutral secondary voltage of shore power transformer.

To meet the requirement of maximum voltage drop for a line to ground a bolted fault at any location in the shore power supply system of 30 V included in [1], the missing information in the standard [1] is that the measured ground grid resistance by IEEE Standard 81 of shore power substation to remote earth shall not be more than the ohm value calculated by (1):

$$R_{\mathrm{GGRID}} = \frac{(30\ \mathrm{V})}{I_{\mathrm{HRG}}\ \Omega} \qquad (1)$$

where: R_{GGRID} is the ground grid resistance to remote earth in ohms.

From the above description, it becomes clear why the measured resistance of each of the ship-side bonds and shore-side bonds needs to be practically very small and not to exceed 1 Ω, currently shown in [1]. Standard rating of a neutral resistor as 10 s or 5 s included in the standard should be used. It is noted that different Annexes use different ohm values for the HRG rating, as shown in Table 1. This should be changed to standard ampere rating per IEEE Standard 32 [2], which will meet ground grid resistance to remote earth included in (1).

Berthing Ship Electromechanical Corrosion

Every practical effort is made for the berthing ship to minimize its movement from the water tides (which are unpredictable) by using metallic ropes to fasten the ship to steel anchors at the wharf edges [5]. Thus, these fastening steel ropes act as ship-to-shore earthing electrodes. On the other hand, the salty water under the ship acts as a conductive path for a fraction of the phase-ground fault (occurring inside the ship) to return to the shore power substation ground grid. For 10 cycles, a stray current of a fraction of 20 A or 25 A from ship hull to shore substation will not lead to objectionable electrochemical corrosion, included in Par. 4.3.r [1], and thus this wording may require future review.

Shore Power Transformer

The published standard [4] on shore power transformer rated 7.5 MVA used in U.S. ports and many other global ports today requires a transformer primary switching device to be a circuit breaker and not fuses. Transformer internal faults, especially in the case of the transformer, are oil filled, may be of low magnitude, and may not be cleared by the fuses. Additional discussion on use of primary fuses and other related items is included below.

Primary Protection by Fuses

The shore power transformer primary should employ a power circuit breaker (not fuses) so that it can be tripped when:

1) A continuous monitoring scheme of NGR fails, which may cause a hazardous situation [3], even when the transformer secondary breaker becomes open
2) Shore power transformer internal monitoring devices, such as winding temperature and oil pressure, require tripping by a primary breaker and not by fuses
3) A switching surge can damage one phase fuse, causing a single fusing condition; ship loads will be operating but can lead to some damage of ship loads operating at the same voltage as shore power voltage
4) With the secondary breaker in open position, a heavy switching surge from the primary supply system can see a doubling effect, which may cause arc across the breaker contacts
5) A very low-level fault current on the load side of a transformer secondary breaker or fault within the transformer secondary can't be cleared by the primary fuses and can lead to a hazardous situation.
6) Per the IEEE standard [4], all transformers rated 5 MVA and larger must use 87 T, which can help trip both the primary and secondary breakers and clear all faults, within the transformer, and a secondary fault on line-side of the secondary breaker. Hazardous conditions caused by continuous monitoring of NGR can be wired to trip the primary breaker.

Primary On-Load Tap Changers

Primary on-load tap changers are known for causing low-level arcing based upon the magnitude of load current at the time when taps are continuously hunting to match load voltage. Most of these transformers rated at 7.5 MVA are oversized to connect the ship with maximum load, which may be only half (3,750 kVA). Additionally, shore is supplying power to the connecting ship at HV, 11.0 kV for a cruise ship and 6.6 kV for other ships, indicating 3% voltage drop is identical to the voltage drop criteria for a low voltage (LV) power supply system. Those ship loads that are directly connected at shore power HV supply, mostly motor variable frequency drives (VFDs), can tolerate load switching voltage dips of 15–17.5% of nominal voltage. Other loads at the ship include step-down transformers, which inherently have a 4% voltage safety factor and a ratio of transformer secondary voltage to rated motor voltage (480 V/460 V). If needed, no load fixed taps set at 2.5% below nominal will lead to a secondary voltage elevated to 1/.975 per unit of secondary voltage. Likewise, a tap set at 5% below nominal will provide a secondary voltage of 1/.95 per unit of secondary voltage. On-load tap changers can't change transformer secondary voltage, as it is linked to transformer primary and secondary windings by the transformer steel core and its flux. On-load tap changing leads to changes in transformer flux that lags behind the changes occurring on the secondary voltage. It can cause voltage hunting on secondary and should be avoided. Based upon this discussion on the need of no-load taps, it is the judgement of the authors of this article that actual experience where such on-load tap changers are needed or not needed can be verified by turning off on-load tap changers at ports where they have been employed to validate if, during ship cold ironing operation, any ship load has experienced objectionable voltage drop.

In those countries where the shore power from the utility is 50 Hz, it will be necessary to add frequency converter(s) to provide the 60 Hz that is required at the ship.

Shore Power Transformer Protection-Need of Relay 87 T

Dangerous low-level fault current on the line-side of a main secondary breaker or within the transformer can't be cleared by the secondary breaker and it will not be cleared by primary fuses (see additional discussion under the "Primary Protection by Fuses" section). To clear such a transformer, relay device 87 T is used. It requires three-phase current transformers (CTS) on the line-side of the transformer primary circuit breaker and three-phase CTS on the load side of the transformer secondary breaker. Any fault within the zone of the 87 T relay includes the transformer, with HR secondary resistor. A transformer primary breaker will also help in isolating the HRG resistor in the event of an open circuit or short circuit monitored by online monitoring of a neutral resistor, which should open both the main primary breaker as well as the secondary breaker. Opening the secondary breaker only is not enough to isolate faulted neutral resistor circuit trouble [3].

Shore and Ship Frequency

It is well known that shipbuilders design their onboard generating systems to operate at 60 Hz. In those countries where the shore power from the utility is 50 Hz, it will be necessary to add frequency converter(s) to provide the 60 Hz that is required at the ship.

The current wording used with respect to shore and ship frequency is that it shall "match," which may lead to confusion in enforcing the standard [1]. This clause should be reworded to clarify what is being required. The shore electrical grid frequency in many parts of the world is 50 Hz, whereas it has been established that on-board generation for ships is at 60 Hz. If the utility grid supply voltage frequency is 50 Hz, it should be converted to 60-Hz voltage. Further reasons to have the frequency converter on shore are to avoid the space and weight added by the frequency converter(s) on the ship. There are many protection signals that require communication between the frequency converter station and the connecting ship during cold ironing. Perhaps some additional wording should be added in [1] .

The current statement in the standard is correct, that the frequency converter equipment shall be on shore and not on board, as it is not in the interest of the ship owner to install a frequency converter on the ship just for shore powering the ship in a country where the utility power grid is 50 Hz.

Other Clarifications

Figure B.1 in [1] perhaps incorrectly shows a disconnect switch interlocked with the circuit breaker inside the onboard shore connection switchboard. This figure does not match with Figure 1 under Par. 4.1 in [1], where the onboard switchboard is in a separate location where the synchronizing of shore and ship takes place. Perhaps a clarification note is needed in Figure B.1 in [1] for those who may not be familiar with the design of this type of ship that no other separate breaker exists for synchronizing purposes other than a breaker interlocked with the disconnect switch, which acts as a synchronizing breaker. Therefore, the disconnect switch at the ship should be opened before receiving shore power. In this case, if it needs to match with Figure 1 Par. 4.1 in [1] there should be another breaker inside the ship other than the breaker shown interlocked with the disconnect switch.

Conclusions and Recommendations

The following conclusions and recommendations are intended to improve operator safety by minimizing the electrical hazards associated with shore-to-ship power supplies. This is achieved by helping all those who use this standard to better understand the items discussed in this article.

The equipotential grounding conductor continuous monitoring circuit should remain in the standard .The shore power HRG rating should be given in amperes and seconds [2] and not in ohms, as shown in Table 1.

The shore power transformer primary should employ a power circuit breaker (not fuses) to comply with thre recommended industry practice of protecting a 7.5 MVA transformer [4].

To avoid the hazards described in the “Compatibility Assessment” section, there is a need to add a few more requirements in the standard, such as verifying that the plug and receptacle assemblies are clearly free of moisture before making their connections. Berthing ships should provide all electrical tests performed at the retrofitted ships or new ships with shore power provisions inside the ship.

In the countries where utility power supply is 50 Hz, frequency converter equipment (ac-to-dc and dc-to-ac conversion) and associated infrastructure is required at the port to be able to provide 60-Hz power at the required ship voltage 6.6 kV or 11.0 kV ac 60 Hz. This standard makes no clear statement on 50- to 60-Hz frequency.

There seems to be no concern of a berthing ship from electrochemical corrosion included in Par. 4.3.r, and thus this wording may require future review.

Use of long HV power cables shield grounding at one end by application of surge limiters in the link box not only helps in reducing power losses during shore-to-ship operation, it may also help in eliminating a parallel conducting path to CMGC, when monitoring the circuit. Therefore, grounding long HV power cables shield grounding at one end only should be the subject of review by the WG members of the standard [1].

Acknowledgment

The authors thank Kor Yen for his input on the two accidents described in the “Compatibility Assessment” section, which illustrate the need to enhance/improve the safety of shore-to-ship power supplies; and International Electrotechnical Commission/International Organization for Standardization/IEEE JWG28 members who have contributed in this collaborative effort to update 80005-1. The authors request all other ports to report to the working group such incidents for improvement of applicable marine standards.

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