

# COLD IRONING POWER SYSTEM DESIGN AND ELECTRICAL SAFETY

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**Abstract**--Cold Ironing Power System design requires unique components to supply shore power to ships for "cold ironing" operation. Currently, development of new standards are in progress and operating procedures are being written to maximize electrical safety, standardization of the process and interchangeability from one location to another. This paper describes the power system design including power system protection scheme which should enhance the electrical safety by design. Power system grounding, equipment grounding, and touch potential that can impact personnel safety are described. A very basic outline of the operating procedures and training needed for the operators to maximize electrical safety during cold ironing operation are also included in the paper. In addition, paper provides the current status of the Draft IEC/ISO/IEEE Standards 80005-1 [5] and 80005-2[6].

**Index Terms**— Cold Ironing Power System, Electrical Safety, equipment grounding, ground grid, safe touch and step potentials, shore-to-ship connection.

## I. INTRODUCTION

Due to environmental considerations, ships are being required to turn off their auxiliary generators and instead receive power from shore system. This method of connecting ships to shore power supply system during berthing at the port is called "cold ironing". The true definition of "cold ironing" does not exactly apply to this process, however this process at a berth is becoming understood as "cold ironing" in the shipping industry. This method helps to minimize air pollution as the on-board crude oil generators are turned off while shore power generated at a remote location with relatively less polluting fuel is supplied to ships during cold ironing. [1][2][3][4][9]. Shore power rated at 6.6 kV or 11 kV at 60 Hz frequency is supplied to ships by use of multiple parallel feeder circuits to supply the required power to match the auxiliary generator load requirements of various ships. Unlike any other industrial or commercial power system which once gets energized are tripped only in case of maintenance or under fault conditions, the cold ironing power system requires turning ON and OFF breakers which pose safety concern for operators. In addition, electrical power system infrastructure of a major port needs to be supplemented to meet this need through the addition of several cold ironing substations and a local bulk power substation (BPSS) with high voltage (HV) primary. The later poses additional safety concern of dangerous touch potential. This paper provides a cold ironing power system design using draft standard

IEC/ISO/IEEE 80005-1 [5] criteria. The current status of this draft standard is also addressed.

## II. SHORE TO SHIP POWER SUPPLY SYSTEM

Shore to ship power supply systems go by variety of names: Cold Ironing, Alternative Maritime Power (AMP), Onshore Power Supply, and Shore to Ship Power Supply and Shore-side Electricity. These variations in names are strictly due to usage adopted by different organizations involved in this application and have no other significance. Authors of this paper recommend the adoption of "Shore to Ship Power Supply", which is descriptive to the application implemented. Different vessels during berthing will require different power depending upon the type and size of the vessel. The power requirements of various vessel types and sizes presented in Table 1 are taken from current draft standard IEC/ISO/IEEE 80005-1 [5].

TABLE 1 POWER REQUIREMENTS AT BERTH

Ship Type	Voltage	Power
Cruise ships	6.6 kV or 11 kV	16-20 MVA
Container ships	6.6 kV	7.5 MVA
Liquefied Natural Gas Carriers (LNGC)	6.6 kV or 11 kV	10.7 MVA
Ro-Ro ships	11 kV	6.5 MVA
Tankers	6.6 kV	7.2 MVA

To connect a berthing ship to shore power for cold ironing operation, a dedicated substation transformer of adequate rating with secondary voltage of either 6.6 kV or 11.0 kV is required. The word dedicated substation transformer means only one ship connection to one transformer in order to satisfy the galvanic isolation requirements of the current draft standard [5]. Such a design will protect the ship power system from abnormalities of the shore power system, especially if the shore power system is common for power distribution to other facilities within port area. Many power system grounding problems and stray currents associated with other port facilities can affect the ship power supply ground fault protection unless the shore power system has its own grounding zone provided by a dedicated transformer with a neutral grounding resistor (NGR) as shown Fig. 1 for connection to ship depicted in Fig. 2.

Most ships under construction today are designed for 60 HZ operation as a standard order. However, 50 HZ ships are considered as a special order at an added cost and will require an additional footprint for the 60 Hz to 50 Hz

frequency converters (FC) on the ship for connection to 60 Hz shore power. Therefore, it is expected that the majority of the ships will require 60 Hz power supply and not 50 Hz. Consequently, where utility power supply is 50 Hz frequency converters will be required on shore before the shore power substation transformer [7]. The design of a cold ironing project requiring FC is the subject of another paper and thus will not be addressed here. A major port with several cold ironing projects may require a BPSS with the HV primary close to the port facilities. A dangerous touch potential can be caused by high line-ground fault on HV side of such a BPSS without appropriate design considerations. This paper provides a design method for mitigating such dangerous touch potential.

**A. Unique Features:** The shore power transformer is kept energized even when a ship is not connected to draw shore power and thus a transformer with low no load losses is desirable. Each "cold ironing" operation requires power circuit breakers of the shore's and ship's power systems to close and then open, posing unusual duty on the breakers. Operators perform connections of shore power to ships by use of cable management system (CMS), which are a combination of flexible cables and power plugs/receptacle assemblies. Power plugs are very heavy and require cranes to maneuver before being plugged into the receptacles. Applications such as cruise ships require continuity check wiring monitoring of emergency trip circuits and separate plug and receptacle assemblies. Each "cold ironing" operation require two synchronizing operations, one for transferring the ship's auxiliary generator load to shore power and the second for transferring the ship's load back to the ship's auxiliary generator. Physically, the substation switchgear AMP-A and the load interrupter switchgear ES and AMP boxes shown in Fig. 1 may all be physically far apart from each other. These unique features of the power system design and operation pose many safety concerns. The design approach presented in this paper considers and mitigates these safety concerns. If with the movement of the ship; causes the flexible cable to pull, the continuity circuit pin which breaks the continuity of the circuit, then the circuit breakers would open automatically on both the shore and the ship systems. Emergency trip push buttons are also installed on shore and on the ship at specific locations to manually trip the circuit breakers in case of emergency.

**B. Unique Power System Components:** listed below are unique components of cold ironing power system.

- Three pole grounding switch to discharge MV cables [16].
- Three pole main disconnect switch for isolation of AMP boxes
- Standard ratings of female power receptacle are 350 A or 500 A at both 6.6 kV and 11.0 kV. They consist of six pins: three power, one ground and two pilots. Ground and pilot pins make last and break first for safety. Pilot pins are used for continuity check circuit and the emergency trip circuits [5].

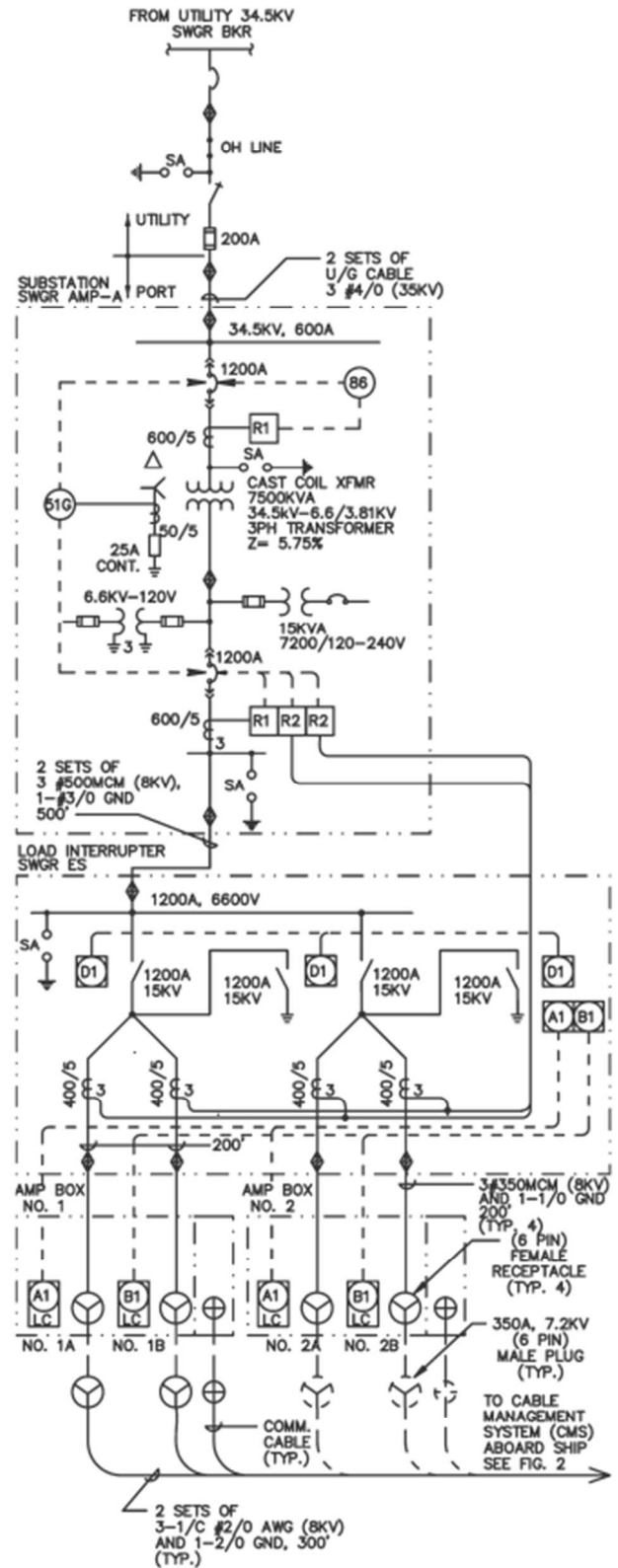


Fig. 1 Cold Ironing Power System – One Line Diagram

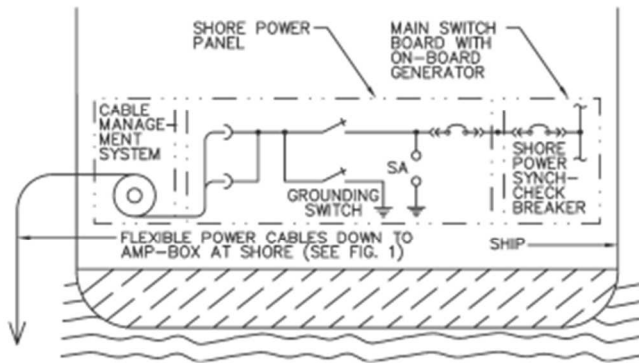


Fig. 2 Shore power panel on ship

- Matching male power plugs assembled at the end of flexible power cables are designed to make safe connections. Power plugs standard ratings are also 350 A or 500 A at both voltage ratings 6.6 kV and 11.0 kV [5].
- Cable management system (CMS) for reeling and unreeling the flexible power cable. Fig. 2 shows CMS located on ship however, this can be on shore on movable trolley. Safety limit switches are built into the cable reel system to avoid pulling tension on cable system and the plug/receptacle assembly [5].
- Separate receptacle and matching plug assemblies are implemented for communication and emergency trip circuits.
- Kirk-Key interlocks between the power receptacle cover, grounding switch, and main disconnect switch are implemented to assure power system is de-energized and cable system is discharged by grounding switches [16] when shore to ship connections are performed.
- High resistance grounded (HRG) power system with a neutral grounding resistor (NGR) and associated ground fault protection relay [13]. NGR is monitored continuously for open circuit or short circuit conditions and breakers open automatically on both sides if any of these abnormalities are detected.
- Multifunction individual protection relays on each feeder to power receptacle includes minimum of device 50/51, 50/51N as well as live line indicating lights for protection of equipment and safety of operators.
- Transformer primary protection includes multifunction relays with minimum devices 50/51, 50/51N, 59 and 27.
- Transformer secondary power system protection includes multifunction relays with minimum devices of 50/51, 50/51N, 32, 59, 27, 47, 46, 81O, 81U and 25.
- Power transformer protection devices include 49W for a dry-type cast-coil transformer and devices 49W; 71Q; 26Q; 63SR; and 63PR for the oil-filled transformer. All devices listed here for the oil-filled transformer are not in the current draft standard [5]. Considering the application of the upcoming frequency converters (FC) where utility power frequency is 50 Hz will require additional power transformers on line-side of the FC whereas the dedicated shore power transformers will still be required for the cold ironing power supply system. These

additional transformers may require all protection devices associated with oil-filled transformer depending upon the configuration and design of the FC package at a particular port.

**C. Substation Transformer Rating:** To accommodate varying load requirements of the ships indicated in Table 1, the overload capability of the transformer should be considered. Both the liquid-immersed and the dry-type transformers overload guides are contained in ANSI/IEEE C57.91 and C57.96 [7]. Forced air (FA) cooling is a common method that can increase the loading of both types of transformers. For a liquid-immersed transformer, FA options can offer 12% overload at  $\leq 2.5$  MVA and 25% for anything larger. For a dry-type transformer, FA options can offer 33 1/3% overload at  $\leq 3.75$  MVA and 25% for anything larger.

**D. Major Electrical Upgrades at Port Facilities:** Major ports with several cold ironing berths may require a utility power supply at HV ranging from 34.5 kV to 230 kV. Such HV supply system with associated BPSS located within the port facility can pose additional challenges associated with safety to operators during line-to-ground fault especially on primary side of the BPSS. With the application of equipotential grounding conductor between the shore and the ship, the voltage at the ship hull may rise to dangerous touch voltage during line to ground fault on primary HV side of BPSS. Section III below discusses such touch voltage and grounding design of the BPSS.

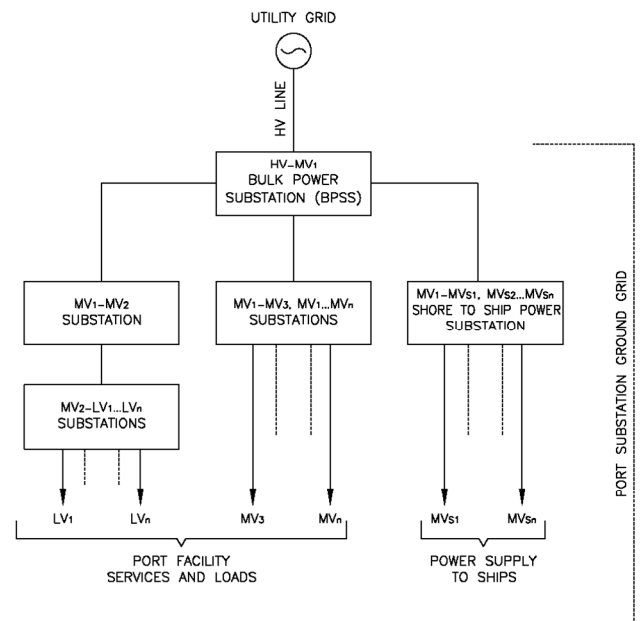


Fig. 3 Bulk power substation within port facilities

### III. GROUNDING AND TOUCH POTENTIAL

To make a HRG power system, ship generators are either grounded by individual neutral resistors or they are kept ungrounded to use one common homo-polar grounding scheme [2]. Connection of a dedicated ship to a dedicated

shore power substation has lead the design of the shore power system to be a HRG with a ground fault sensor relay at the NGR to minimize equipment damage during line-ground fault [5] [10] [13].

**A. Grounding Criterion:** The criterion of a HRG system is that during bolted line-to-ground fault condition, the neutral resistor should allow the resistive component of the fault current to be equal to or greater than the total system charging current [10] [13]. The combined system charging current of the ship and the shore power system should be known to determine the rating of the NGR. This criterion is depicted graphically in Fig. 4 [8]. For example, assuming total system charging current of 17A, this will result in a maximum line to ground fault current of 24A if NGR is rated at 17A. Now if the actual installed system charging current becomes higher than 17A, then this NGR rated at 17A may become unacceptable as the fault current point will fall in the unacceptable zone. This can cause transient overvoltage and equipment damage. To avoid such an uncertain situation a multiplication safety factor of 1.25 should be applied to the estimated or calculated system charging current to determine NGR rating by use of equation (1). Measurement of the system charging current in the case of a cold ironing project is also recommended to assure correct NGR rating [10]. Such measurements should involve largest expected ship for cold ironing project. Such measurements may be avoided if the NGR ampere rating is increased, however, ship authority may not allow such a design. Consequently, the best approach is that the ship authority should provide ship's on-board power system charging current for correct NRG rating. Using some safety factors for NGR rating, taking an example of 17 A total systems charging current, all points such as B, C or D in Fig. 4 will be in the acceptable zone for NGR rating.

$$R_N = E_{LN} / (1.25I_C) \quad \Omega \tag{1}$$

Where:

- $R_N$  is the transformer neutral grounding resistor
- $E_{LN}$  is the line to neutral voltage
- $I_C$  is the total (combined) system charging current of the shore and the ship power system

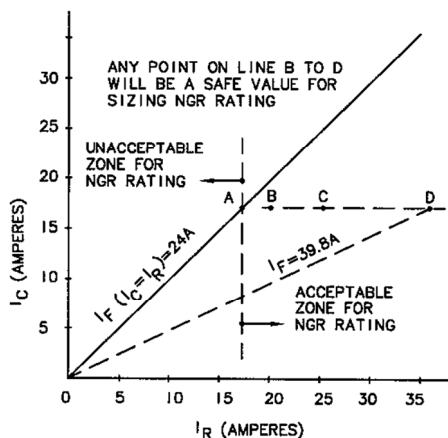


Fig. 4 Representation of a HRG power system criterion

**B. Touch Potential:** During the line-to-ground fault condition, a ground potential that rises ( $V_{GPR}$ ) above the remote earth (zero reference point) takes place and all electrical equipment enclosures bonded to the same ground are exposed to this voltage  $V_{GPR}$ . Touch potential will be a certain % of  $V_{GPR}$  depending upon the voltage delay profile of  $V_{GPR}$ , see Fig. 5. This  $V_{GPR}$  in volts is indicated in equation (2).

$$V_{GPR} = G_R / I_G \tag{2}$$

Where

- $G_R$  is the ground grid resistance in ohm
- $I_G$  is the portion of ground fault current penetrating through the ground grid to return to the power system grounding location. In the case of a BPSS, power system grounding location is the neutral of the HV source which will be away from the port facility

Both ground grid resistance ( $G_R$ ) and grid current ( $I_G$ ) should be made low to make touch potentials less than tolerable voltages. Practical low limit of  $G_R$  is near 1 ohm. On the other hand  $I_G$  can be made low by installing a ground conductor with the HV primary overhead line or the underground HV cable system such that this ground conductor is grounded on both sides at the BPSS ground grid and at the HV primary source neutral. For example, if the impedance of this ground conductor is 0.25  $\Omega$  and  $G_R$  is 1  $\Omega$ , then  $I_G$  will be 20% of the line-to-ground fault current. This can help in designing economical safe ground grid at the BPSS.

Tolerable step and touch potentials are a function of the surface resistivity and generally crushed rock is used at the HV substation ground grid design due to its higher resistivity IEEE Std. 80 [11]. This IEEE Std. 80 is used by the industry to provide a safe substation ground grid design based upon on the tolerable touch and tolerable step potentials verses calculated touch and step potentials during line-to-ground fault within the substation. This safety analysis is related to how much current from hand-to-feet (touch potential) or from foot -to-foot (step potential) flows through the human body and for how long to be considered safe without the electric shock hazard. Maximum line-to-ground fault current, clearing time of the fault by ground fault protection device, and resistivity of the earth surface in the substation and around the energized electrical equipment are needed for safety analysis. IEEE Std. 80 establishes safe limits of potential differences (tolerable voltages) between points that can be contacted by the human body. The tolerable voltage equations provided in the IEEE Standard 80 are derived from the research work of C.F. Dalziel. The standard provides simplified formulas for calculating 50Hz and 60 Hz ac voltages that can be tolerated by 99.5% of the population. Step voltages are generally 3 times higher than the touch voltage for similar conditions. A simplified formula for tolerable touch voltage follows:

$$E_{Touch} = I_B (R_B + 1.5 p) \tag{3}$$

Where:

$R_B$  is human body resistance generally assumed as 1000  $\Omega$  (equivalent resistance of the human body)  
 $\rho$  is the electrical resistivity in ohm-meters for the material on which the person is standing (assumed here to be homogeneous material)  
 $I_B$  is the tolerable body current in amperes for a person weighing 110 lb (equal to  $0.116/\sqrt{t}$ ), where  $t$  is the tripping time of the circuit breaker in seconds or the duration of the touch voltage.

Using equation 3, tables 2 and 3 below provide the tolerable ac touch voltages in volts (rms.), where a line to ground fault current is such that current flow through the grounding grid  $I_G$  is 6.78 kA (approximately 1/3 of 20 kA ground fault current). This is based upon the assumption that due to the split factor of ground fault return current, 2/3 of the ground fault current returns to the power source via the grounding conductor installed with the supply conductors.

TABLE 2: TOLERABLE AC TOUCH VOLTAGES

Time (s)	Wet Concrete Low-Range $\rho = 21 \Omega$ meter	Wet Concrete Low-Range $\rho = 100 \Omega$ meter	Dry Soil $\rho = 1000 \Omega$ meter	Remarks
0.03	691	770	1,674	Note 1
0.05	535	597	1,297	Note 1
0.10	378	422	917	Note 1

Note 1: The table above conservatively assume that the hand and foot contact resistances are equal to zero and that glove and shore resistances are also equal to zero.

TABLE 3: TOLERABLE AC TOUCH VOLTAGES

Time (s)	Wet Concrete Low-Range $\rho = 21 \Omega$ meter	Wet Concrete Low-Range $\rho = 100 \Omega$ meter	Dry Soil $\rho = 1000 \Omega$ meter	Remarks
0.03	2700	2779	3684	Note 2
0.05	2092	2153	2853	Note 2
0.10	1479	1522	2018	Note 2

Note 2: The above table was developed assuming that the person in the substation has proper gloves and shoes with assumed resistance of 3000  $\Omega$ . This will change the value of human body resistance in equation (3) to 4000  $\Omega$

Suppose the substation ground grid resistance is 1  $\Omega$  and the ground grid current is 7 kA, then the  $V_{GPR}$  will be 7 kV, which may result in not to exceed the tolerable touch voltage as the touch voltage is a fraction of  $V_{GPR}$  as shown in Fig. 5. The voltage decay profile  $V_{GPR}$  is related to characteristics of soil under the ground grid and the surrounding area.

For the BPSS it can be assumed that the HV line can have ground fault close to the BPSS and that it will be the utility upstream breaker's protection device to clear this fault. For short duration until the fault is cleared, it can raise the BPSS to a dangerous  $V_{GPR}$  and touch potential at the ship hull may also be high due to the equipotential grounding conductor. *To minimize such a problem of dangerous touch potential if there is a ground conductor with the HV feeders then  $V_{GPR}$  may be only 20% (as explained earlier in the example using ground grid resistance of 1  $\Omega$  and ground conductor resistance of*

*0.25  $\Omega$ ), which is 1.4 kV (0.2x7 kV) less than the tolerable touch potential.*

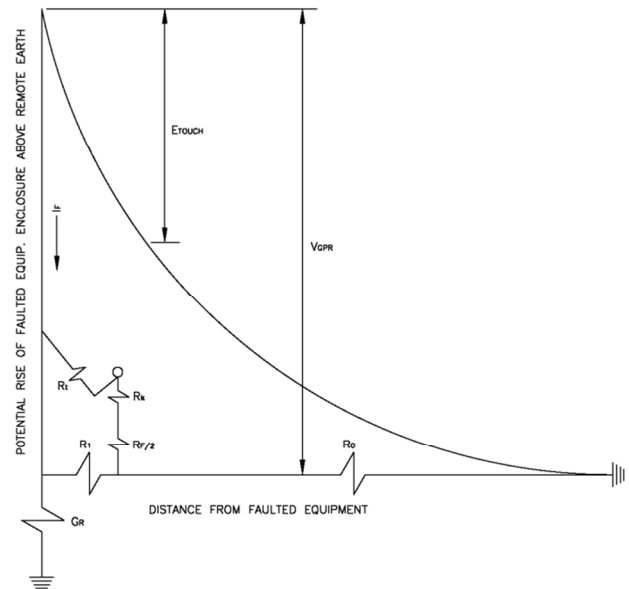


Fig. 5  $V_{GPR}$  Voltage Profile and Touch Potentials

In the case of ship hull which is bonded to shore by equipotential bonding conductor voltage on ship can be 1.4 kV and in the absence of insulating surface around swimmer. The barge operators may be exposed to dangerous touch potential due to potential difference between the ship hull and the barge as shown in Fig. 6. To solve such a problem, application of safety bonding conductors between the ship hull and the barge are recommended. Swimmers should use gloves and swim suits made of non-conducting material or warning signs should be posted for swimmers to be away from the busy port facility. Fault current at shore power facilities especially the BPSS should use ground conductor installed with HV feeders where it is an overhead line or the underground HV feeder cables.

In certain port area where rushed rock is not possible for the BPSS for certain reasons, then other possible ways are to work with the utility company that provide power to the port to perhaps change the BPSS transformer to a wye (solidly-grounded) – delta - wye (resistance grounded) instead of using delta-wye transformer. This will limit higher voltage exposure at the ship hull in case of line-ground fault on primary side of the BPSS as source grounding location is at the BPSS. On the secondary side, a low-resistance grounded secondary of the BPSS will result in less ground fault hazards at all other down-stream substations as well as use of less copper in the ground designs. Such a design change recommendation of making medium voltage (MV) power system as a low-resistance grounded system instead of a solidly grounded system will have no impact on power system reliability and protection other than the higher insulation level of the MV system and line-line rated surge protection devices. This cost impact of such a change may be minimum against

the benefit of the increased safety and economical ground grid designs.

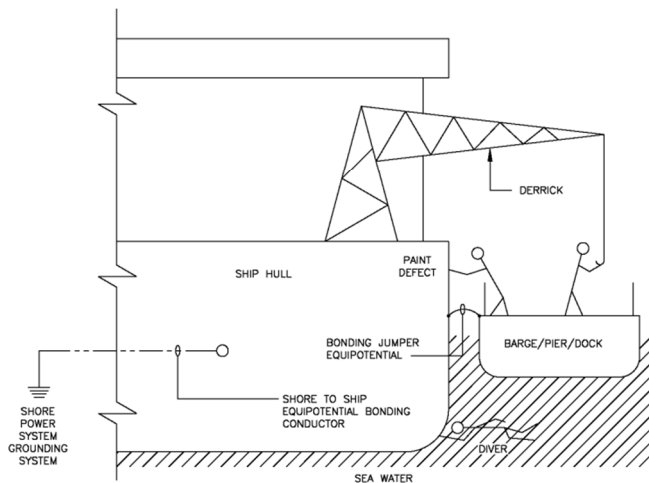


Fig. 6 Ship touch potential during berthing

**IV. COLD IRONING STANDARDS**

Various standards organizations have been working for the past five years on developing standards for implementing shore power. The three international bodies include the International Electro-technical Commission (IEC), the International Organization for Standardization (ISO), and the Institute of Electrical and Electronic Engineers (IEEE). Initially, all three bodies worked independently on developing new standards. IEEE Standards Working Group P1713 – Electrical Shore-to-Ship Connections was formed in 2006. All three have now combined their efforts to issue one joint standard, IEC/ISO/IEEE 80005-1 [5] High Voltage Shore Connection Systems. A committee draft for vote (CDV) of 80005-1 was issued in March 2011.

Committee members from 26 countries are involved in this triple logo standard IEC/ISO/IEEE. Authors of this paper originally worked on the IEEE Draft Standard P1713, which now has been integrated with IEC/ISO/IEEE 80005-1[5]. Some of the technical difficulties and issues that still need resolution are as follows:

1. Equipotential bonding conductor is described as the conductor that makes the connection between the electrical equipment enclosures on shore to the electrical equipment enclosures on the ship. In other words, this conductor bonds the shore substation to the ship hull. Through the application of continuous monitoring of this conductor and upon sensing of its' open-circuit condition, an automatic alarm at the ship and shore and tripping the both the shore and ship power circuit breakers require further reviews for reasons that there is another parallel path to this conductor. In the shore to ship power system, there are other inherent parallel paths to the equipment enclosure grounding conductor between the shore and the ship. These parallel paths are: a) each power cable's semi-conducting shield, and b) low resistivity earth path at port sites. These parallel paths will make continuous monitoring of the equipotential bonding conductor depicted in

Fig. 7 inappropriate (Fig. 7 taken from draft standard IEC/ISO/IEEE 80005-1 [5] for discussion purposes). The working committee of this draft standard [5] should review this circuit thoroughly and determine whether there is a need of such a design in the standard. Based upon using a HRG scheme of the shore power substation with NGR rating of 25A, there will not be a dangerous situation if equipotential grounding conductor breaks as the maximum touch voltage will be far less than 30V in a line-to-ground fault anywhere on shore to ship power system. Ground fault relay at the NGR will still operate properly as the current will return via cable shield and earth if the equipotential grounding conductor is lost.

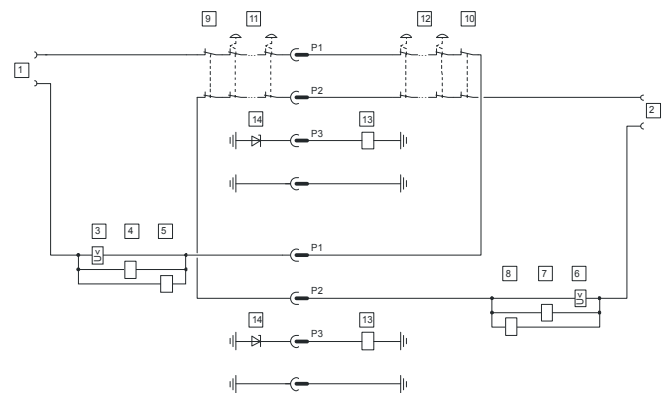


Fig. 7 Safety Circuits – Container Ship

- 1 Control power pilot loop shore
- 2 Control power pilot loop ship (VT fed from shore power source)
- 3 Circuit breaker undervoltage coil (shore)
- 4 Safety circuit coil on shore
- 5 Earthing (grounding) switch permission shore side
- 6 Circuit breaker undervoltage coil (ship)
- 8 Earthing switch permission ship side
- 9 Control ES shore (emergency shutdown)
- 10 Control ES ship (emergency shutdown)
- 11 Manual ES shore (two shown)
- 12 Manual ES ship (two shown)
- 13 Equipotential bond monitoring device
- 14 Equipotential bond monitoring termination device

2. For a cruise ship, an application of NGR disconnect switch (DS) to ground the NGR at the ship's hull during cold ironing period and then to ground the NGR on shore during non-cold ironing periods has no technical explanation in the current draft standard [5]. See Fig. 8 for such a DS at the NGR. A separate plug and receptacle assembly is needed for implementation of such a DS which can pose additional task for the operators and safety concerns and should be

evaluated by the committee to see if there is a need for such a DS. In the draft standard [5], for a container ship and other ships there is no such requirements of a NGR disconnect switch.

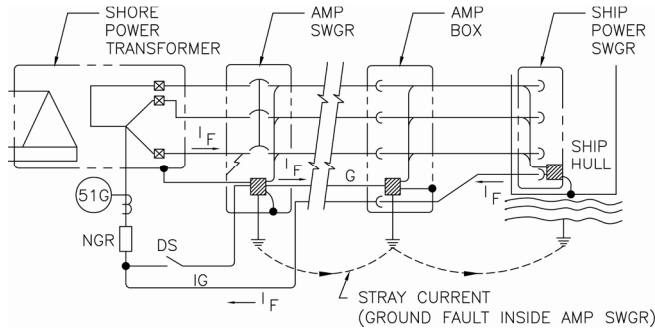


Fig. 8 Cruise ship grounding with NGR disconnect switch

3. For a cruise ship, a NGR rating of 540  $\Omega$  is shown in the draft standard [5] will allow maximum of 7A system charging current at 6.6 kV and 11.8 A at 11.0 kV. This rating may prove to be inadequate if the combined total system charging current of the shore and the ship power system exceeds 7A or 11.8A ratings for the 6.6 kV or the 11.0 kV power supply system respectively. Grounding criteria discussed under Section III should be stated in the standard and making current ratings made close to 20A to 25 A which will make the NGR ohm rating much lower than 540  $\Omega$  recommended in the standard [5]. See discussions on equipment damage at the fault location during line-to-ground fault on a HRG power system where impedance at the fault location may conclude that 25A NGR is better than NGR rated at 540  $\Omega$  [10]. See Fig. 9 for the shore power transformer grounding configuration with NGR.

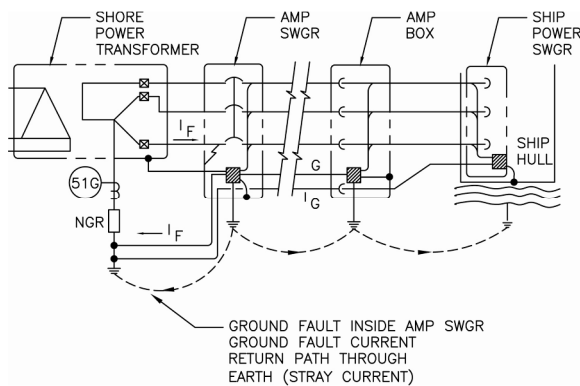


Fig. 9 Container ship grounding without NGR disc switch

4. Not all applicable IEEE standards appear to be listed in the Draft IEC/ISO/IEEE 80005-1 standard. This may cause project installation approval delays in USA where interpretation of all IEC listed standards in draft standard [5] may not apply. A review of normative IEC references listed under Section 2 of the draft standard [5] should be conducted

by working members to add applicable IEEE standards to correct this situation.

5. The authors do not believe that the IP based communications system of the draft standard 80005-2 [6] is necessary, especially for the container ships in USA where FC are not required. It is not clear what is perceived as so critical about the shore power transformer and other associated power system switching equipment where all protection devices are properly sized and set to protect the equipment during fault conditions. This assumes that equipment is adequately sized and then trained operators are on duty both on the port and at the ship during cold ironing period. Control monitoring and communications system between shore and the ship should be kept simple and practical to facilitate cargo loading and unloading operations without an unnecessary burden to the business.

6. IP based communications system currently described in IES/ISO/IEEE 80005-2 [6] is with a secure IP address for each ship and also alarm signal uses User Datagram Protocol (UDP). This approach will require IT professionals to develop a system that will be compatible with open protocols for interface devices on the ship and the shore to avoid being limited to proprietary equipment from one manufacturer. This current draft communication system standard between ship and shore perhaps should consider some changes to the wording prior to its enforcement to various categories of ship's cold ironing projects. Such change of wording may simply be "if any cold ironing project needs to implement such a requirement, they should do so outside of this standard".

## V. BASIC SAFETY TRAINING

Ports that have installed cold ironing projects have realized the need for special training for the shore and ship operators involved in the cold ironing operations. This section provides the very basic training needed for the operators to enhance safety.

- All persons go through the arc-flash hazard training.
- All installed equipment meet IEEE Standard 1584 [14] and NFPA 70E [15] and has proper energy labels and danger signs.
- All operators go through the training associated with cold ironing power system basic technical knowledge and understanding.
- Training on sequence of operation and steps needed for cold ironing operation for all operators.
- Person in charge (PIC) on the shore and PIC on the ship make all communications during cold ironing operation.
- Pre-assigned contact lists for electrical emergencies on shore or on the ship is clearly defined to avoid delays in case of emergency.

## V. CONCLUSION AND RECOMMENDATIONS

1. Unique features and components of the cold ironing power system that has direct impact on the safety have been discussed. To enhance safety through the design of the power system require the use of ground discharging disconnect switches, Kirk-Key interlocks, component safety devices to automatically trip the power system under abnormal operating condition, emergency trip stations, and HRG system and appropriate power system protection.
2. Mitigating the dangerous touch potential caused by a line to ground fault on the HV side of the local BPSS can be achieved by installing grounding conductor between the BPSS and the utility supply substations. The Port authority needs to coordinate and work with the local utility to see if grounding conductor with HV incoming line can be implemented. It also appears that there are benefits of requesting utility company to allow use of BPSS transformer with three windings, primary winding solidly grounded, middle windings delta connected, and the secondary windings low resistance grounded.
3. Operator training for the operation of the cold ironing power system and a need for a person in charge (PIC) on both shore and ship is highly recommended. Ports and ship authorities are working on standardizing such procedures.
4. This paper also provides the current status of both the IEC/ISO/IEEE draft standards 80005-1 [5] and 80005-2[6].

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