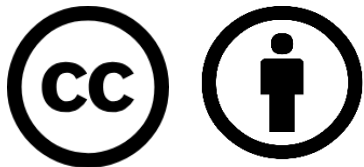


Electrical Distribution System Grounding

Distribution System Design

Revision of 10 October 2026

Dr. Norbert Doerry



<http://doerry.org/norbert/MarineElectricalPowerSystems/index.htm>

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Essential Questions

What are the principal features and methods of implementation of ungrounded systems, high-resistance grounded systems, and solidly grounded systems?	Understand
What grounding methods are appropriate for primary buses, distribution buses, secondary buses, and special buses?	Understand
How does one determine the required resistance of a neutral grounding resistor?	Apply
What are the different configurations of grounding transformers?	Understand
What are the advantages and disadvantages of a grounding bus?	Understand

Types of grounding systems onboard ship

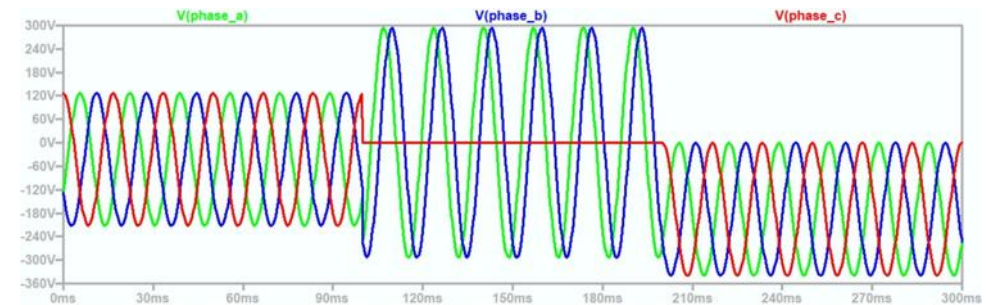
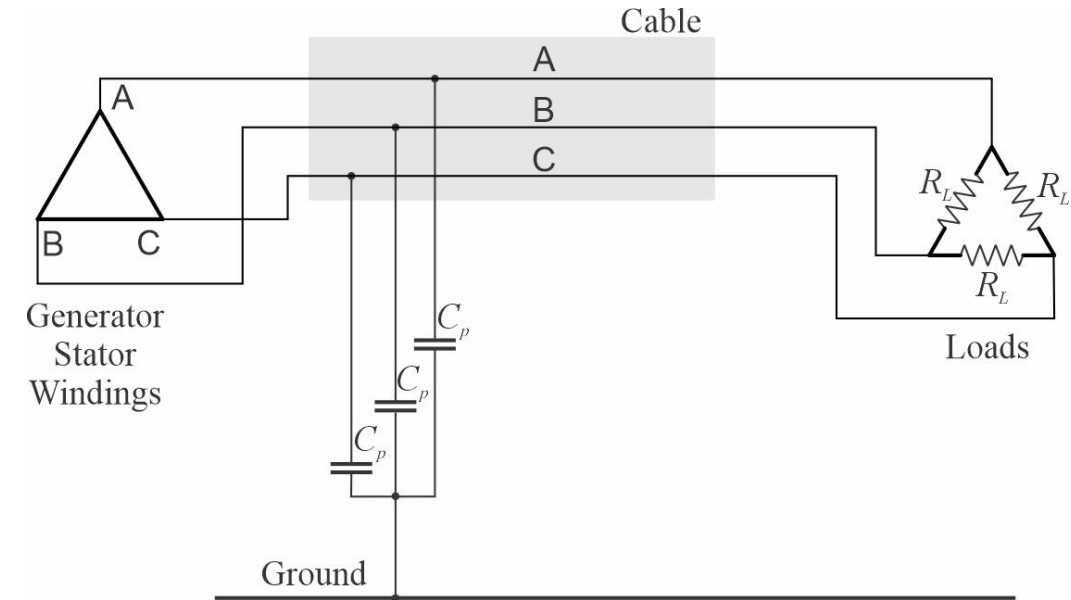
- Power system grounding
 - Protect insulation systems on shipboard power cabling, transformers, motors, generators, and other components.
 - Subject of this presentation.
- Equipment grounding (Protective earthing)
 - Protect personnel by bonding all exposed conductors together so they are the same voltage.
- Common mode grounding
 - Provide a designed path for higher frequency common mode currents instead of through parasitic impedances. Typically, implemented via Electromagnetic Interference (EMI) filters.
- Cathodic protection
 - Inhibit galvanic corrosion of the hull and other ship components.
- Lightning protection
 - Provide a designed path for lightning currents into the water.

Grounding methods for shipboard power systems

- Ungrounded
 - Traditional method used on ac systems with nominal system voltages at or below 1000 volts.
 - Recommended option for systems with a nominal system voltage at or below 1000 volts with mission critical equipment.
 - Enables operation with a single line-to-ground fault.
 - Susceptible to damaging transients from intermittent ground faults.
- High Resistance Grounded
 - Recommended for use on ac and dc systems with nominal system voltages above 1000 volts.
 - Recommended option for systems with a nominal system voltage at or below 1000 volts with mission critical equipment.
 - Enables operation with a single line-to-ground fault.
 - Much less susceptible to damaging transients from intermittent ground faults as compared to ungrounded systems.
- Solidly grounded
 - Recommended for use on ac and dc systems with nominal system voltages below 1000 volts and supplying only non-vital loads.
 - Improves compatibility with equipment designed for terrestrial power systems.
 - A line-to-ground fault is cleared by the fault protection system (circuit breakers).

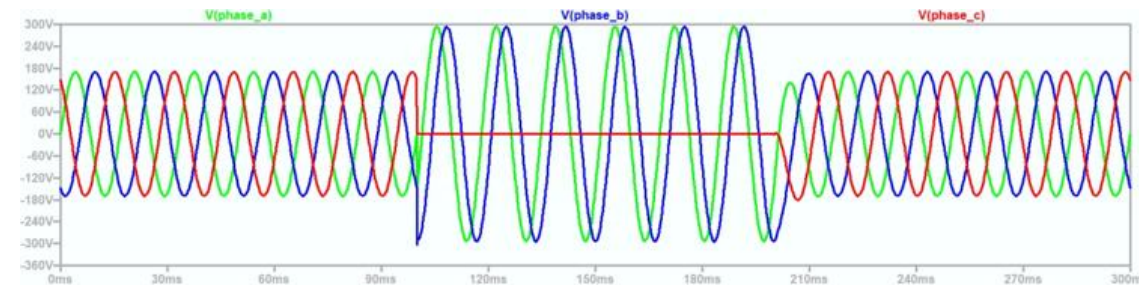
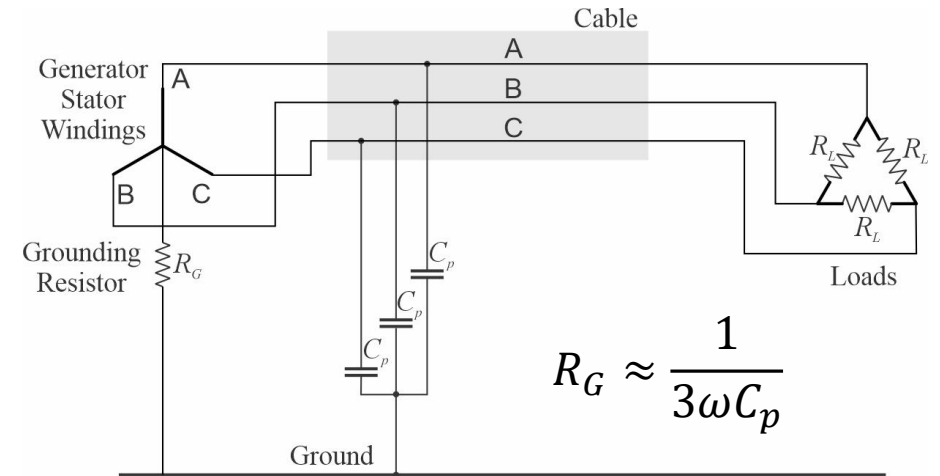
Ungrounded power systems

- No intentional connection between power system conductors and ground.
- Parasitic capacitances effectively make an ungrounded system capacitively grounded.
 - Under normal balanced conditions, no current flows through the hull from the parasitic capacitances.
- Continued operation with a single line-to-ground fault possible.
- Line-to-ground insulation must be rated for line-to-line nominal voltage.
- Susceptible to large transient voltages during intermittent ground faults and other transient events.



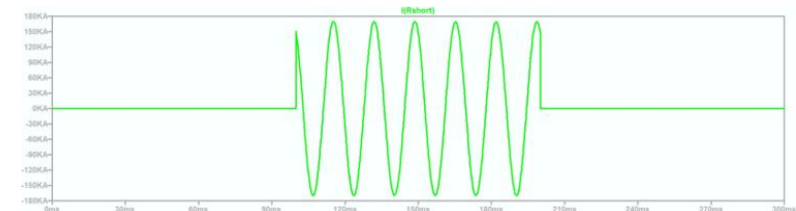
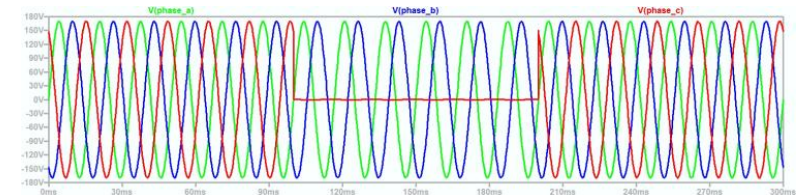
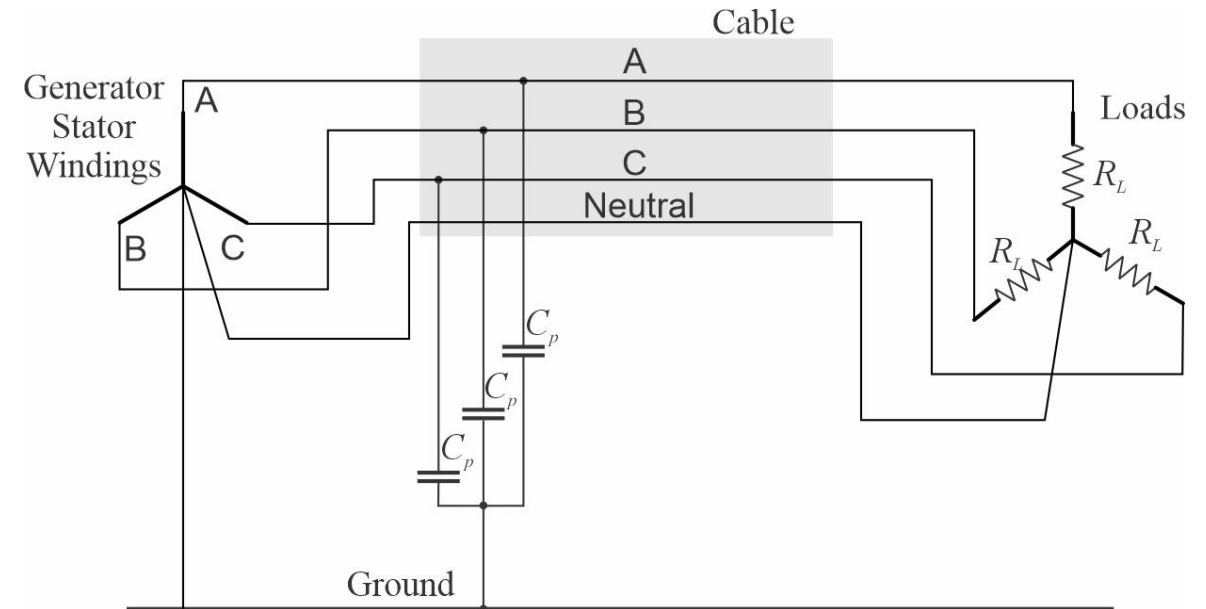
High resistance grounded power system

- Neutral of the power system connected by Grounding Resistor to ground.
 - Resistor resistance should roughly equal the magnitude of impedance of the parallel combination of the parasitic capacitances.
 - Resistor should have power rating greater than the line to neutral voltage squared divided by the resistance.
 - A grounding transformer is required if the source is a delta winding.
- Under unfaulted conditions, no current flows through the hull of the ship.
- Continued operation with a single line-to-ground fault possible.
 - Ground fault currents not high enough to trip circuit breakers.
- Line-to-ground insulation must be rated for line-to-line nominal voltage.
- Much reduced susceptibility to large transient voltages during intermittent ground faults and other transient events.



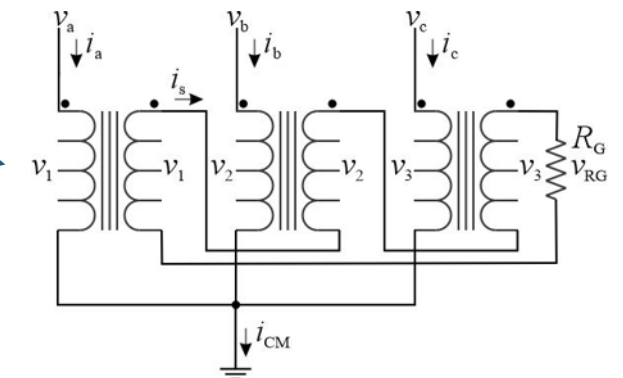
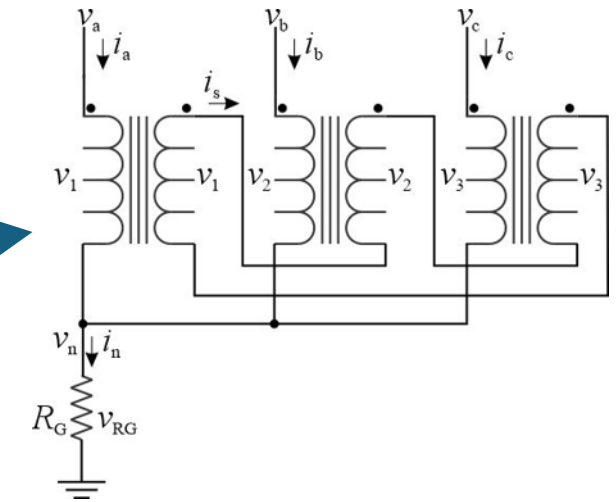
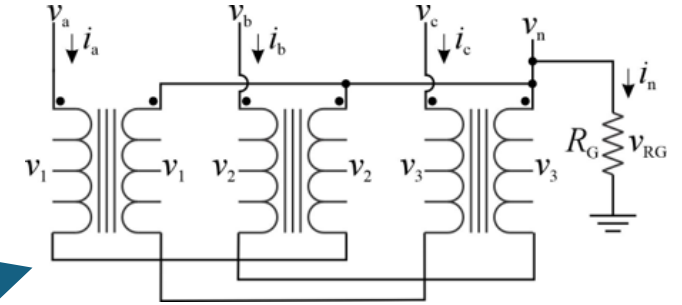
Solidly grounded power system

- The neutral connection of the wye connected source is solidly connected to ground.
- The neutral connection of wye connected loads may also be solidly connected to the neutral connection of the wye connected source.
 - Enables loads with two different voltage ratings (120 / 208 V for example).
- During a ground fault, large fault currents flow.
 - Circuit breakers trip to isolate the ground fault.
 - Loads on faulted circuits automatically lose power; even when it is not desirable.
- Generally limited to circuits where the loads are all non-vital.
- Line-to-ground Insulation need only be rated for line-to-neutral voltages.
- Much reduced susceptibility to large transient voltages during intermittent ground faults and other transient events.



Grounding Transformers

- Goal: two terminals with a voltage proportional to the neutral voltage of a three-phase power system
- Three common types
 - Zigzag transformer
 - Low voltage
 - Requires turns ratio = 1
 - Wye-delta transformer
 - Low voltage
 - Turns ratio does not have to be 1
 - Wye-broken delta transformer
 - Medium voltage
 - Turns ratio enables using low voltage sensors on grounding resistors



Grounding Resistor

- Usually wire wound resistors
- Power dissipation during a ground fault can be high
- Grounding resistors should have an indefinite rating since the length of time the ground fault will persist is unknown

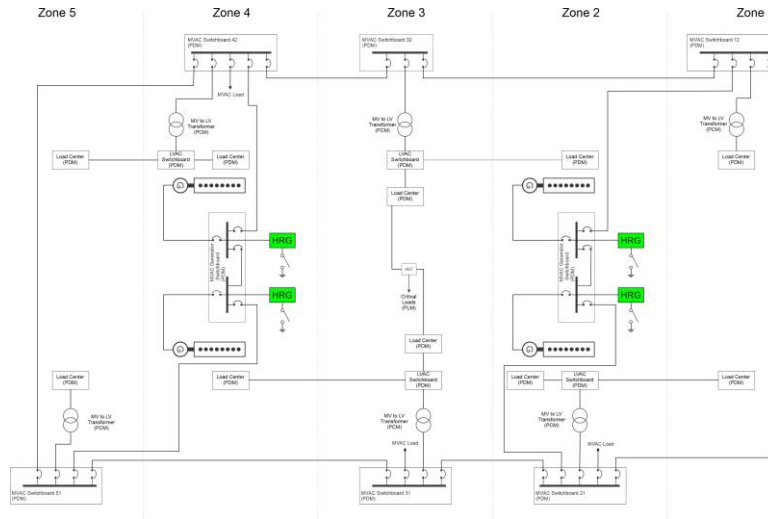
$$P_{GR} = \frac{V_{ll} I_{Gmax}}{\sqrt{3}}$$

	Minimum Power Rating of Grounding Resistor (kW)			
Nominal System Voltage	5 amp Resistor Current	10 amp Resistor Current	15 amp Resistor Current	20 amp Resistor Current
400	1.2	2.3	3.5	4.6
450	1.3	2.6	3.9	5.2
480	1.4	2.8	4.2	5.5
600	1.7	3.5	5.2	6.9
690	2.0	4.0	6.0	8.0
3300	9.5	19.1	28.6	38.1
4160	12.0	24.0	36.0	48.0
6600	19.1	38.1	57.2	76.2
11000	31.8	63.5	95.3	127.0
13800	39.8	79.7	119.5	159.3

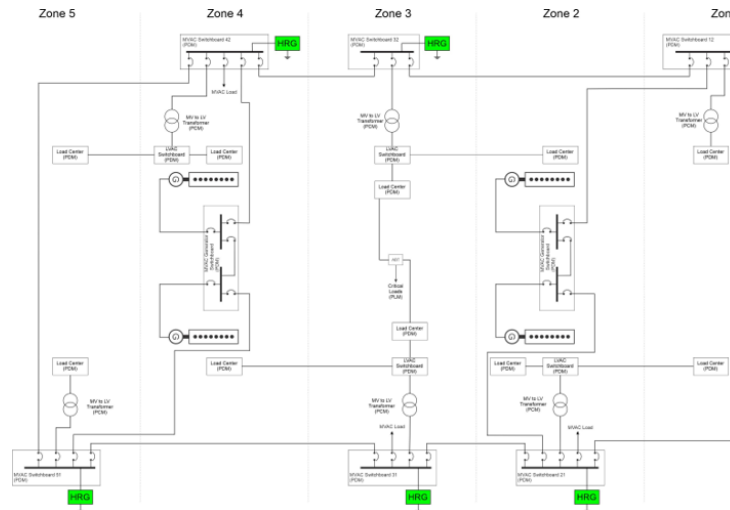
Grounding bus – High resistance grounding

- Each separately derived system is required by regulation to have only one point of connection to ground
 - Makes sense for solidly grounded systems.
 - Not clear why necessary for high resistance grounded systems.
- Grounding bus
 - facilitates simplifying systems with high resistance grounding,
 - while providing only one point of connection to ground.

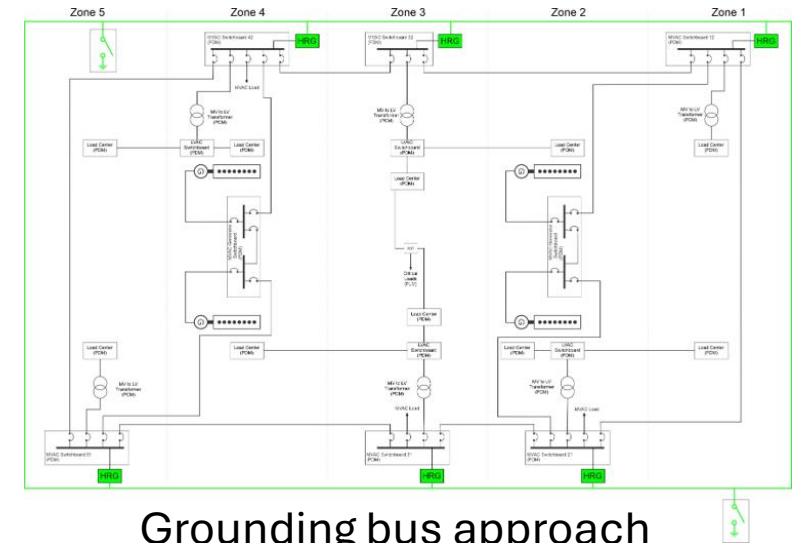
Grounding examples



Traditional approach
Ground Resistors sized
for total ship C_p

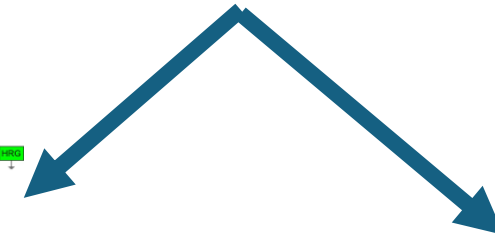


Zonal approach
Ground Resistors sized
for zonal served load C_p



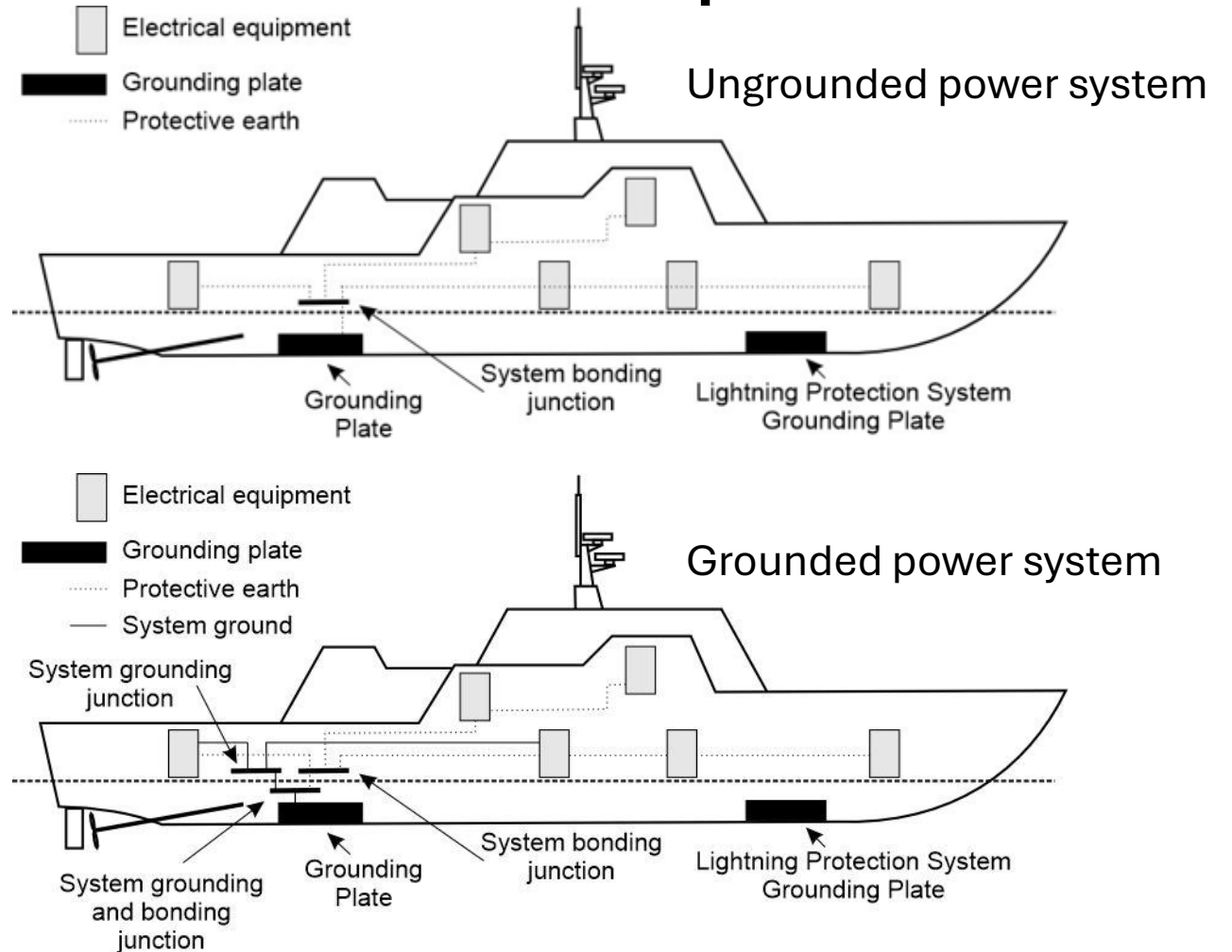
Grounding bus approach
Ground Resistors sized
for zonal served load C_p

Grounding resistors individually
dissipate much less power as
compared to Traditional Approach



Grounding bus – nonmetallic hull ships

- Grounding plate
 - Copper
 - Minimum 0.2 m²
 - Lowest point of hull
- Common plate for
 - System ground (if needed)
 - Protective earthing
- Not common with
 - Lightning protection system grounding plate

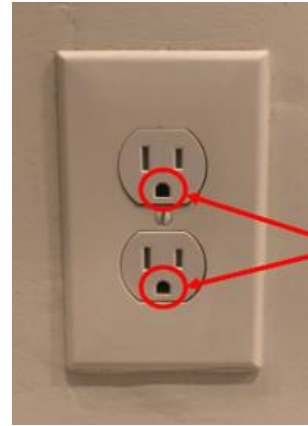


Applications

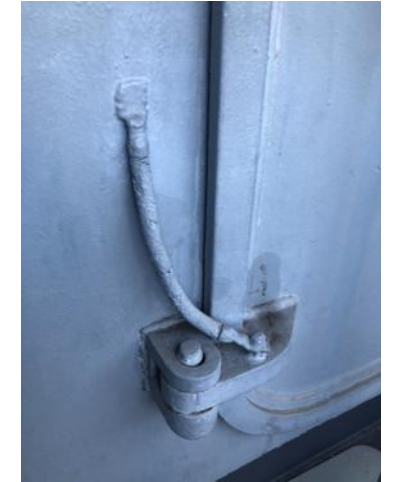
- Primary bus
 - High resistance grounded system
- Distribution bus
 - Either high resistance grounded system or,
 - Ungrounded system
- Secondary bus
 - Critical loads: high resistance grounded or ungrounded
 - Non-critical loads: solidly grounded
- Special bus
 - May require special grounding treatment

Bonding – Equipment Ground – Protective Earthing

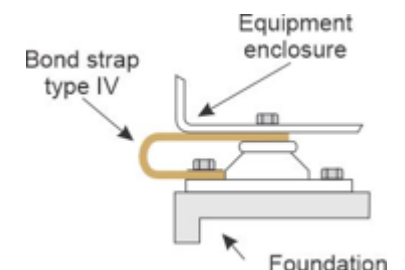
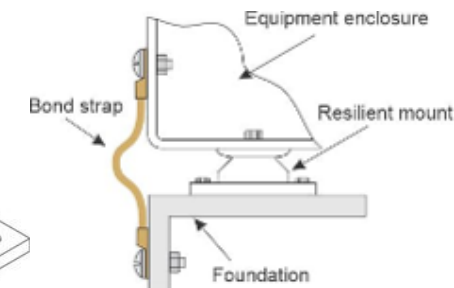
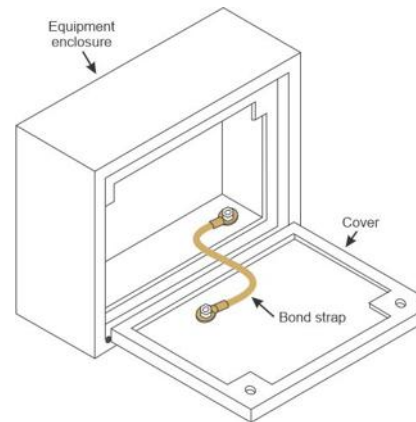
- Connect all exposed conductors to ground
 - Typically, the ship's structure
- Primarily for personnel protection
- Also used to control EMI.



Equipment
Ground



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Illustrations adapted from MIL-STD-2003-2

References

- IEEE Std 45.1 IEEE Recommended Practice for Electrical Installations on Shipboard--Design
- IEEE Std 45.3 IEEE Recommended Practice for Electrical Installations on Shipboard--Systems Engineering
- IEEE Std 3003.1 IEEE Recommended Practice for System Grounding of Industrial and Commercial Power Systems
- MIL-STD-1310 Department of Defense Standard Practice – Shipboard Bonding, Grounding, and other techniques for electromagnetic compatibility, electromagnetic pulse (EMP) mitigation, and safety
- MIL-STD-2003-2 Department of Defense Standard Practice – Electric Plant Installation Standard Methods for Surface Ships and Submarines (Equipment)
- Doerry, Norbert, Mohammed M. Islam, John Prousalidis, *Design of Shipboard Power System Grounding / Earthing*, IEEE Press - Wiley, January 2025, ISBN-10 1119933080 ISBN-13 978-1119933083

