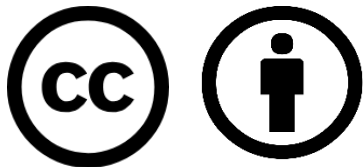


Ground Fault Detection and Insulation Monitoring

Distribution System Design

Revision of 15 October 2026

Dr. Norbert Doerry



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

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Essential Questions

What are ground detection lights? What methods of grounding do they apply? Understand

What is an insulation monitoring system? What methods of grounding does an Insulation Monitoring system work with? Understand

What are other methods of detecting a ground fault? Understand

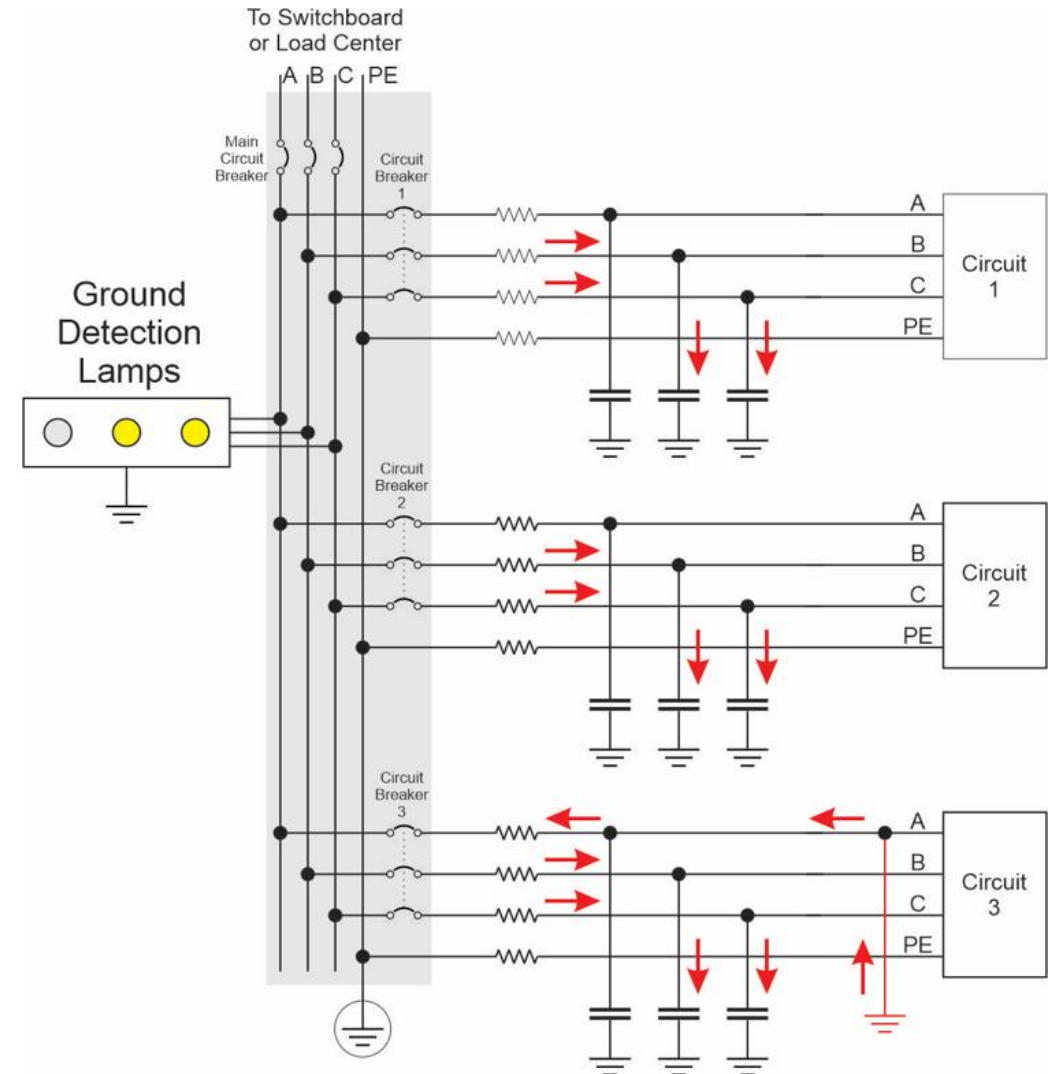
How are ground faults localized and isolated? Apply

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.

Ground faults – ungrounded systems

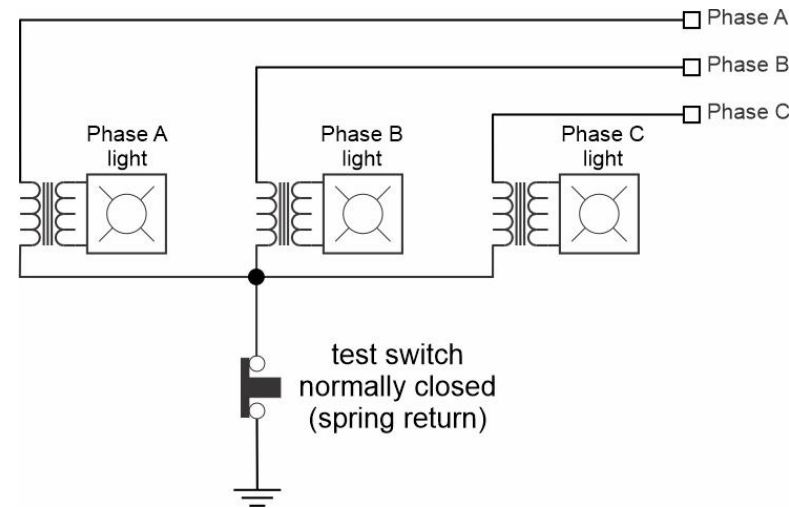
- Under normal conditions, very little current flows in the hull.
 - Parasitic capacitances are more or less balanced.
- In a ground fault, fault current:
 - Flows through the distributed parasitic capacitances to ground of the unfaulted phases.
 - Flows through the ship's hull.
 - Returns via the faulted phase through the ground fault.



Ground fault detection – ungrounded systems

Ground detection lamps

- Three lamps connected in wye
- Common point connected to ground via a normally closed switch
- Three lamps are dimly lit (line-to-neutral voltage) when no ground fault
- If a ground fault is present
 - Fault phase lamp extinguishes
 - Unfaulted phase lamps are brightly lit (line-to-line voltage)
- Test switch disconnects connection to ground to test lamps
 - All lamps should be dimly lit



USS Slater (DE-766) Ground Detection Lamps
(Photo by Norbert Doerry: CC BY 4.0)

Ground fault detection – ungrounded systems

Insulation monitoring devices

- Estimates the resistance of the insulation for each phase.
 - Injection of voltages and currents and measuring response.
- If the insulation resistance falls below a preset value, the operator is notified.
 - Can identify failing insulation before an actual ground fault occurs.
- Insulation monitoring systems and ground-detection lamps are not compatible.
 - Line-to-ground impedance of the lamps is likely low enough for the insulation monitoring system to interpret the impedance as failing insulation.

Ground fault detection – ungrounded systems

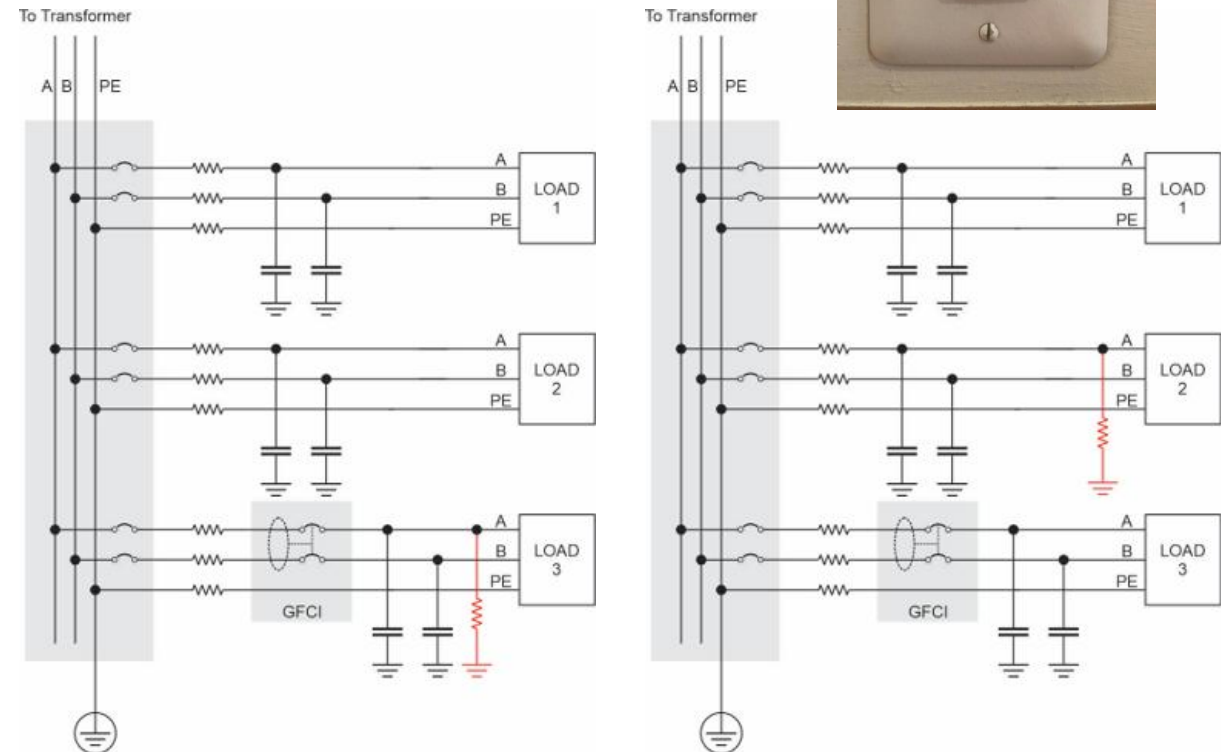
Line-to-ground voltage measurement

- Detect ground faults by directly measuring each of the three-phase line to ground voltages.
 - Calculate the neutral voltage.
 - If differs significantly from ground, have a ground fault.
- If impedance of the voltage sensors are not high enough, may interfere with insulation monitoring devices.

Ground fault detection – ungrounded systems

Ground fault circuit interrupter (GFCI)

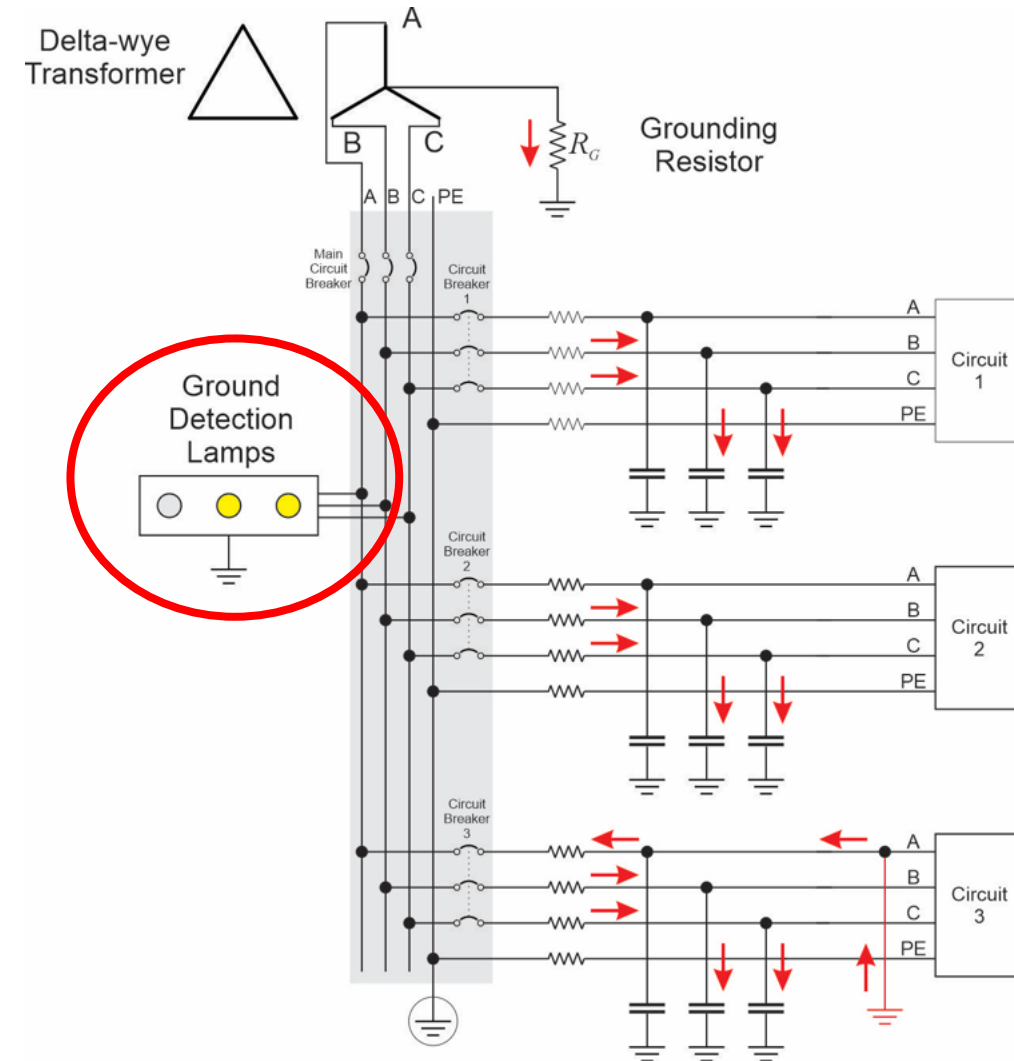
- Measures common-mode(CM) current.
- Trips if CM current too high.
- Similar to:
 - Residual Current Detector (RCD)
 - Combination of an RCD and miniature circuit breaker (RCBO)
 - Appliance Leakage Current Interrupter (ALCI)
- Will only trip if the fault current from the parasitic capacitances is high enough.
- Can inappropriately trip if the line-to-ground capacitance of GFCI protected circuit is large and ground fault in on a different cable.



Ground fault detection – high resistance grounded systems

Ground detection lamps

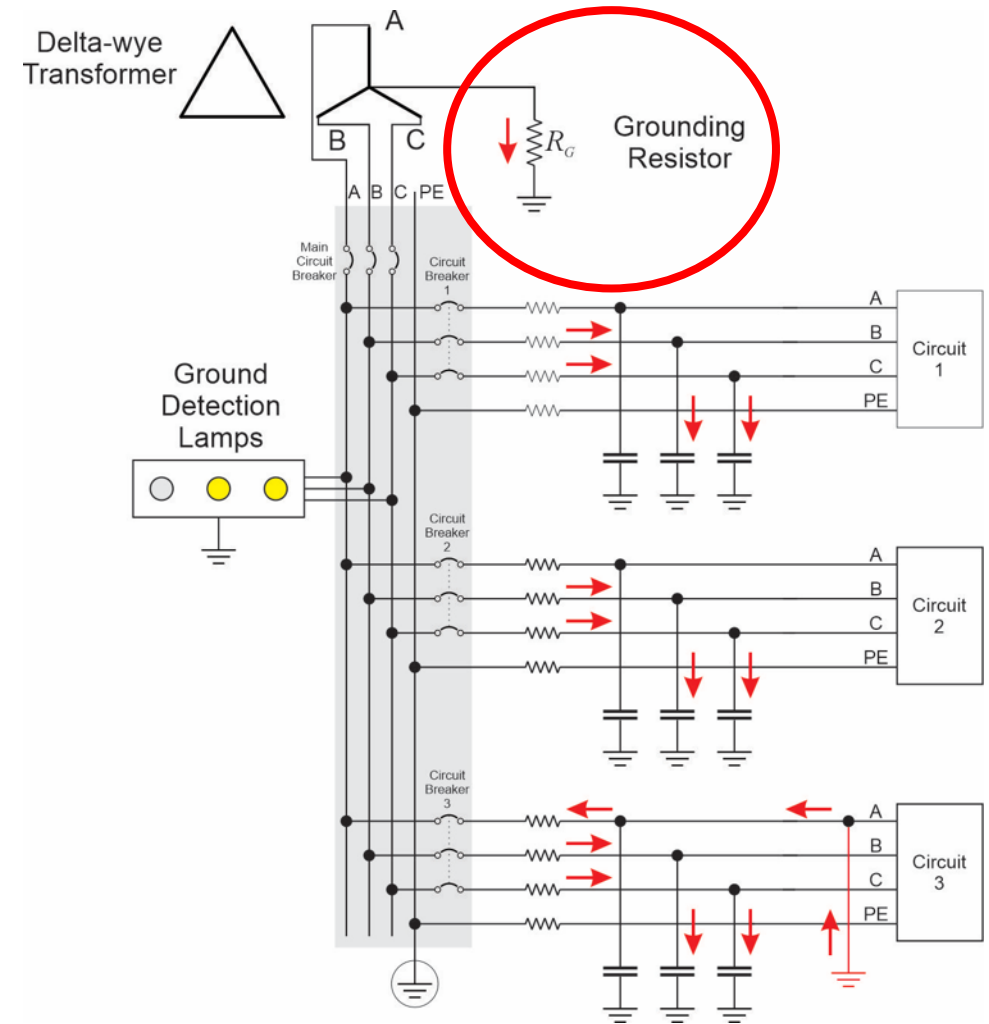
- Work in same way as for ungrounded systems.
 - Grounding resistor provides additional path for ground fault current.



Ground fault detection – high resistance grounded systems

Voltage and current measurements on grounding resistor

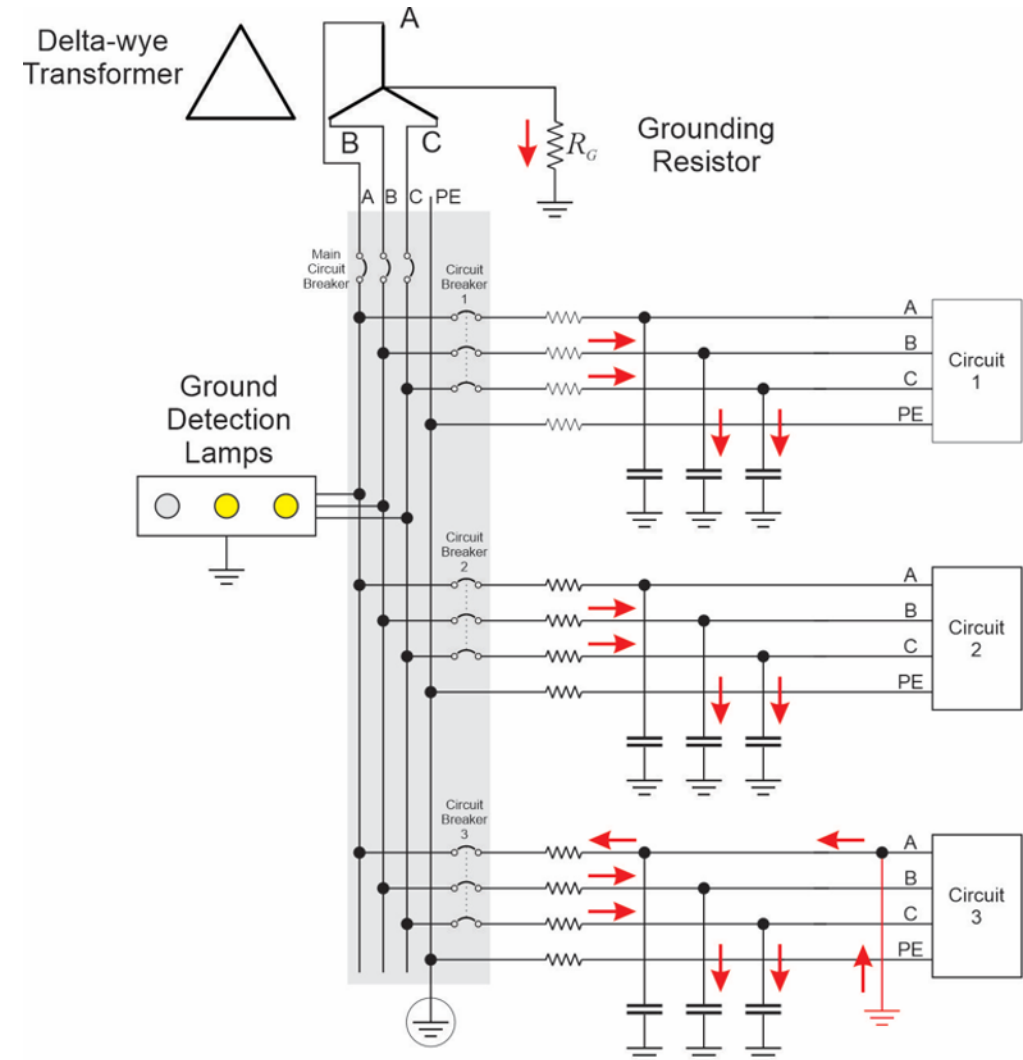
- Measure current through and voltage across grounding resistor.
 - Under normal conditions, both should be near 0.
 - If a ground fault is present, both should not be 0.
 - Only one being 0 is an indication of a failure in the grounding resistor.
- If the magnitude of the current and voltage is above a threshold, the operator is notified.



Ground fault detection – high resistance grounded systems

Line-to-ground voltage measurements

- Work in the same way as for ungrounded systems.
- Need not be concerned about impedance of voltage sensor.
 - Insulation Monitoring Devices are not compatible with high resistance grounded systems.



Ground fault detection – high resistance grounded systems

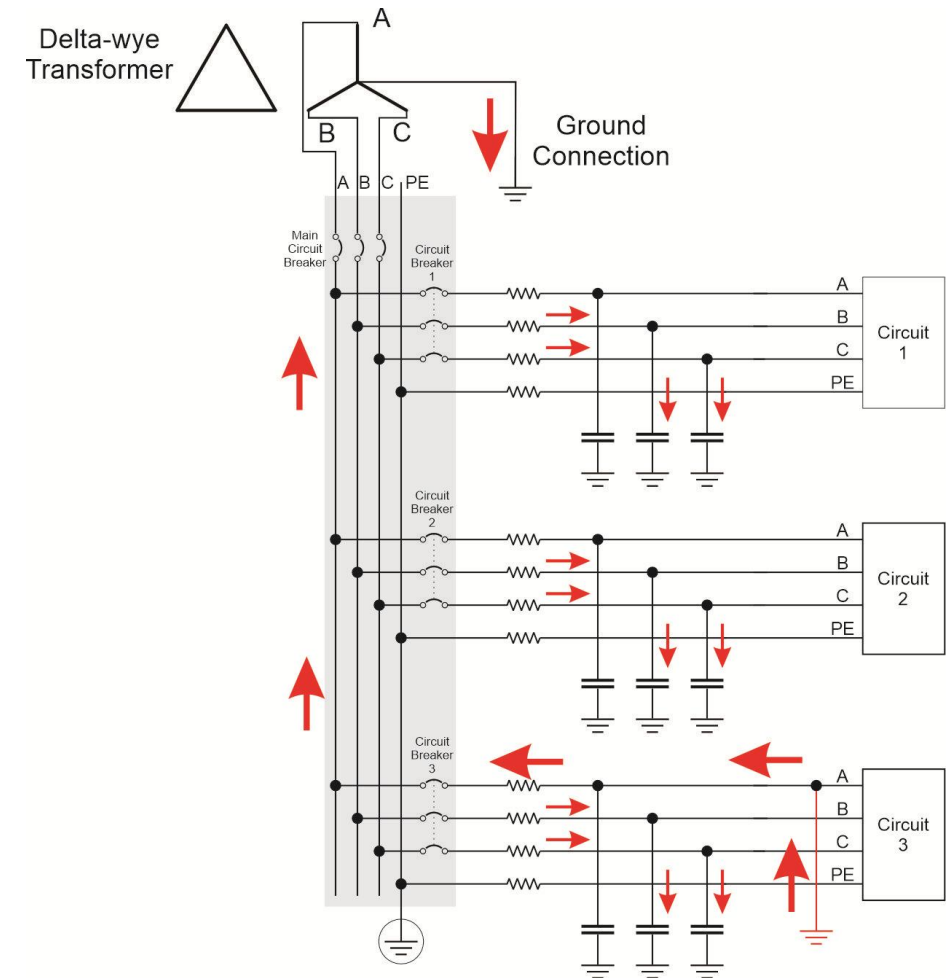
GFCI

- Work about the same as in ungrounded systems.
- Grounding resistor provides additional ground current.
 - More likely that there will be sufficient ground fault current on a faulted circuit to trip the GFCI.
- Keeping line-to-ground capacitance on the GFCI protected circuit is still important.
 - Avoid tripping GFCI due to ground fault on a different circuit.



Ground faults in solidly grounded system

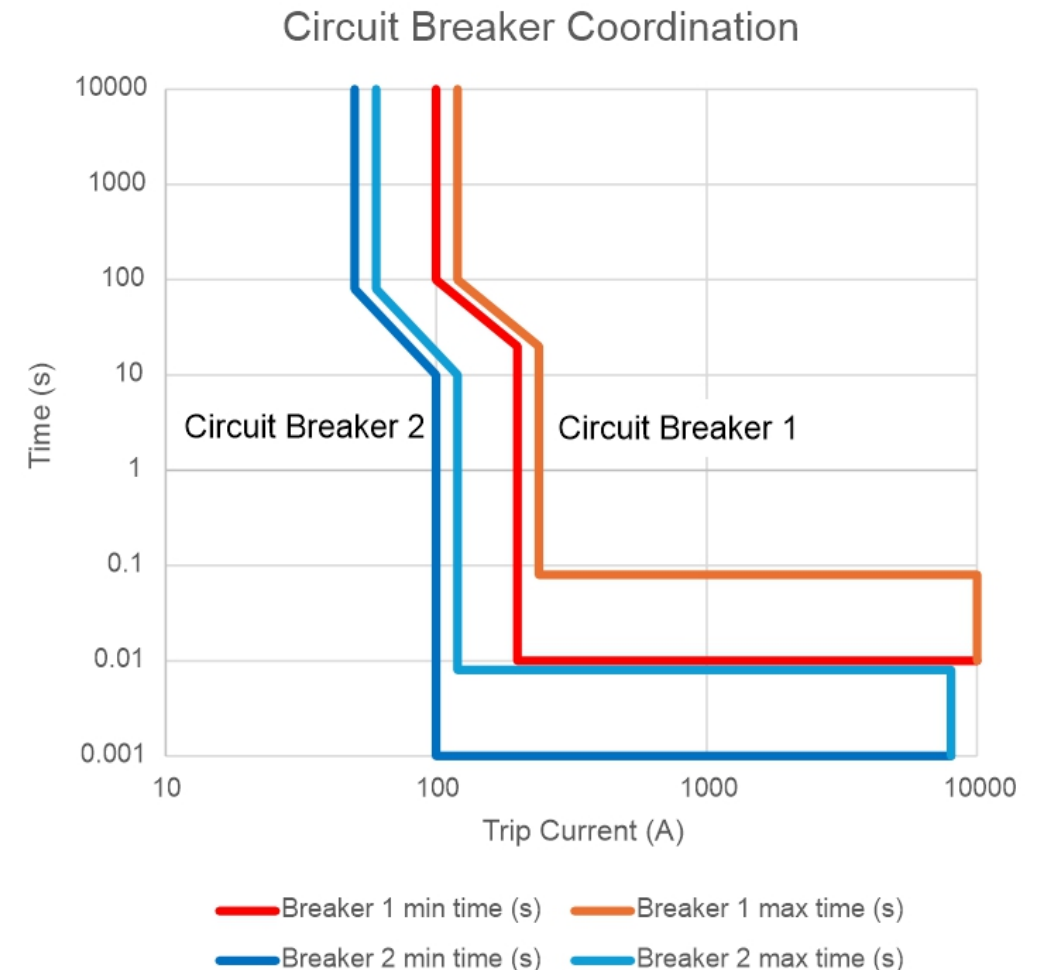
- Faulted phase results in high fault currents.
 - Limited only by the impedance of cables, source, ground fault, and the ground.
- Fault current activates the standard fault protection system for line-to-line faults.
- Cannot delay fault response to better accommodate operational conditions.



Ground fault detection – solidly grounded systems

Coordinated circuit breakers

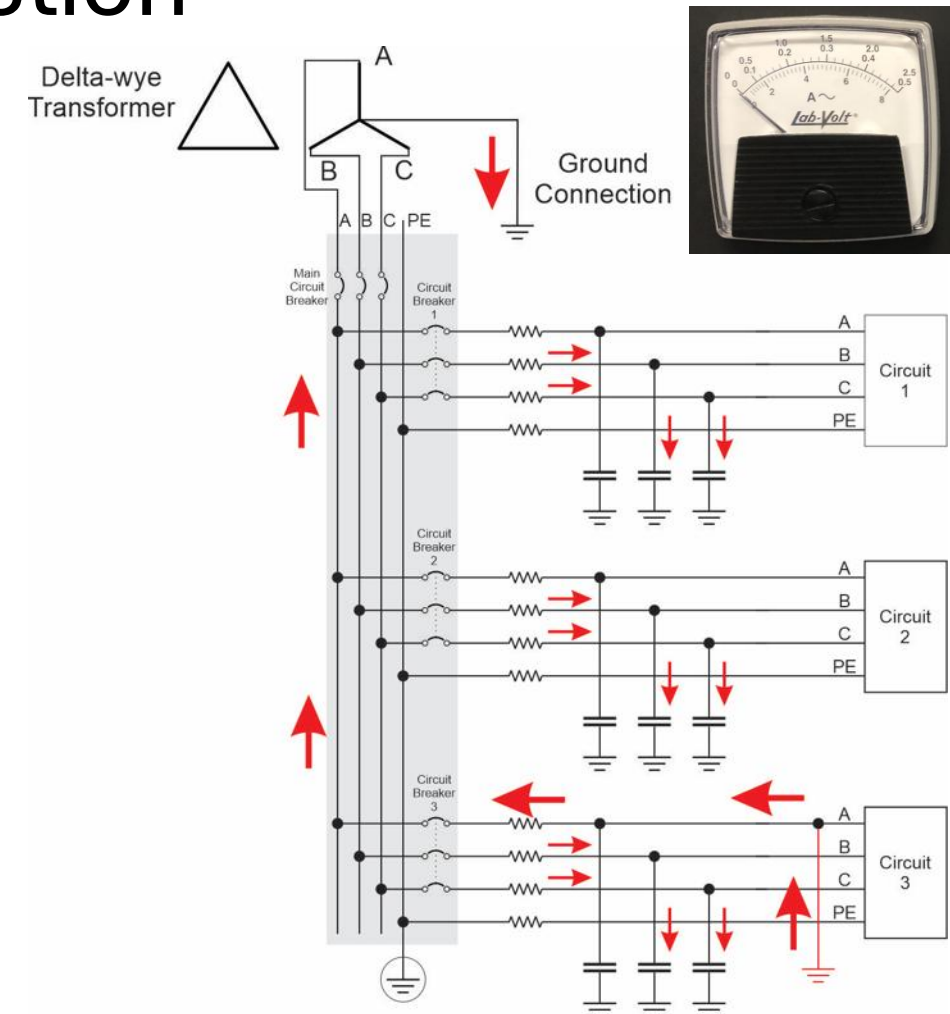
- Grounds are detected, localized, and isolated at the same time.
- Coordinated circuit breakers help ensure the circuit breaker “closest” to the fault on the supply side trips.
 - Minimizes number of loads impacted.
 - Achieved by the time vs trip current of series connected circuit breakers.



Ground fault detection – solidly grounded systems

Current meter on ground connection

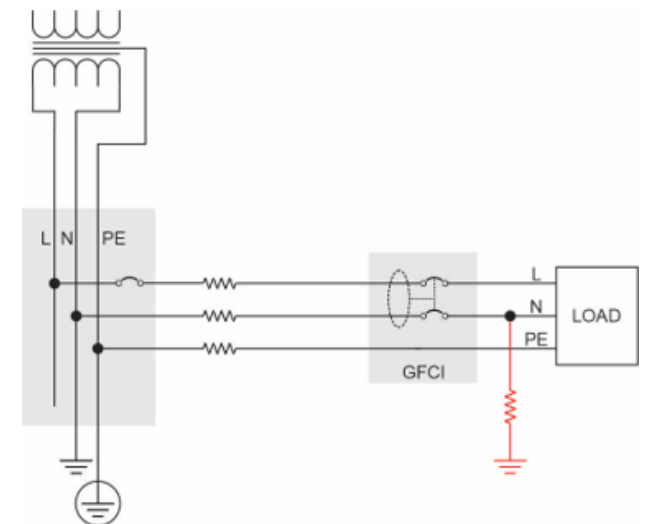
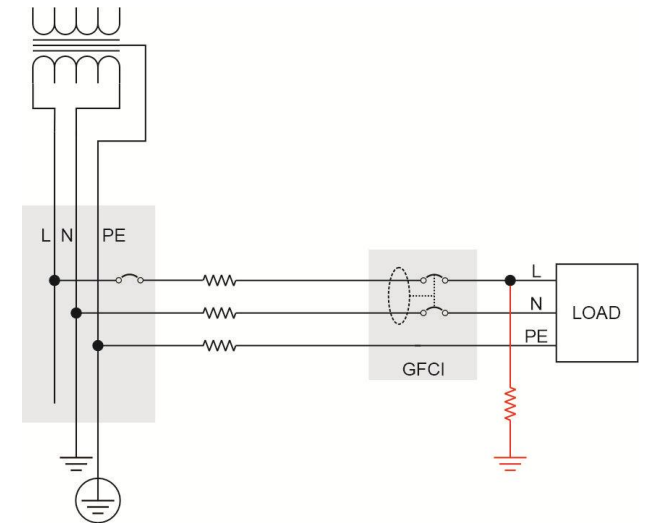
- In an unfaulted condition, little if any current flows in the ground connection.
 - Parasitic capacitances are more or less balanced.
- Current flows through the ground connection during a ground fault.
- A high impedance ground fault can still be detected by the current meter even though it is not sufficiently high to trip the circuit breakers.



Ground fault detection – solidly grounded systems

GFCI

- In a solidly grounded 120 V Distribution system, one conductor is grounded (N) while one operates at the nominal system voltage (L).
- Ground fault on the L conductor results in a current flow through the hull of the ship.
 - Results in CM current that depends on the ground fault impedance.
 - If CM current too high, GFCI trips.
 - Will trip even if the load is off.
- Ground fault on the N conductor results in the return current dividing between the N conductor and the ship's hull (via the ground fault).
 - Amount of current that flows in hull (CM current) depends on relative impedance of the N conductor and the path through the hull from the ground fault
 - If CM current too high, GFCI trips.
 - Will not trip if the load is off.



Ground Fault localization and isolation

- Once a ground fault is detected, should find where it is located and then isolate the ground fault.
 - Ideally, system would still operate normally until operational conditions enable safely turning off parts of the power distribution system.
 - Localization may be:
 - Only to the impacted circuit – physical inspection to find the problem, or
 - To the equipment or cable location where the ground fault is located.
- Some ground fault detection methods also locate and isolate the ground fault.
 - Generally, should limit to non-critical or safety applications.
 - Examples:
 - Solidly grounded systems – coordinated circuit breakers.
 - GFCIs.

Ground Fault localization and isolation

Ungrounded system – stripping the board

- Turn off and on each circuit breaker in sequence:
 - If ground fault disappears when the circuit breaker is off, then have found the faulted circuit – turn it back off.
 - Fails if more than one circuit has a ground fault on the same phase.
- Alternate: Turn all of the circuit breakers off, then turn on each circuit breaker in sequence:
 - If a ground fault exists when all the circuit breakers are off, ground fault is in the power panel or in the supply to the power panel.
 - If ground fault appears when a circuit is turned on, have identified a faulted circuit – turn it back off.
 - Works for multiple faulted circuits.
- Both methods can be disruptive to ship operations.

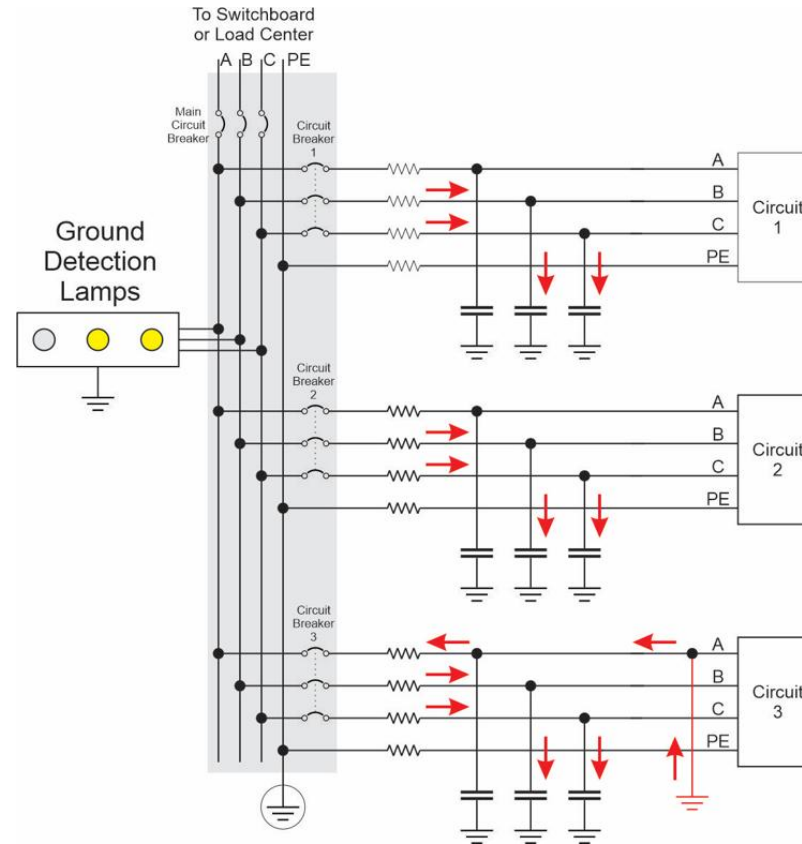


USS Midway (CV-41) Power Panel (Photo by Norbert Doerry CC BY 4.0)

Ground Fault localization and isolation

Ungrounded system – CM current measurement

- Use a current meter around all the conductors of a cable to measure the CM current.
- The cable for the faulted circuit will likely have the largest CM current.
- Along a faulted cable, the CM current should drop significantly at the location of the ground fault.

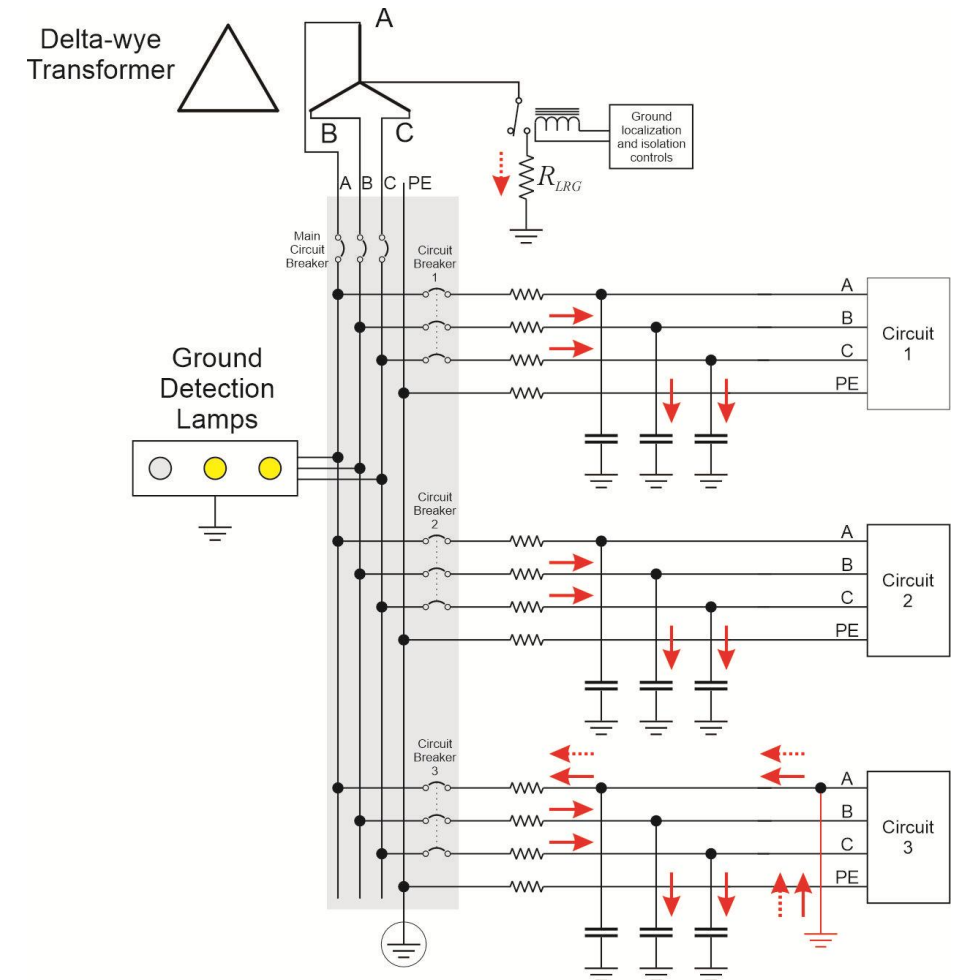


Fluke 301A Clamp Meter (Photo by Norbert Doerry CC BY 4.0)

Ground Fault localization and isolation

Ungrounded system – Low resistance grounding

- Ground faults can be automatically localized and isolated by inserting a low resistance between the system neutral and ground.
 - Resistance is low enough for normal circuit breakers to trip.
 - Resistance is high enough to reduce damage to cables and equipment.
- Neutral may be obtained from:
 - Common connection of wye connected windings.
 - Grounding transformer.
- System should be activated only when safe to do so within the context of the ship's operations.



Ground Fault localization and isolation

Ungrounded system – GFCI

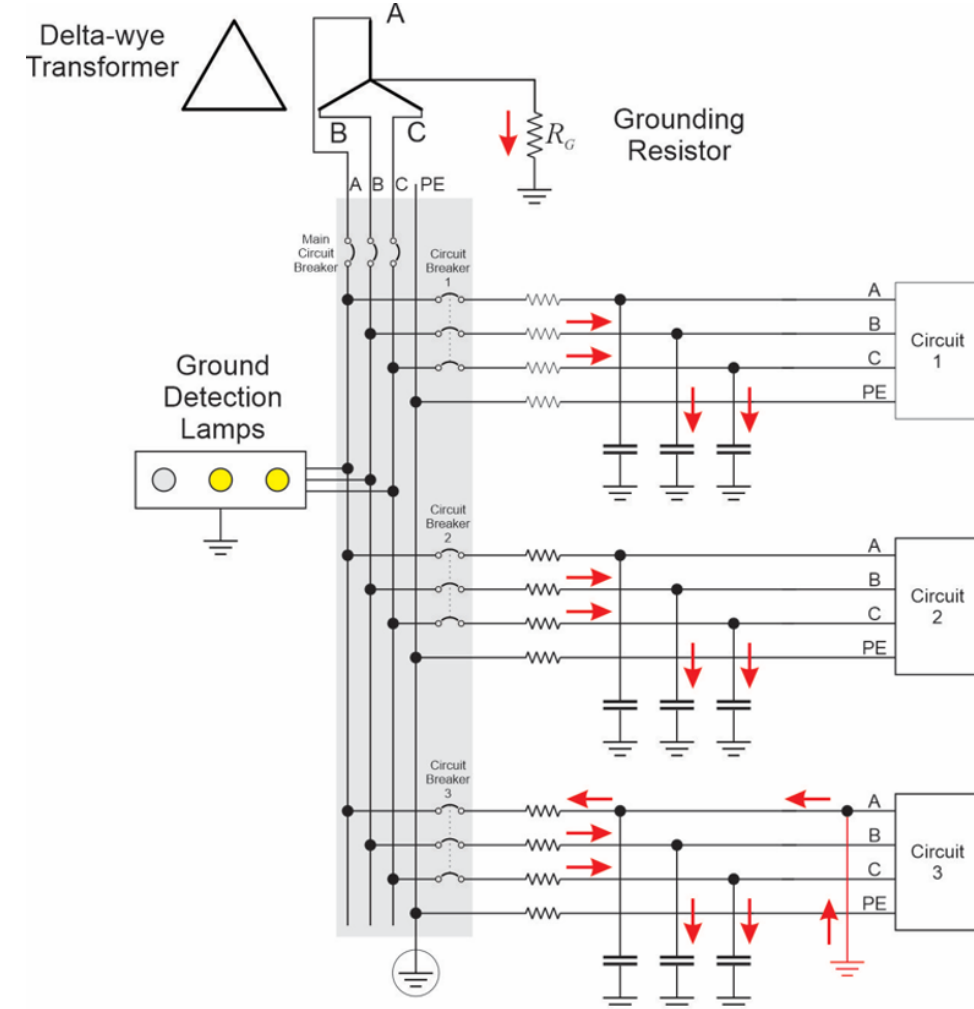
- Ground faults that the GFCI detects are automatically cleared.
- GFCIs in ungrounded systems may have nuisance trips if the protected circuit has significant line to ground capacitance.



Ground Fault localization and isolation

High resistance grounded system – CM current

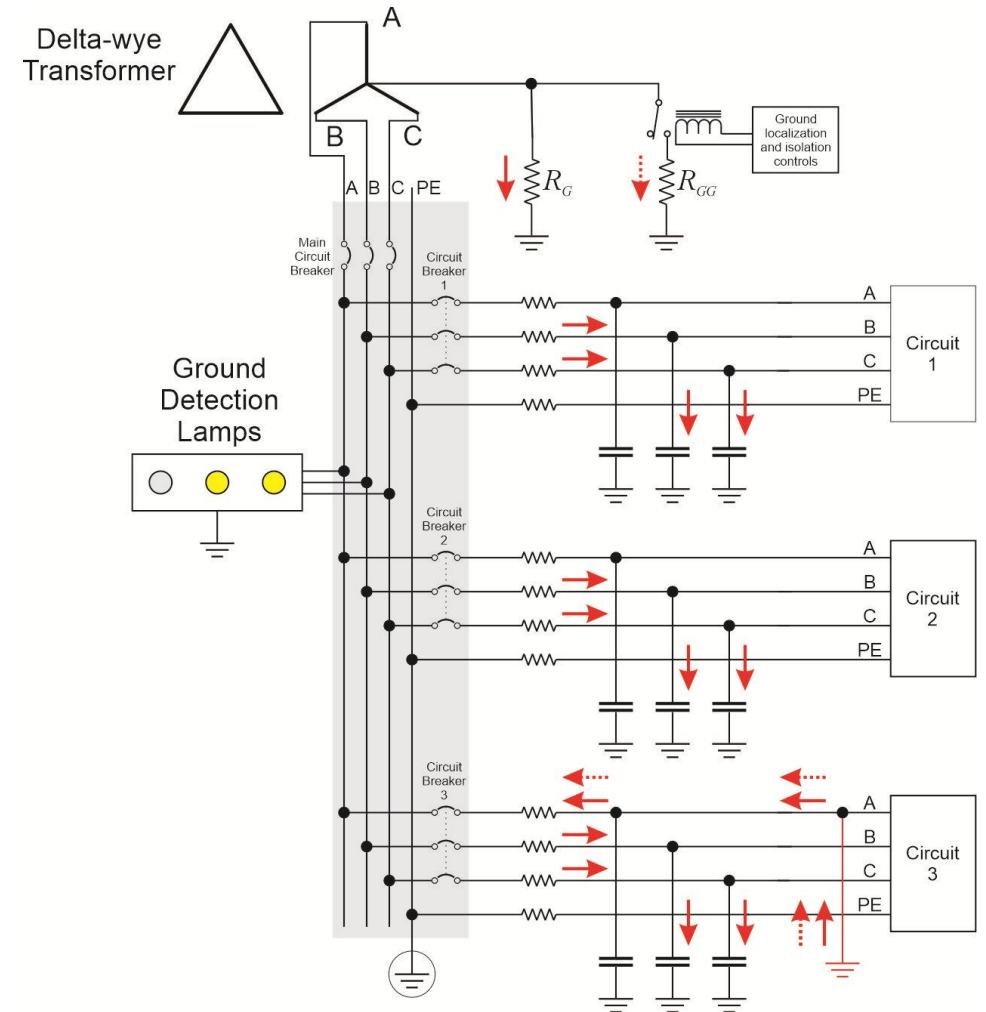
- Works better than for the ungrounded system:
 - CM current in the faulted phase includes the current from the ground resistor and should be larger than all unfaulted phases.
 - Current phase is different for faulted and unfaulted circuits.
 - Unfaulted circuits will largely be capacitive.
 - Faulted circuits will have both resistive (from grounding resistor) and capacitive components.



Ground Fault localization and isolation

High resistance grounded system – Pulsed resistance

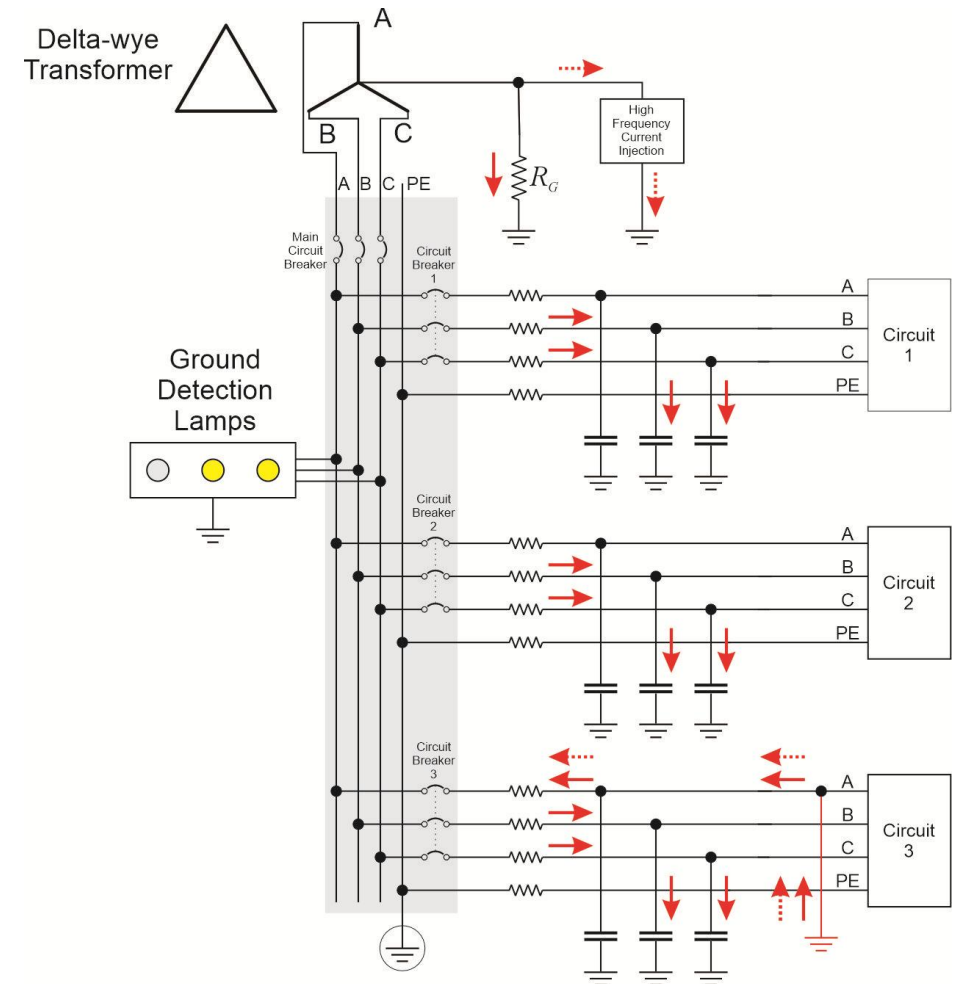
- A second grounding resistor of higher resistance is periodically inserted in parallel to the grounding resistor. Usually about 1 Hz.
 - Results in the ground fault current having a square waveform.
 - Common mode current of the circuit with the ground fault will show the square waveform.
 - Common mode current of the non-faulted circuits will not be significantly impacted by the pulsing ground fault current.
- Alternately, a second grounding resistor of resistance low enough for the coordinated circuit breakers to trip is switched in to clear the ground fault.



Ground Fault localization and isolation

High resistance grounded system – Injected signal

- A high frequency current signal is injected between the neutral and ground.
- This signal can be detected by a portable receiver.
- The signal will be strongest on the faulted circuit.
- The signal can be traced along the circuit until it disappears.
 - The ground fault is likely near where the signal disappears.



Ground Fault localization and isolation

High resistance grounded system – GFCI

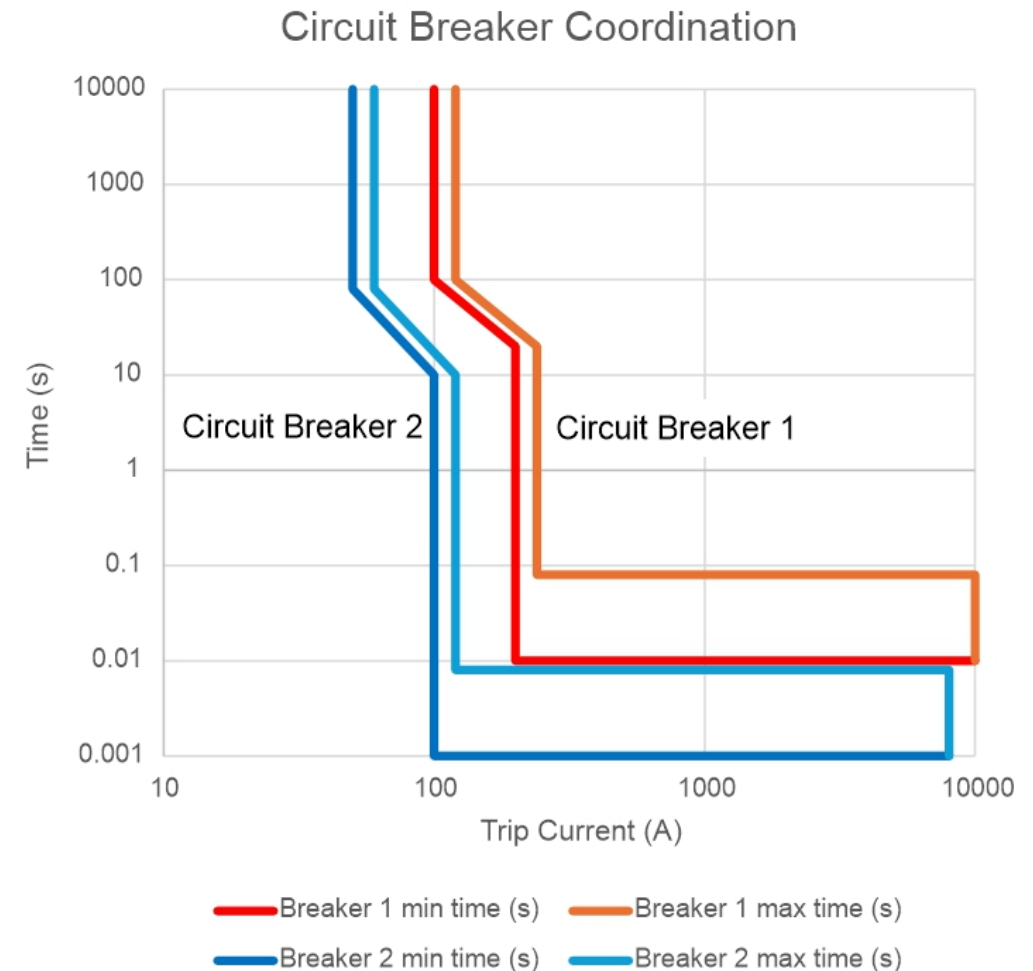
- Ground faults that the GFCI detects are automatically cleared.
- GFCIs in high resistance grounded systems may have nuisance trips if the protected circuit has significant line to ground capacitance.



Ground Fault localization and isolation

Solidly grounded system – Coordinated circuit breakers

- Ground faults of sufficiently low impedance should result in the supplying circuit breaker closest to the ground fault tripping.
 - Automatically clears the ground fault.
 - May not occur at an ideal time with respect to ship's operations.
- High impedance ground faults may not produce sufficient fault current to trip the circuit breaker.



Ground Fault localization and isolation

Solidly grounded system – GFCI

- Ground faults that the GFCI detects are automatically cleared.



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
- 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

