

ENJOY PROGRESS

Earthing of ship's AC distribution system

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version 0.1



Earthing of ship's ac distribution system

1. Earthing definitions
2. Power systems
3. History of ship's power systems
4. Aspects of earthing
5. Earth fault behaviour
6. Earthing, matter of choice?



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Earthing of a ship's ac distribution system

“Earthing” is a connection between an electrical power grid and earth which has been made deliberately.

On board a metallic ship “Earth” is the hull and superstructure and as a consequence it is everywhere.

Even if no earthing connection has been made, the grid is connected to earth through (parasitic) capacitances and inductive couplings.



Earthing

- Earthing of (non-active) exposed conductive parts (Bonding)
 - Enclosures
 - (Cable) screens
- Earthing of (Neutral of) supply grid
 - Non-earthed (IT system)
 - Directly earthed (TT / TN-S / ~~TN-C~~ / ~~TN-S/C~~ system)
 - Impedance earthed (??? System)
 - High resistance earthed
 - Low resistance earthed
 - Reactance earthed



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Non-earthed system

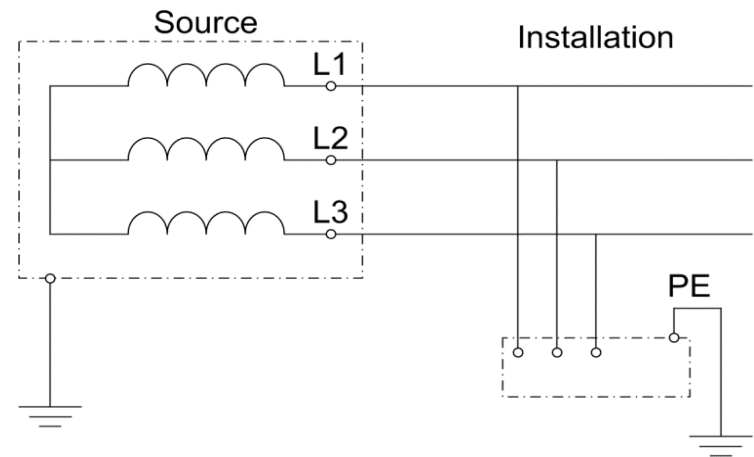
On ships (except yachts) mostly:

- Non-earthed system (IT system)

- Neutral not earthed
- Earthing of exposed conductive parts locally

Usually:

- Neutral not accessible
- Three-phase, 3-wire
- Lighting separated from Power
- Lighting across L-L





Directly earthed system

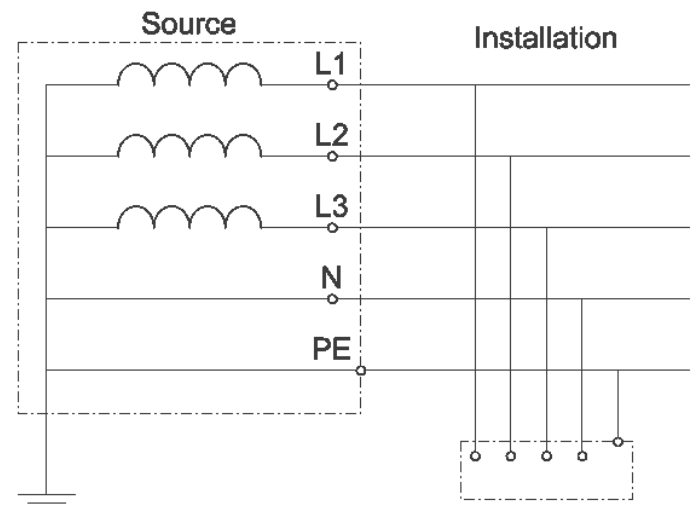
On land mostly:

■ Directly earthed system (TN-S system*)

- Neutral earthed
- Earthing of exposed conductive parts at the source

Usually:

- Neutral accessible
- Three-phase, 5-wire
- Lighting not separated from Power
- Lighting across L-N



*TN-C system and TN-CS system not considered

Earthing at the Source

Exposed conductive parts



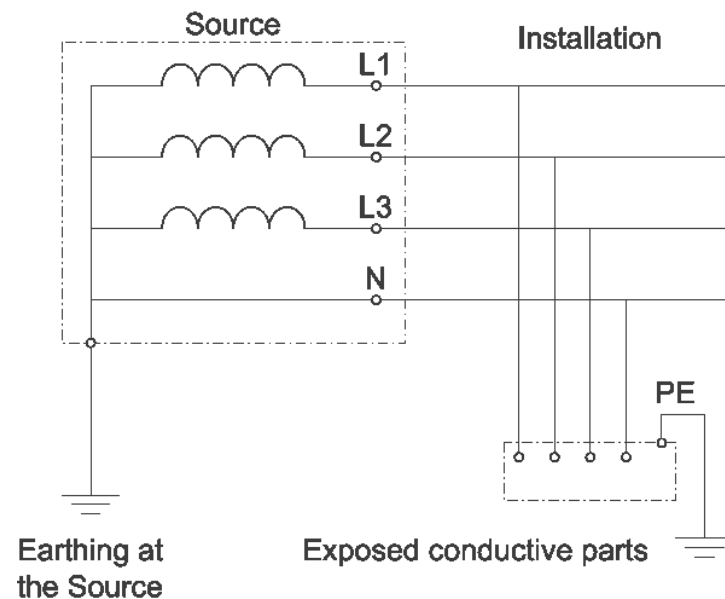
Directly earthed system

Or:

- Directly earthed system (TT system)
 - Neutral earthed
 - Earthing of exposed conductive parts locally

Usually:

- Neutral accessible
- Three-phase, 4-wire
- Lighting not separated from Power
- Lighting across L-N





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Why IT-systems on board ships?

Poor insulation materials

- Rotating machines Class A materials
 - varnish
 - contained organic fibres like silk and cotton
- Cables insulation materials
 - paper
 - rubber, reinforced with cotton fibre

Materials were highly hygroscopic.

Insulation deteriorated rapidly and due to moisture insulation resistances could fall to low values.



Direct current

Ship's electrical power systems:

- Up to the 1950's: mainly DC

Example: Ocean liner "D.S.S. Nieuw Amsterdam" (1938)





Example

Electrical distribution:

- Main generation 220 Vdc (3 x 1000 kW + 2 x 425 kW)
- Lighting distribution 110 Vdc via 5 rotating converters, 100 kW each

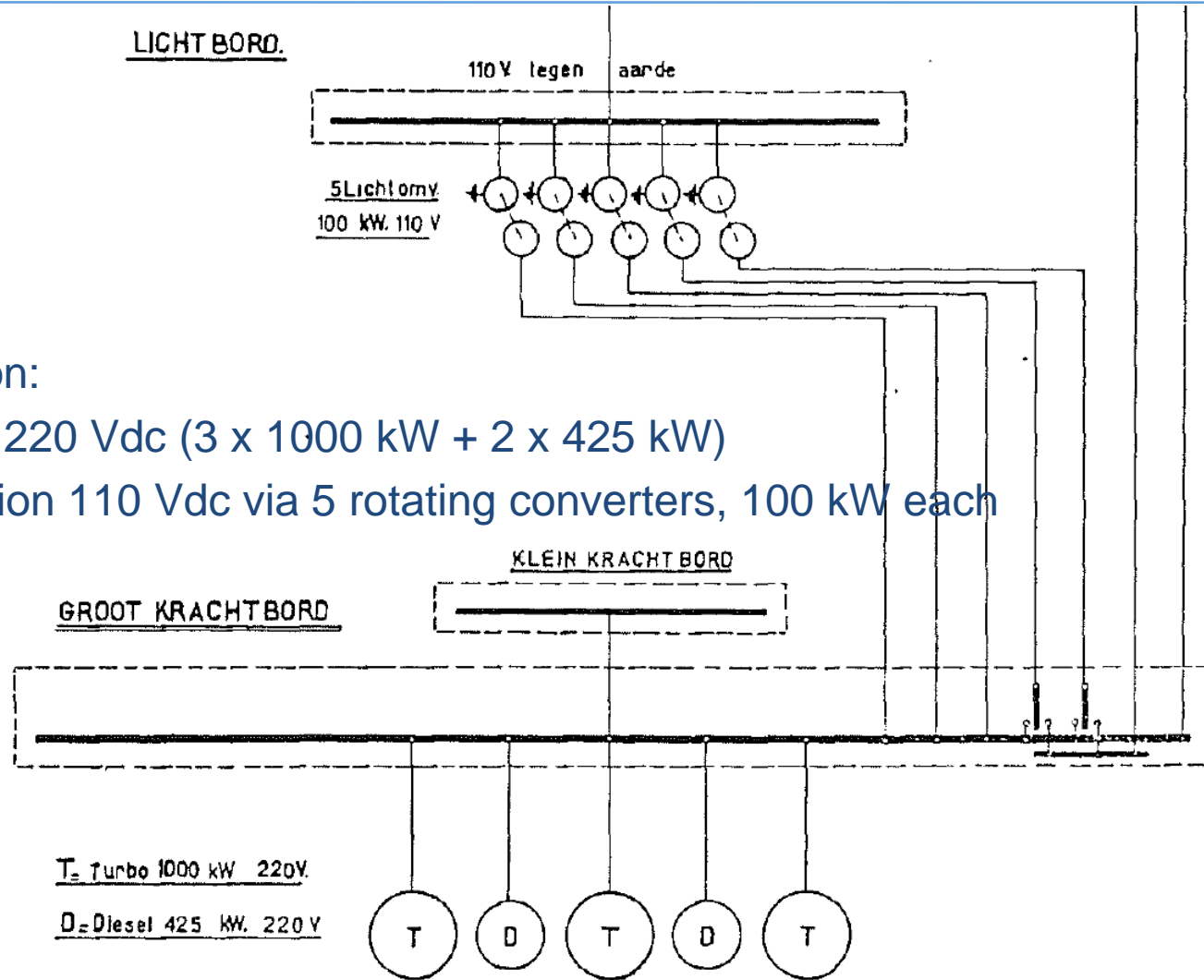


Fig. 124. HOOFDSHEMA



Consequence

Choice: Isolated power system

- Continuity of service:

An earth fault is not (yet) a short circuit. Equipment will not fail, repair can be made at a convenient moment

- Safety:

When accidentally touching a live part current will not flow through the body because no return path is available

This works in DC.....but what about AC?



Developments

- Cable Insulation materials improved: not hygroscopic anymore
 - Earth faults mostly “spot earth faults” instead of complete cable bunch
- Generators and Motors: Class B as a minimum (far less hygroscopic)
- Switchboards: Metal clad, generally IP20 with doors open:
 - No live parts can be touched accidentally



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Aspects to be considered with respect to Earthing

- Safety
 - Protection against electric shock
 - Protection against excessive earth leakage currents
 - Limitation of arc flash
 - Short circuit forces
- Harmonic distortion and Electromagnetic interference



Standards

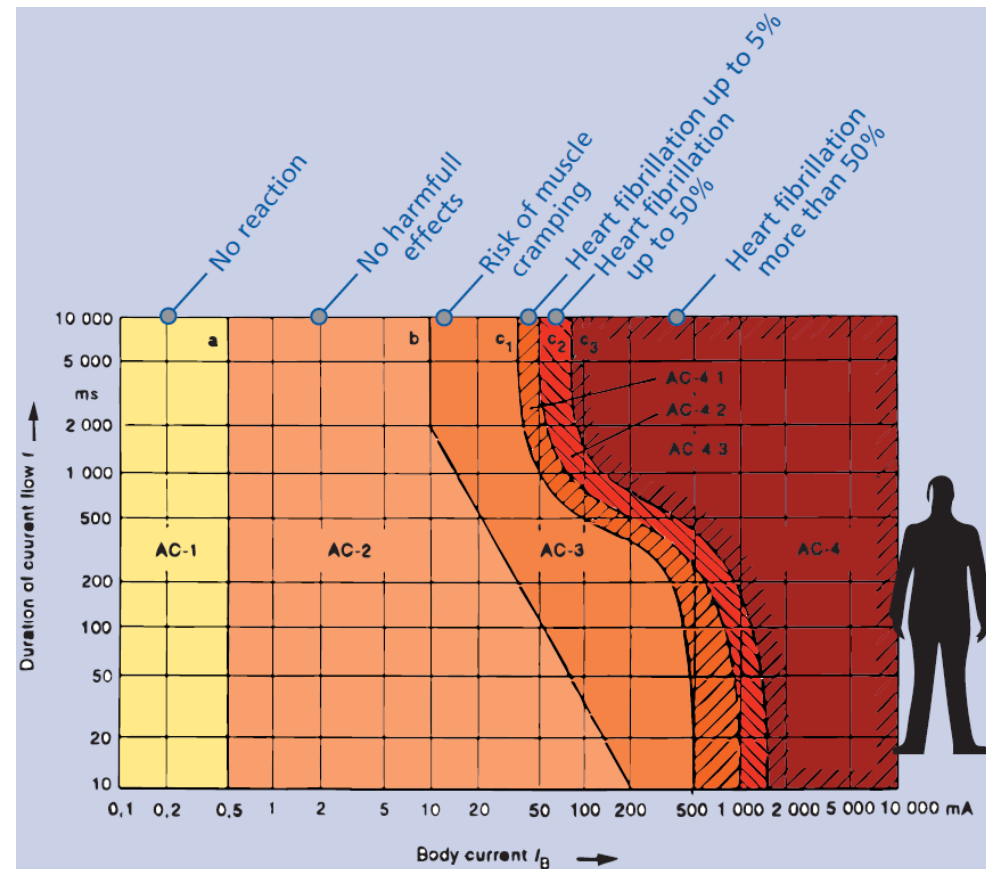
- Protection against electric shock
 - BS 8450 (2006):
(additional requirements and recommendations to IEC 60092)
 - Limited voltage (50 V or 115 V with mid-point earthed)
 - Monitor continuity of earth connection of enclosures (automatically disconnect supply)
 - RCD (< 30 mA) for socket outlet groups (earthing required)
 - STANAG 1008:
 - Mentions “equivalent of 30 mA” as max. capacitance toward earth “...to avoid one user creating disturbances which adversely affect other users...”.
Coincidence?
 - Others: close to nothing



Electric shock

Danger of electric shock is current, not voltage

- Beyond 10 mA: Risk of muscle cramping (unable to let-go)
- Beyond 16 mA: Breathing difficulty
- Beyond 30 mA: Potentially lethal due to risk of heart fibrillation



Source: IEC 60479-1 Technical Report - Effects of current on human beings and livestock



Safety

■ Fire

- Protection against excessive earth leakage currents
 - Excessive earth leakage currents can cause fire
In adverse conditions (flammable materials) 300 mA

■ Short circuit

- Short circuit forces
 - In a directly-earthed grid Phase-to-Earth short circuit currents can be up to 50% greater than 3-phase symmetrical short circuits
IEC 61363 does not take that into account



Arc flash

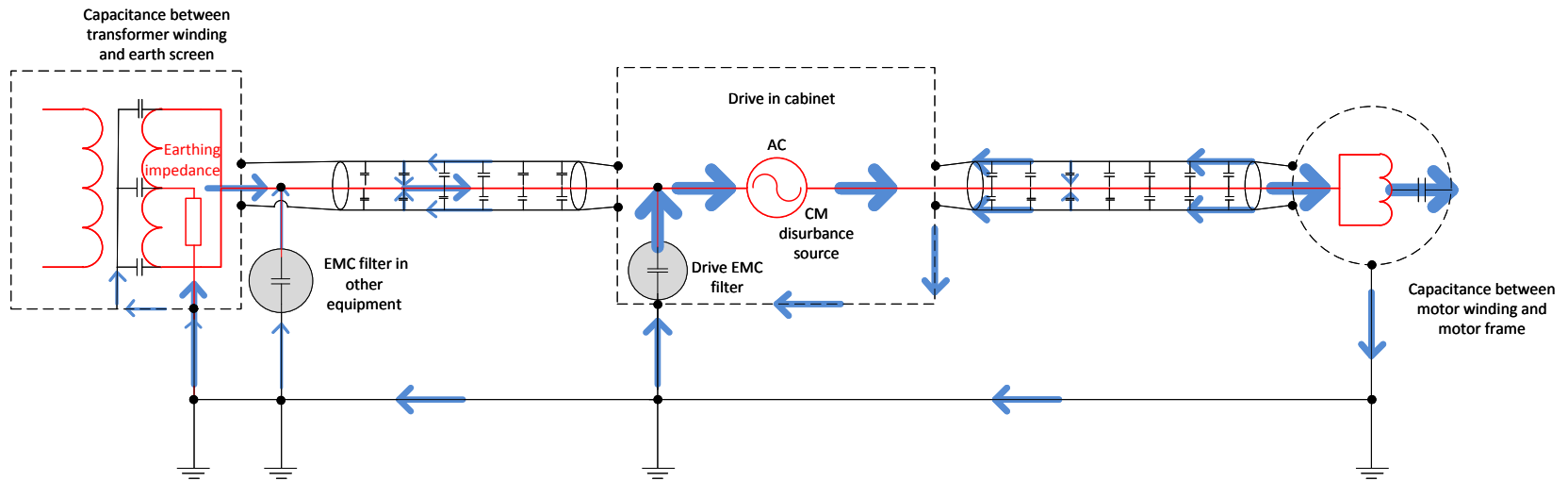
- Limitation of arc flash (“The other electrical hazard”)
 - What is arc flash?
 - Arc flash is increasingly recognised as a risk
Lloyd’s Register requires assessment





Common mode disturbance

- Common mode filters
- Common mode loops change due to earthing





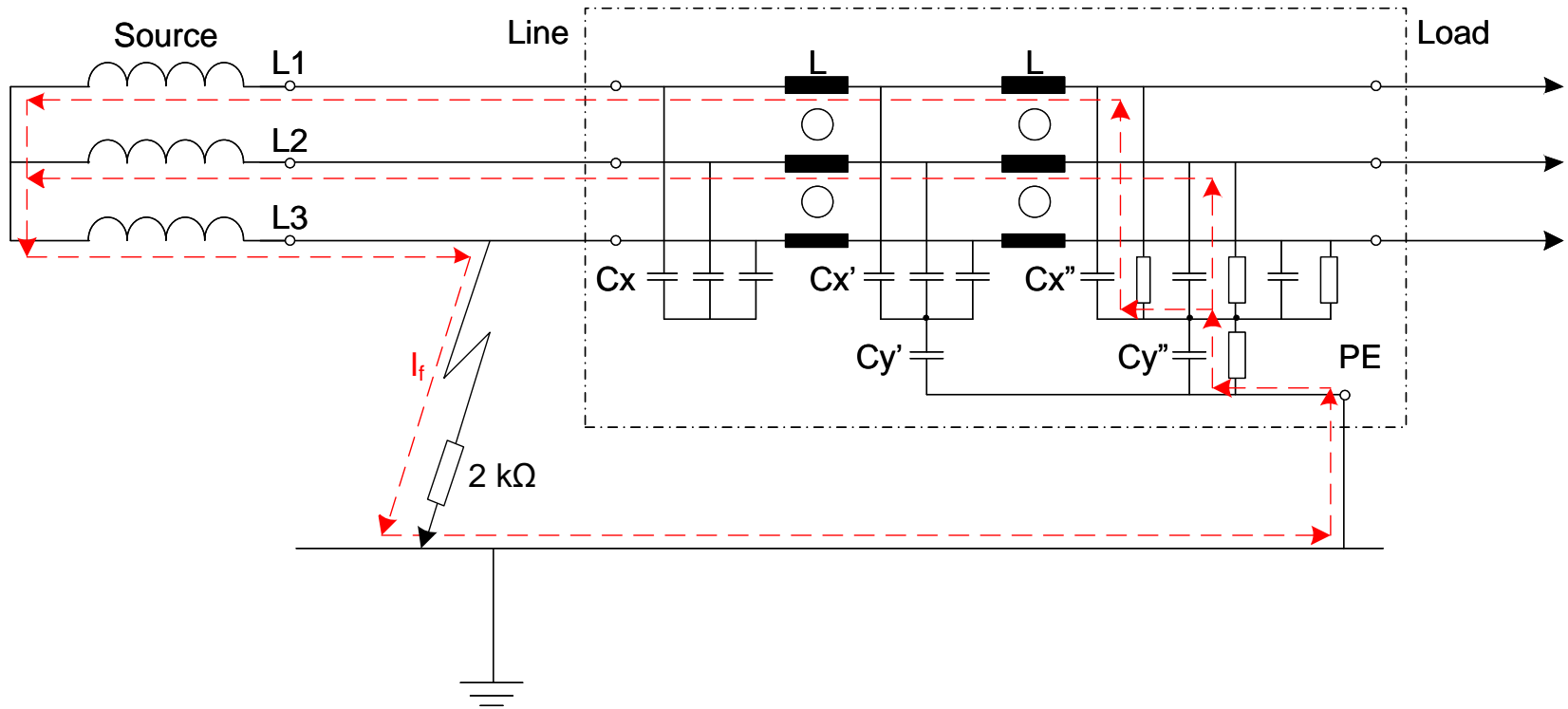
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Common mode (Drive) filters

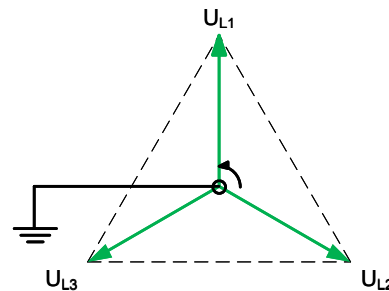
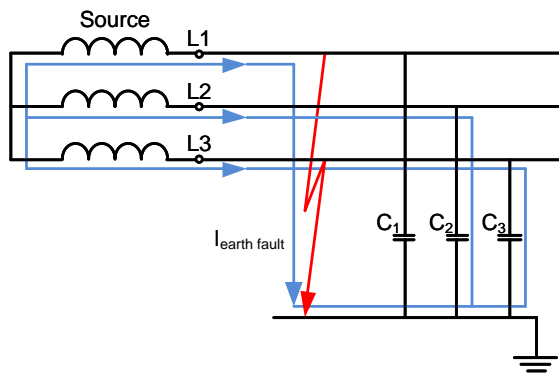
- Typical EMI filter in non-earthed grid (IT-system)



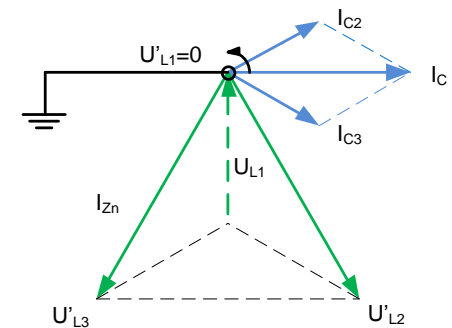


Non-earthed grid

- Earth fault in non-earthed grid (IT-system)
 - Phasor diagram
 - Earth fault current
 - Determined by capacitances. Large AFE drives: up to 2.5 A per drive.
 - Earth fault is detected, but not located. No switch-off.



Normal operation

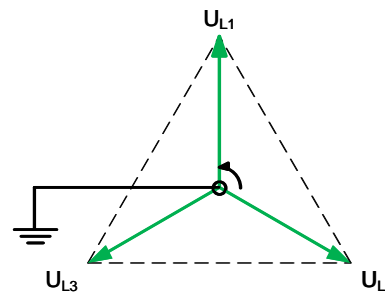
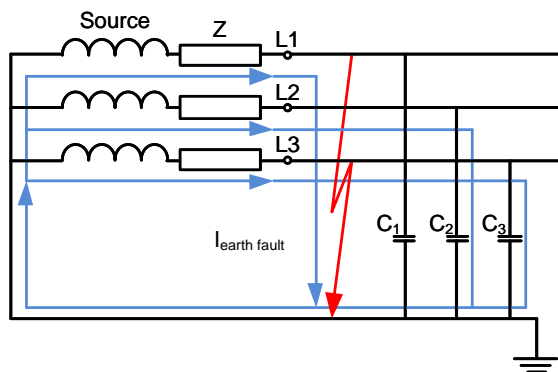


Earth fault

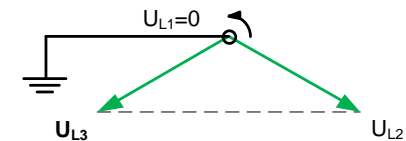


Directly earthed grid

- Earth fault in directly-earthed grid (TN-S-system)
 - Phasor diagram
 - Earth fault current
 - Determined by source impedance. Up to 50% higher than 3-phase symmetrical short-circuit. (100 kA or even more)
 - Earth fault is short-circuit. Immediate switch-off.



Normal operation

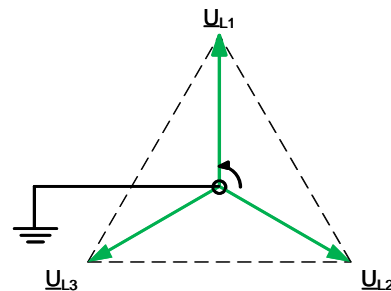
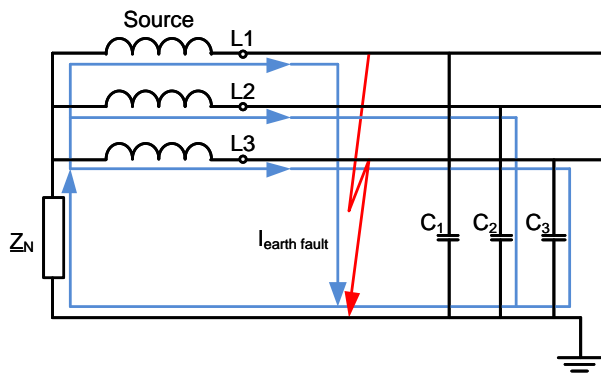


Earth fault

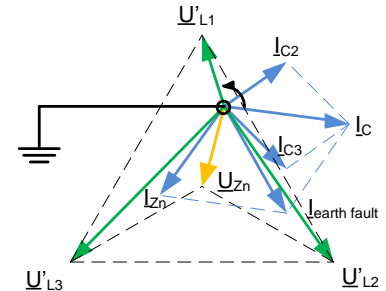


Impedance-earthed grid

- Earth fault in impedance-earthed grid
 - Phasor diagram
 - Earth fault current
 - Determined by earthing impedance and capacitances
 - Earth fault can be detected, located and switched-off, provided earthing impedance is carefully determined



Normal operation



Earth fault



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Priorities

- Safety for personnel
 - Protection against electric shock
 - Arc flash hazard
- Risk of fire
- Continuity of service
 - Ability to sustain operation under fault conditions
 - Ease of fault finding



Directly earthed grid

■ Advantages

- Protection against electric shock with RCDs < 30 mA
- L-N consumers can be connected
- Earth fault finding is easy

■ Disadvantages

- Enhanced risk of arc flash (phase-to-earth fault)
- Bigger short-circuit forces
- Inability to sustain service under fault conditions
- Earth fault inside generator can cause irreparable damage

■ Application advise:

- Domestic grids (accommodation areas) containing sockets
- RCDs < 30 mA to be applied
- Short circuit power to be limited



Non-earthed grid

■ Advantages

- Reduced risk of (phase-to-earth) arc flash on 1st fault
- Ability to sustain service under single fault conditions for a limited time, provided earth-capacitances are limited ($< 1 \mu\text{F}$ at 440 V)

■ Disadvantages

- L-N consumers cannot be connected
- Protection against electric shock with RCDs unreliable, unless sockets are protected separately, RCD $< 10 \text{ mA}$
- Fault finding difficult (1st failure) to nearly impossible (2nd failure in same phase)
- Enhanced risk of arc flash on 2nd earth fault

■ Application advise:

- Small special purpose grids. Examples:
 - Hospital (CM capacitors to earth prohibited. Earth fault current $< 10 \mu\text{A}$)
 - Sub grid separated by transformer to (locally) control CM



Resistance earthed grid

■ Advantages

- Reduced risk of (phase-to-earth) arc flash
- Earth fault finding is easy (switch-off by selective earth fault protection)
- Earth fault inside generator not likely to cause irreparable damage

■ Disadvantages

- L-N consumers cannot be connected
- Inability to sustain service under fault conditions

■ Application advise:

- Normal ship's main grid



And what about EMC?

- Directly earthed grids
 - Behave like on land.
 - CM Filters can be applied without any problem.
 - AFE converters meet requirements as stated in the standards.

- Non-earthed grids
 - Any deliberate connection between the grid and earth is a violation and should be forbidden. So apply CM filters without earthing capacitors.
 - Standards say that AFE converters don't need to meet any standard.

- Resistance-earthed grid
 - Earthing capacitances of CM filters and earthing resistors must be coordinated.
 - If done carefully, AFE converters will meet standard's requirements.



And what about cooperation?

Way of earthing has an important impact on:

- Character of supply grid
- EMC

Coordination and cooperation is required



Shared Success