Come Back to Ground!

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1. **Introduction**

   Many ships, particularly small tugs and supply boats have used a neutral grounded distribution system for 120 volt single phase hotel and domestic loads. This system is identical to that used in most North American 120 volt land based installations. The land based installations distribute power using a 3 wire system; one wire is used for the "live" connection, one for the neutral and one for the ground bond. Circuit protection is provided by single pole circuit breakers installed in a standard single phase 3 wire panelboards.

   Marine installations followed the same practise but often used a 2 wire system to save on cable costs. When the two wire system was used, it was essential to ensure that each fixture and 120 volt device is separately bonded to ground at the fixture or device. On marine installations, the fixtures themselves are often installed directly onto metallic bulkheads that are part of the vessel's structure, this also being the medium for the ship's "ground".

   IEEE 45 1998 clause 13.1 introduced the requirement that "Circuit breakers in grounded neutral distribution panels should include a pole or switch for the neutral". This requirement therefore removes the possibility of using single pole circuit breakers for the 120 volt services.

   When two pole circuit breakers are used, the standard single phase 3 wire distribution panel cannot be used without modification and three phase panels may be required configured for single phase loads.

   As the major benefit of using a grounded single phase system was generally the cost saving in circuit breakers and panels, compliance with IEEE 45 1998 begs the question "why ground?". Ungrounded installations offer other benefits and perhaps the area of marine system grounding should once again be reviewed.

2. **Grounding, and bonding - it's all a matter of safety**

   The major factor which determines the grounding method is safety - primarily safety of people and secondly safety of equipment. On marine installations, safety of equipment may also contribute to safety of personnel particularly if loss of vital equipment places the ship in danger.

The majority of faults on a marine system are ground faults. A ground fault occurs when the insulation between live conductors and the "ground" whatever that is defined to be, no longer maintains an effective resistance between the live conductor and ground. On a "grounded" system, the fault will be removed by the automatic opening of the circuit breaker. On an "ungrounded" system, the fault is detected but not removed automatically. This enables the service to be retained until such time as it may be shutdown safely. For vital services this is obviously advantageous.

The "ground fault" may result from a live conductor touching equipment metal cases. Personnel safety can be in jeopardy when a live conductor comes into contact unintentionally with parts that an operator may touch. For marine installations the ground is usually the ship's hull and all electrical equipment metallic enclosures are bonded to it. By bonding the case to the ship's hull, a direct path is provided between the equipment and the ship's hull thereby ensuring they are both at the same voltage level. A person standing on the hull is then protected against electrical shock. Furthermore, the path enables "fault current" to flow and thus allows any protection or detection devices to operate.

Safety is affected in two ways.

- The method of grounding dictates if the equipment will continue to operate when a ground fault occurs. Failure to operate may be a hazard to the ship or other equipment.
- The method of grounding will affect the magnitude of any transient overvoltages that could occur as a result of "restriking" grounds. Such transients may permanently damage equipment. Accordingly the method of grounding may detract from a safe system by causing equipment to disconnect on a ground fault - or be permanently damaged.

3. **What is the difference between a grounded and ungrounded system?**

A review of some historical data provides an insight into marine system grounding and grounding methods.

When a.c. installations became popular during the 1950 - 60's, the majority of these systems operated with an ungrounded neutral. There were a few notable exceptions.

- MV Bergensfjord (1950) used a resistance grounded neutral system
- The QE 2 (1968) used solidly grounded neutral systems for domestic and hotel services following land based practices.
- Many Danish Navy vessels used the "Peterson coil" to connect the neutral to ground.
- Some small German, Yugoslavian and Australian vessels used solidly grounded neutral systems.

Marine system grounding is a topic for which the references are prolific! The most comprehensive document on the subject is a study completed by YARD in 1982 in which the technical, commercial and operational and safety aspects of marine system grounding are extensively discussed.

There are generally three methods of grounding applied to marine systems:

- Solid and low impedance grounding
- High impedance grounding
- Insulated neutral (ungrounded)

Solid and low impedance grounded systems are sometimes referred to as being "effectively" grounded. These systems are arranged such that on the occurrence of a ground fault, the short-circuit protective devices operate as quickly as possible, to disconnect the faulty circuit from the system.

High impedance grounded and insulated systems are sometimes referred to as being "non-effectively" grounded. With this type of system it is possible to operate with a ground fault on the system. It is important however to include detection and alarm equipment to notify the operators when a ground fault occurs, and to isolate the grounded circuit as quickly as possible.

For marine systems it is generally preferred that the first ground fault will not disconnect the grounded circuit, the electrical system or any part of it. Continuity of supply, and particularly of propulsion, is considered of paramount importance and non-effectively grounded systems are generally preferred.

Non-effectively grounded systems
The main advantages of the non-effectively grounded system are:

- Continuity of service on the occurrence of a ground fault

- Ground fault currents can be kept low

The main disadvantages are

- A high level of insulation may be necessary.
- The possibility exists for high transient over-voltages to occur
- Grounded circuit detection is difficult

Effectively grounded systems
The main advantages of the effectively grounded system are:

- Equipment insulation does not require any special attention
- Ground faults are detected automatically and immediately isolated
- Ground fault current flows for a short period of time thereby restricting damage
- Arcing ground over-voltages can be avoided

The main disadvantages are:

- Immediate disconnection and loss of the service
- High ground fault currents flow, which can cause extensive damage and the risk of explosion.

It is generally accepted that there is no single "best" method for grounding a marine electrical system. Selection must generally be made based on cost, operation and safety issues. Generally in the marine world the desirability of maintaining a service although a ground fault, and having low ground fault currents favours the non-effectively grounded systems (i.e. neutral point insulated or grounded through a high resistance).

From the technical viewpoint the most suitable criteria on which to choose the grounding system must be the prospective ground fault current. The principal objective is to design a system such that system over-voltages are prevented, ground fault current is restricted to a low value to limit fault damage but not so low that detection becomes difficult and expensive.

Finally having decided on the "best" grounding system for your particular application, the system should be configured such that the consequences of a ground fault minimise the dangers and do not limit the operational aspects of the ship. This is done by applying restricted grounded systems to specific services (e.g.

domestic, hotel, galley), and applying insulated systems to essential services and splitting systems and applying redundancy.

For example:

Low power -low voltage systems - solidly grounded
The majority of low power, low voltage marine systems use a solidly grounded neutral. This permits the use of the phase to neutral point as a source of low voltage for small power and lighting consumers. With this system a single ground fault will cause an overcurrent in the faulted circuit and this in turn will trip the circuit supply breaker to disconnect the service. For many services this is quite acceptable but for services such as steering gear, lubrication and fuel pumps, this could be an unacceptable practice.

Low voltage systems - insulated neutral
The majority of low voltage marine systems (380 - 600 volts) have an ungrounded configuration. The main reason is that transient over-voltages on a low voltage system are generally within the equipment insulation level (under 2 kV) but more importantly, an ungrounded system can still operate even if there is a ground fault present. With ungrounded systems however it is important to have a ground fault detection system in place and to clear ground faults as quickly as possible. It should be remembered that when the first fault occurs on an insulated neutral system, the system immediately becomes "grounded" and consequently the next fault that occurs will be limited by the much lower zero sequence reactance of the system. This can cause fault currents in excess of the 3 phase fault current for which most switchgear is rated. Consequently, to avoid the risk of protection equipment failure, any fault should be cleared as rapidly as possible. The prudent electrician will check with the navigating staff to find a time slot when essential "grounded" equipment can safely be checked out and brought back into full reliable service!

For systems in hazardous areas, insulated neutral systems should be used. Although a grounded neutral system will provide rapid fault clearance, the risk of a faulted cable causing flashover to ground with resulting explosion, is too high.

Medium voltage systems - high impedance grounded
The high impedance grounding system offers several advantages:

- Low ground fault current which limits damage and reduces the fire risk

- Minimal ground fault flash hazard due to system over-voltages
- Low protection equipment costs.

A variety of grounding methods are in use on medium voltage systems. On some UK designed tankers, insulated neutral systems were used at 3.3 kV. Other systems use solidly grounded neutrals.

Insulated neutral systems have certain inherent disadvantages and unless it is vital that particular equipment remains operational even though a ground fault exists, it is recommended that insulated neutral systems be avoided. Although the ground fault current is inherently small, the integrity of the system is at risk unless rapid fault detection and clearance is carried out. Furthermore all equipment must be capable of operating with one phase at ground potential. For high voltage equipment this may require additional insulation.

By solidly grounding the neutral, the ground fault current will undoubtedly trip the protection equipment and clear the fault. However if the zero sequence impedance, which limits the ground fault current, is considerably less than the positive sequence impedance, the high ground fault current may exceed that due to a three phase fault. This should be checked when determining protection equipment short-circuit current ratings.

The majority of medium voltage systems use a resistance ground. The resistance is connected between the neutral point and the ship's hull. The resistance limits the ground fault current to a low value, but one that is high enough to ensure selective operation of ground fault protective devices.

Practice in the US was to limit the ground fault current to 3 times the system capacitive charging current (Ico). As a guide 6 kV marine systems generally have a capacitance of about 1.4 mF. This means that the resistance should be sized to limit the ground fault current to about 5.5. amps (3 x Ico). This will then prevent any charge being built up on the system due to transient over-voltages. However marine systems generally have high losses and consequent heavy damping; therefore such over-voltages are generally not a problem. It is generally better to limit the ground fault current to a value just higher than 3 Ic to ensure the operation of the ground current detection and protection equipment.

Although operation of a high voltage system with a ground fault is possible, it cannot be recommended and steps should always be taken to initially limit the fault current to as low a value as is acceptable, and secondly to isolate the equipment and repair the ground fault as soon as possible. If this is not done there is always a danger that the fault will escalate to a phase-to-phase fault and cause fire or extensive equipment damage.

4. **In summary:**

Low-low voltage systems (120, 220 etc.)
Solidly grounded systems can be applied effectively and can reduce circuit breaker requirements from 2 to single pole. (Note: Some regulatory bodies do not permit the use of single pole breakers and would still require ground fault detection equipment regardless. See IEEE 45 1998, and Canadian Coast Guard regulations.) Due to the rapid fault clearance inherent with this system, it is preferred for domestic, hotel and catering type loads.

Low voltage systems (380, 440, 480, 600 volts)
Insulated neutral systems are the most widely used. Such systems include ground fault detection equipment to warn of ground faults. Ground fault ammeters can be added to give indication of the level and location of the fault. System over-voltages resulting from capacitive charging are rare and generally result in voltages less than the equipment insulation rating (2 kV).

Medium voltage systems (3.3 kV 6kV 6.6 kV 13.8 kV)
Practice has been to use high resistance grounded neutral systems where the fault current is limited to a value that will operate the protection equipment but is above that required to encourage transient over-voltages.