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Grounding method key to system protection

The stability of an electric power system and its ability to recover from ground faults is directly related to the grounding system used. Most 3-phase electric systems are either ungrounded, effectively (solidly) grounded, or grounded through a resistance. Transmission systems are usually ungrounded; distribution systems are usually solidly grounded; while industrial systems use different methods in different parts of the world.

However, industrial systems are more susceptible to ground faults and require the added protection that resistance grounding provides. Most of the industrialized countries now used resistance grounding for industrial systems, while developing countries are in a transitional stage. For example, Indonesia, Malaysia, and Singapore currently use resistive grounding for most of their industrial systems. The same trend can be seen in other Southeast Asian countries. However, the Philippines and Thailand use resistive grounding much less frequently. As the industrial bases of these countries increase, the undesirable effects of ground faults—voltage instability and excessive fault currents—are becoming more of a problem. It is probable that resistive-grounding protection will be applied in these countries also.

The following is a description of the relative merits of the three grounding techniques.

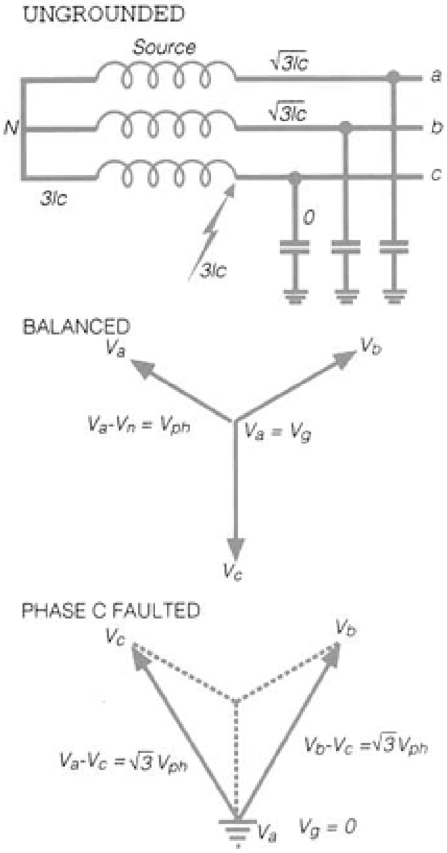
Ungrounded-systems are those in which no intentional connection is made between any part of the system and ground. However, an electrical system is always capacitively grounded because of a coupling through the inherent shunt capacitance that exists between the conductors and ground. In a balanced system, with no loads connected between line and neutral, the neutral is held at ground potential because of the presence of this shunt capacitance. Line-to-neutral voltage equals line-to-ground voltage and the neutral-to-ground voltage is zero.

Under balanced conditions, a charging current (I_c) flows through the capacitive reactance (X_{co}) between each phase and ground. However, because each current is displaced by 120 deg, the vectoral summation at ground is zero.

When a ground fault occurs, a fault current of several amperes flows. Because the faulted phase assumes ground potential, the neutral potential (Fig 1) is displaced from ground by an amount equal to the line-to-neutral voltage (V_{ph}). Now the voltage between each of the healthy phases and ground rises to the line-to-line value. (Line-to-line voltage = $\sqrt{3}.V_{ph}$). The resulting increase in voltage across the shunt capacitance causes the current between each of the two healthy phases and ground to increase by a factor of $\sqrt{3}$. And since the currents are displaced by only 60 deg, the vectoral summation at ground is $3I_c$.

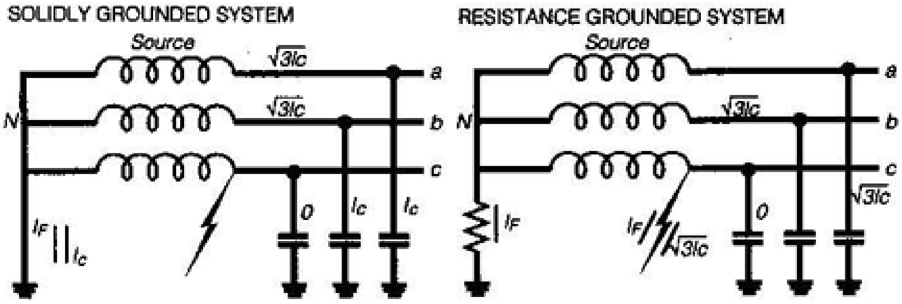
An ungrounded system can continue to operate with a ground fault, provide that the ground fault current ($3I_c$) does not rise above a few amperes and the phase-to-ground voltage of the healthy phases do not rise above the line-to-line voltage. This allows production to be continued until the end of the shift or day and the fault located when the plant is normally shut down.

However, operating experience with ungrounded systems has shown that substantial over-voltages can develop. The presence of capacitance and inductance in the system leads to arcing and intermittent, sputtering type faults, which cause the system voltage to escalate to dangerously high values (up to six times normal valve have been produced in laboratory tests). Overstressing of the insulation and failures in system components can be caused by voltages of this magnitude. Transient overvoltages, especially in medium-voltage systems, increase the probability of failures and generally outweigh any advantages an ungrounded system might offer.



1. Ungrounded system exhibits overvoltage when one phase is faulted

Effectively-grounded (solidly-grounded) systems have a direct connection between the neutral and ground, with no intentional impedance (Fig 2). Multi-


SOLIDLY GROUNDED SYSTEM

RESISTANCE GROUNDED SYSTEM

2, 3. Solidly grounded system can be damaged by high fault currents (left). Resistance grounding can be designed to suit system needs

Characteristics of different grounding methods

Characteristic	Ungrounded	High-resistance	Low-resistance	Effective
Transient overvoltages	Up to 6 p.u.	2.5 p.u.	2.5 p.u.	2.5 p.u.
Positive fault location	No	Yes	Yes	Yes
System interruption on first fault	Sometimes	Optional	Yes	Yes
Personnel safety	Poor	Best	Good	Fair
Multiple faults	Often	Seldom	Seldom	Seldom
Fault damage	Low	Low	Medium	High
Coordination of protective relay	Impossible	Best	Good	Good

grounded utility distribution systems have a neutral wire which parallels the 3-phase conductors for the length of the distribution line and is grounded at intervals. Effectively grounded systems are not subject to transient over-voltages that result from intermittent ground faults. The solid ground connection stabilizes the neutral voltage and prevents elevation of the phase-to-ground voltage.

If the neutral is available for connection, effective grounding involves no additional equipment and is the least expensive method. However, the ground-fault current is limited only by the arc and stray return-path impedances which are small, resulting in a high fault current. Extensive and time-consuming repairs may be needed after a ground fault on an effectively grounded system. This is especially true of low-voltage (<600 V), where this method of grounding presents a substantial protection problem.

Resistive-grounding systems have an essentially resistive impedance inserted between the neutral and ground (Fig 3). This method of grounding has advantages of both the ungrounded and effectively grounded system, while eliminating most of their disadvantages. For example, the potentially dangerous system overvoltages caused by arcing-type ground faults are suppressed by dissipating the energy in the resistor. Safety to personnel and system stability are significantly improved.

The mitigation of a ground fault's damaging effects and resulting hazards to personnel are even more pronounced when compared to solid grounding. A useful rule of thumb: The energy released and the damage done by a fault are approximately proportional to the square of the fault current multiplied by the fault duration. If the fault current is reduced from 10 000 amp with solid grounding to 100 amp with resistive grounding, the magnitude of the fault energy is reduced by a factor of 10 000. The table summarizes system characteristics as a function of the grounding method used.

High- or low-resistance ground

There are two types of resistive grounding: high- and low-resistance. Within each category there are several configurations available that allow the system designer flexibility.

Low-resistance grounding provides a ground-fault current typically between 25 and 2000 amp. The magnitude of the ground fault current must be at least as large as the current flowing through the system's shunt capacitance in order for the resistance to adequately limit the transient overvoltages. The protection scheme is optimized by selecting a fault level low enough that fault damage is minimized, while still allowing enough current to flow to reliably operate relays selectively.

Because the fault is cleared quickly by relays, damage to equipment is minimized. The fast response time also improves personnel safety, prevents additional faults from occurring, and limits overheating and mechanical stress on conductors.

High-resistance grounding uses a resistance sized to limit the ground fault current to slightly higher than the capacitive current and typically no more than 10 amp ($R \leq X_{CO}/3$). If possible, the ground fault current should be large enough to allow for system growth. The fault current in high-resistance-grounded systems is low enough to permit continued operation while the fault is located and a scheduled shut down can be arranged for repairs. Fault tracking in high-resistance-grounded systems can be accomplished without circuit interruption.

The common detection scheme uses a relay to sense the voltage that appears across the resistor under fault conditions. (The relay usually includes a time delay to filter out transients and nuisance indications.) Once a fault is detected it is annunciated locally and/or remotely.

To locate the fault, a technician initiates a control circuit that produces a tracer signal. Typically, 40 current pulses/min are used. This signal is easily distinguished from background noise. The pulses can be traced to the fault with a very sensitive, split-core window ammeter. ■

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