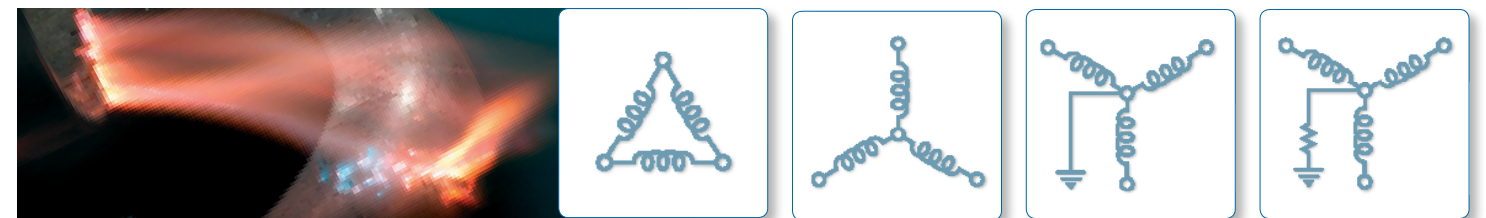




## NEUTRAL GROUNDING RESISTORS

DESIGN AND APPLICATION



ASK THE EXPERTS

## NEUTRAL GROUNDING RESISTORS

neutral grounding Resistors are similar to fuses in that they do nothing until something in the system goes wrong. Then, like fuses, they protect personnel and equipment from damage.

damage comes from two factors, how long the fault lasts and the fault magnitude. ground fault relays trip breakers and limit how long a fault lasts based on current. neutral grounding resistors limit the fault magnitude.

To improve coordination between resistors and relays and to avoid loss of protection, many neutral grounding Resistors are now being designed with integral combination ground fault and monitoring relays. in distribution systems employing resistance grounding, the relay protects against ground faults and abnormal conditions in the path between system and ground possibly caused by loose or improper connections, corrosion, foreign objects or missing or compromised ground wires.

neutral grounding resistors limit the maximum fault current to a value which will not damage generating, distribution or other associated equipment in the power system, yet allow sufficient flow of fault current to operate protective relays to clear the fault.

To ensure sufficient fault current is available to positively actuate the over-current relay and that the fault current does not decrease by more than 20% between ambient and the full operating temperature, it is recommended that the ngR element material to be specified to have a temperature coefficient not greater than 0.0002 ohms / C.

The element material is critical in ensuring high operating performance of the neutral grounding resistor. The element material must be a special grade of electrical alloy with a low temperature coefficient of resistance. This prevents the resistance value from increasing significantly as the resistor operates through a wide temperature range. it also ensures a stable value of the fault current for proper metering and relaying.

There are two broad categories of resistance grounding: low resistance grounding and high resistance grounding in both types of grounding, the resistor is connected between the neutral of the transformer secondary and the earth ground and is sized to ensure that the ground fault current limit is greater than the system's total capacitance-to-ground charging current.

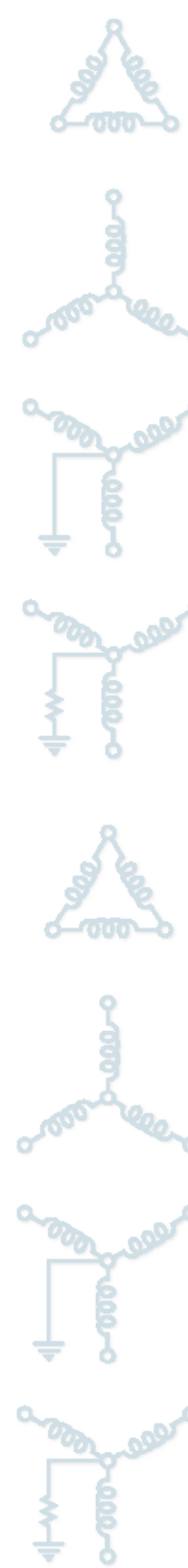
There are two broad categories of resistance grounding: low resistance grounding and high resistance grounding low resistance grounding of the neutral limits the fault current to a high level (typically 50 amps or more) in order to operate protective fault clearing relays. These devices are then able to quickly clear the fault, usually within a few seconds.

The key reasons for limiting the fault current through resistance grounding are:

- To reduce burning / melting effects in faulted electrical equipment, such as switchgear, transformers, cables and rotating machines
- To reduce mechanical stresses in circuits and apparatus carrying fault currents.
- To reduce electric shock hazards to personnel caused by stray ground fault currents in the ground return path.
- To reduce arc blast or flash hazard to personnel who may have accidentally caused or who happen to be in close proximity to the fault current.
- To secure control of transient over voltage



## NEUTRAL GROUNDING RESISTOR IN ALTERNATOR



**Q.** What is the advantage of using ngR to connect Alternator

**A.** You are referring about an ungrounded System, which does not have a direct connection from neutral to ground. Because of this, there is no direct return path for a ground fault. The ground fault is then made up of only system capacitive charging current, which is typically 2-3A for a 600V or less system. due to this low ground fault current, no over-current protection device operates and the ground fault is left on the system (continuous operation). The problem is ... an intermittent (or arcing) ground fault causes transient over-voltages due to the charging of the system capacitance.

iIEEE Std 242-2001 (Buff Book - Recommended Practice for Protection and Coordination of industrial and Commercial Power Systems) section 8.2.5 states "if this ground fault is intermittent or allowed to continue, the system could be subjected to possible severe over-voltages to ground, which can be as high as six to eight times phase voltage. Such over-voltages can puncture insulation and result in additional ground faults. These over-voltages are caused by repetitive charging of the system capacitance or by resonance between the system capacitance and the inductance of equipment in the system."

iIEEE Std 141-1993 (Red Book - Recommended Practice for Electric Power distribution for industrial Plants) section 7.2.1 states "Accumulated operating experience indicates that, in general purpose industrial power distribution systems, the over-voltage incidents associated with ungrounded operation reduce the useful life of insulation so that electric current and machine failures occur more frequently than they do on grounded power systems."

Another Hazard is the inability to locate ground faults. So, in the 1950s a couple of end users and manufacturers collaborated with a common goal of designing a system that has the only advantage of an ungrounded System (continuous operation) and without the disadvantages (severe transient over-voltages and inability to locate ground faults). THE RESOLUTION WAS HIGH-RESISTANCE gRounding (HRg). HRg Systems allow for continuous operation by inserting a resistor between the neutral and ground, which allows for a direct return path for ground faults so that they can be easily found. The resistor also provides for discharging of the system capacitance to avoid severe transient over-voltages, ONLY IF the resistor current is higher than system capacitive charging current, which is extremely easy to design and install.

Recently, HRg Systems have been used to eliminate another Hazard, Arc Flash Hazards associated with ground faults on Solidly-grounded systems. There are other Hazards that must be considered due to the very high ground fault currents.

iIEEE Std 141-1993 (Red Book - Recommended Practice for Electric Power distribution for industrial Plants) section 7.2.4 states "A safety hazard exists for solidly grounded systems from the severe flash, arc burning, and blast hazard from any phase-to-ground fault." By placing a resistor between the neutral and ground, the ground fault current is typically reduced to 5A for 600V or less systems.

iIEEE Std 141-1993 (Red Book - Recommended Practice for Electric Power distribution for industrial Plants) section 7.2.2 states that "There is no arc flash hazard, as there is with solidly grounded systems, since the fault current is limited to approximately 5A." So, by limiting the ground fault to 5A, you have avoided the hazards with Solidly-grounded systems.

in addition, several generator manufacturers require resistance grounding as the generators are not rated for ground faults as they are often times higher than three-phase faults. iIEEE Std 142-1991 (Recommended Practice for grounding of industrial and Commercial Power Systems) states in section 1.8.1 'discussion of generator Characteristics' that "unlike a transformer ... a generator will usually have higher initial ground-fault current than three-phase fault current if the generator has a solidly grounded neutral. According to nEMA, the generator is required to withstand only the three-phase current level unless it is otherwise specified ..." This is due to very low zero-sequence impedance within the generator causing very high earth fault currents. For generators 600V or below, this may not be an issue. However, it is usually always an issue as the voltage class increases.

The resistor also significantly reduces any circulating currents, which are typically triplen harmonics leading to over- heating in the generator windings.

**Q.** We will be erecting a new 22.1MW AC generator of 11kv with 1450A. How much earth fault current do we limit and what rating of ngr should we use?

**A.** The 'Key' to resistance grounding is to know the system capacitive charging current. Then you can decide 'High' or 'Low' Resistance Grounding (good engineering practice sets 10A as the threshold, over 10A then LRG, 10A or below then HRG).

With that being said, you must determine your system and goal of grounding, i.e. system protection or generator protection. Are the generators units connected or bus connected? If unit connected (directly connected to either step-up or step-down transformer), then I would recommend 5A as the physical size of the 11kV system is small, so the system capacitive charging current is < 5A.

If the generator is connected to a bus with distribution, then you must calculate the system capacitive charging current (see Tables 4.1 & 4.2 in our Application Guide 'Ground Fault Protection on Ungrounded and High Resistance Grounded Systems - <http://www.i-gard.com/appguides.htm>).

If the calculations are 10A or less, then I would recommend using 1.5X system capacitive charging current. If it is > 10A, then I would recommend using a Hybrid High/Low Resistance Grounded system. In this case, the generator has (2) parallel grounding paths, one at 5A and one at 100A. For ground faults external to generator, then the ground fault current is  $100+5=105A$ . For generator internal ground faults, the 100A resistor path is tripped off-line with the generator main circuit breaker. Now the ground fault current within the generator winding is only 5A, significantly reducing the damage that occurs while the machine is coasting to a stop.

## GROUNDING RESISTOR SIZING CONSIDERING THE SYSTEM CAPACITIVE CHARGING CURRENT

**Q.** I realize that to have a proper ngR size for a 7.2kV mining project the let-through rated current of ngR should be equal or greater than the system capacitive charging current, and then based on the number of the feeders on the 7.2kV bus. Am I supposed to add all connected feeder capacitive charging current (3iCO) up and then the sum of them will be the system capacitive charging current? if so, then there should be a kind of limitation in terms of the number of the feeders with the associated long trailing cable that are going to be connected to the 7.2kV bus. My issue is an existing 7.2kV system with available 25 A ngR that is going to be extended to have more feeders. We have come up with a total system capacitive charging current around 50A (after summation all prospective connected feeder's capacitive charging current) then I guess the ngR has to be changed. is that correct?

**A.** iCO is the net phase to ground capacitive charging current at line to neutral voltage. The 3 iCO is caused by the net distributed capacitance at 7.2kV. All the cable lengths have to be accounted for. if the 3 iCO exceeds 25A then the resistor let-through current should be increased as you have indicated. **Q.** I am a design Engineer currently

**Q.** I am a design Engineer currently involved in designing a ngR for 33KV/6.6KV transformer (delta/star) configuration. The capacity is 4/50MVA. We had already installed 2 similar types of transformers of 35MVA capacity-ngR details are 76ohm with 50A for 10seconds. We are having around 25HT motor and 5 distribution transformer, so what value would I need to select in order to limit any ground fault to a safe value?

**A.** I do not know the feeder distances or if there are any surge capacitors/arrestors. general rule of thumb is 1.5A/ MVA. So, with a 40/50MVA, the capacitive charging current is approx.  $1.5A \times 50 = 75A$ . This means that the 50A ngR will not dissipate the capacitive charging current resulting in transient over-voltages. unless the length of the feeders is short And there are no surge capacitors/arrestors, I would consider using a larger ngR, say 100A or 150A.

## RESISTANCE NEUTRAL GROUNDING

**Q.** 2MVA, 480V, Y-Y generator set is connected to 2.5MVA, 0.48/25KV, Y-Y step up transformer. The step up transformer is connected to metal clad switchgear. There are 2 sets of 2MVA generator and step up transformer (same size). 3 feeders are running out from the switchgear and feeding 3 step down transformers (Each capacity is 2MVA, 25/0.48KV, Y-Y connected). length of feeder is about 2KM. These transformers are resistor's neutral grounded and feeding MCC's busbar (2000A, 65 KA i.C., 480V). This distribution system is of process unit. So, I would like to make resistor's neutral ground at either step up transformer or generator set for rising up the fault level of the whole system. What is the optimum choice of neutral grounding (at transformer or generator set) and why?

**A.** You can apply the neutral grounding resistor at the generator or at the IV winding of the step up transformer functionally it is the same. Most people prefer to apply them at the generator. A continuously rated 55 ohm, 277 v resistor would be sufficient and it would allow you to just raise an alarm and continue operation.



## SYSTEM CAPACITIVE CHARGING CURRENT

**Q.** What is a capacitive charging current? is it the max generator current that creates the magnetic field for your generator?

**A.** no. Capacitive charging current is current created by the system, almost solely from feeders and surge arrestors/ capacitors. Think of a feeder, which in this case is a cable in a conduit. if you physically look at the installation, the two (cable and conduit) are parallel to each other as well as at different potentials (cable = phase voltage and conduit = ground potential). Both are separated by an insulating material. The result is a big capacitor in terms of physical size.

When you energize the system, current flows from the phase conductor to conduit (actually, this isn't technically true, it actually causes a displacement of charge within the dielectric say the academics, in the real world, it is called current) through the dielectric, you just can't see it or measure it because it is being equally distributed all along the cable.

So when you have an ungrounded system and a ground fault occurs, the phase voltages with respect to ground changes on the 2 unfaulted phases, say from 277V to 480V. What happens to the charge within the feeder capacitance? it rises from 277V to 480V; we are now CHARGing the capacitance.

in this case, we now can measure it because there is a single spot (the ground fault wire). The easiest way to measure a system capacitive charging current is to unground the system, place a ground fault on the system THRU a fast-acting fuse (~10A or less) and measure the current in the wire. This is your system capacitive charging current since it returns to the other 2 phases thru the insulating material, or dielectric. Just remember- this is 3\*ico, if you want just ico, you must divide by 3.

## VOLTAGE LIMIT APPLICATION OF HRG

**Q.** How high of a voltage can we use with High Resistance grounding?

**A.** Mostly depends on the application. Rule of thumb is that HRg can be and is used on MoST systems 5kV and less, and used on SoME 15kV systems. The reason is system capacitive charging current. As system voltage rises, so does capacitive current. The resistor current MuST be higher than the capacitive current. good engineering practice limits the HRg current to 10A and standards limits it 25A. Anything above that, it is known as low-Resistance grounding.

## ADVANTAGE OF NEUTRAL EARTHED RESISTOR TO SOLIDLY EARTHED NEUTRAL

**Q.** Advantage of Neutral earthed resistor to solidly earthed neutral when plant has high voltage motors (3300 V). Which would be the best earthing method and why?

**A.** Solidly-Grounding systems have Safety Hazards that must be considered due to the very high ground fault currents.

IEEE Std 141-1993 (Red Book - Recommended Practice for Electric Power Distribution for Industrial Plants) section 7.2.4 states "A safety hazard exists for solidly grounded systems from the severe flash, arc burning, and blast hazard from any phase-to-ground fault." By placing a resistor between the neutral and ground, the ground fault current is typically reduced to 5A for 3300V systems.

IEEE Std 141-1993 (Red Book - Recommended Practice for Electric Power Distribution for Industrial Plants) Section 7.2.2 states that, "There is no arc flash hazard, as there is with solidly grounded systems, since the fault current is limited to approximately 5A." By limiting the ground fault to 5A, you avoid the hazards with Solidly-Grounded systems.

IEEE Std 142-1991 (Green Book) section 1.4.3 states "The reasons for limiting the current by resistance grounding may be one or more of the following:

- 1) To reduce burning and melting effects in faulted electric equipment, such as switchgear, transformers, cables, and rotating machines.
- 2) To reduce mechanical stresses in circuits and apparatus carrying fault currents.
- 3) To reduce electric-shock hazards to personnel caused by stray ground-fault currents in the ground return path.
- 4) To reduce the arc blast or flash hazard to personnel who may have accidentally caused or who happen to be in close proximity to the ground fault.
- 5) To reduce the momentary line-voltage dip occasioned by the clearing of a ground fault.
- 6) To secure control of transient over-voltages while avoiding the shutdown of a faulty circuit on the occurrence of the first ground fault (high resistance grounding).

## IDMT PROTECTION IN LOW RESISTANCE GROUNDING SYSTEM

**Q.** What could be the normal earth fault current in case of 6.6kV system having NGR restricting the maximum earth fault current to 250Amp? Would it be as low as 30% i.e. 75 Amp? In such case, it would not be possible to detect the earth fault by IDMT earth fault relay connected in residual connection with the phase CTs (for transformer of rating 20 MVA) as minimum relay setting would be 10% (approx. 200Amp).

What is the alternative in such case? Is it preferable to increase the earth fault current value by reducing the resistance or should I go for a separate neutral CT of lesser ratio instead of the residual connection?

**A.** Yes, it is possible to be that low. The biggest problem with residual connected CTs or standard issued CTs on circuit breakers is the minimum detection. In some cases it can be as high as 20%, at least in your situation, it is only 10%. However, this is still a problem as 10% = 200A on a 250A NGR is an 80% pickup. Most times, the earth fault will quickly rise to full NGR value on 6.6kV systems, but not always. I would recommend using a zero-sequence CT for faulted feeder detection or a neutral CT for ground fault alarm or both.

You may also consider a System Ground Monitor, such as our GFR-RM relay. This relay is in parallel with the neutral conductor, NGR, and ground conductor. If an open or short circuit exists due to corrosion or loose connection, it will alarm indicating a grounding problem.

## CALCULATING THE MASS RESISTANCE

**Q.** I had calculated the resistance of NGR 10ohm for 10 sec for 400A current for 6.6kV system. Now I need to calculate the mass of resistance required considering Stainless steel ANSI 304 Grade? How do I calculate that?

**A.** Each company calculates this differently and this is usually proprietary information. One thing to consider using 304 material is that the resistivity increases due to heat rising. This means that the ground fault current will start out at 400A and then drop to 250A after 10



## RESISTANCE AND REACTANCE GROUNDING

**Q.** When should resistance and reactance grounding be used? And when should it not?

**A.** Just a quick note about Resonance grounding: Resistance grounding is preferred in the US mostly due to economics and complexity. Resistance grounding is a passive device that performs independent of system topology and frequency, whereas Resonance grounding must adapt to system capacitance.

Resonance grounding uses an inductor to create an impedance to match the system capacitance impedance. In doing so, both components cancel and the resultant is a small resistive ground fault current.

Disadvantages of Resonance grounding: 1) Typically the inductance is slightly larger to avoid a true resonance condition (if not, an over-voltage condition will occur) 2) System capacitance continually changes as feeders are brought on- and off-line (so monitoring system must be installed and inductor must be variable) 3) Cost for monitoring and inductor variability are high 4) Physical size of inductor is significantly larger than Resistor.

Resistance grounding offers a fixed ground fault current independent of system topology. However, the fixed current must be larger than the system capacitive charging current. So, a value of 100-400A is usually selected.

**Q.** For selecting the value of resistance, system capacitive charging current is less than restricted current during single line to ground fault for resistance ground systems, otherwise system may experience transient over-voltages. Is there any easiest way of estimating the value of system capacitive charging current? If yes, please suggest me the process? Otherwise, how can I estimate the same current?

**A.** There are three ways to estimate the charging current (all of which are shown in our Application guide "ground Fault Protection on ungrounded and High Resistance grounded Systems" on our website <http://www.i-gard.com/appguides.htm>):

- 1) You can quite easily measure it. When a protected phase to ground fault is applied on an ungrounded 3 wire system which has balanced voltages to ground on the three phases, then the current in the fault is the net charging current. If the system is resistance grounded then the current through the resistor will need to be subtracted vectorially, as it is 90 deg out of phase with the capacitive current.
- 2) You can estimate the distributed cable capacitance by the cable characteristics and add to it all other known capacitances to ground from other equipment. Then calculate the charging current in each phase, and then the sum will be the net charging current flow.
- 3) Apply rule of thumb. In general on low voltage systems up to 600 V, the charging current is predictable to be less than 1A per 1000kVA of installed source capacity. For example, if the supply transformer is 3000kVA then the expected charging current will be less than 3A. Add to this any exceptional capacitances to earth, which may be present in devices such as surge suppression etc.

Resistance grounding offers a fixed ground fault current independent of system topology. However, the fixed current must be larger than the system capacitive charging current. So, a value of 100-400A is usually selected.