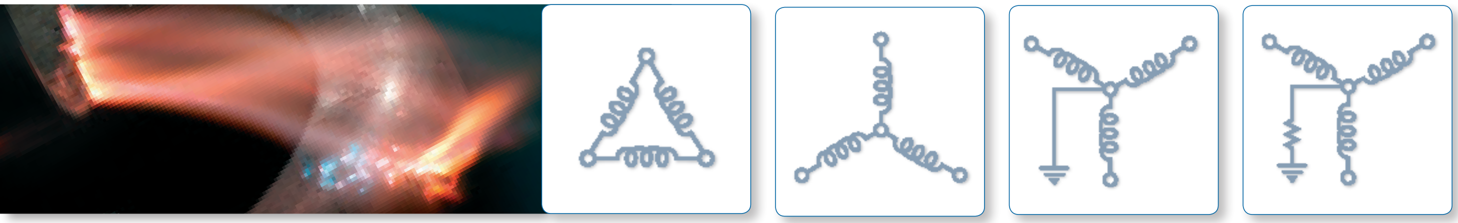
iGARD

Unparalleled Protection

ARC FLASH HAZARD AND HIGH RESISTANCE GROUNDING

HRG



ASK THE EXPERTS, September 2018

ARC FLASH HAZARD AND HIGH RESISTANCE GROUNDING

During a twenty year electrical fault study, one of the world's largest consumer products company found that 98% of their electrical faults were ground faults. So why is this important? In the IEEE Red Book (Std 141- 1993, section 7.2.4), it states that "A safety hazard exists for solidly grounded systems from the severe flash, arc burning, and blast hazard from any phase-to-ground fault."

The good news is that the same standard recommends a solution to resolve this issue. Section 7.2.2 of the IEEE Red Book states that when using high resistance grounding, also known as HRG, "There is no arc flash hazard, as there is with solidly grounded systems, since the fault current is limited to approximately 5A."

When it comes to minimizing arc flash/blast hazards, there is no silver bullet. There are many different tools that can be used. However, none of them offer the protection that HRG does for the price. While it is true that HRG does not protect against phase-to-phase faults, there is test data suggesting that it does significantly lower the hazard. Without question, HRG provides the most safety in terms of protection for the price when compared to any other mitigation tool. HRG lowers your risk by 98% by eliminating arc flash hazards during ground faults and reduces the hazards during phase-to-phase arcing faults when enclosed.

Even though the IEEE Red Book dates back to 1993, many people think that the only advantage to HRG is continuous operation during the first ground fault. There are many safety advantages as well. In addition to elimination of arc flash hazards associated with ground faults, it also prevents dangerous transient over-voltages associated with ungrounded systems.

HRG was first developed over 50 years ago to solve the problems with ungrounded systems. During a ground fault, the arcing nature 'charges' the system capacitance. When the arc extinguishes (possibly due to ac waveform – zero crossover), the charged system cannot dissipate the charge, so it holds it. When arc re-strikes, more charge is added to the system. This continues until the insulation breaks down at the weakest point in the system. So, in the 1950's and 1960's a group of people developed HRG to dissipate this charge between strikes and add the ability to locate a ground fault.

Nowadays, it is being used to replace solidly grounded systems as mentioned beforehand. Although it is the safest grounding method available today, there are design considerations that must be addressed. Fortunately, modern technology helps incorporate these considerations, making the design process straightforward.

There is a concern that the first ground will be left on the system and ignored. Since the zero-sequence current transformers identify the faulted feeder, the relay has the ability to begin a (user programmable, usually in hours) timer when the ground fault first occurs. Unless the ground fault is removed or the timer is reset, the faulted feeder is shunt-tripped offline. The purpose is to continually remind maintenance personnel to either remove the ground fault or to reset the timer every so many hours.
In the event that a second ground fault occurs prior to removing the first ground fault, a phase-to-ground-to phase or phase-to-phase fault can occur. When this occurred on the original HRG, it would cause both feeder circuit breakers and possibly the main circuit breaker to trip. However, the modern relay can be programmed to prevent this and only shunt-trip the lesser priority feeder, leaving the more important feeder on-line.

A major safety concern is the loss of neutral path, i.e. broken wire from source neutral to resistor or between resistor and ground or even a bad or loose connection. The result is changing from a high resistive grounded system to either an ungrounded or solidly grounded system without anyone knowing it! This would cause severe safety hazards. With modern technology, the neutral path from neutral to ground (including resistor) can be continuously monitored for integrity. If an open or short circuit occurs, the relay will alarm.

Q&A

QUESTION AND ANSWER

Q. We have a 2000kVA, 6.6kV/433V transformer, dyn11 vector group, 6.21% impedance HV CT 200/1; LV CT 3000/1. I wish to provide an earth-fault relay on HV as well as LV to protect against the earth fault. The LV of the transformer is solidly earthed. At what value should I set the relays, and what will be the value of earth-fault current in the case of earth fault on HV and LV sides. Some people suggest 10%. So, what is the logic behind setting the relay at 10% of the CT primary rating?

A. If you set the relay to 0%, there will be nuisance tripping. So, the question is … how high do you set the relay to avoid? Over the years, 10% was selected due to older mechanical relays protecting 90% of the windings.
The trade-off is that there must be enough ground fault current to trigger a relay without causing nuisance tripping. More information is available in Protective Relaying texts. Presumably you have a shunt-trip device (52) on the HV side and that the transformer feeds a switchboard with main LV breaker and some feeder breakers. Assuming infinite source supplying the 6.6 KV then the maximum earth fault current on the LV side will be ~43kA. Earth fault (e/f) downstream from the main breaker will most likely involve arcing and thus the potential for very high arc flash and blast damage exists on solidly grounded systems.

This can be avoided one of two ways:

- Install high-resistance grounding (I-Gard Sleuth or DSP MKIII System) on the LV side. This will eliminate arc flash hazards for ground faults per IEEE and allow for continued operation.
- The earth-fault protection can be maximized by lowering the tripping time of the earth fault element on the feeder breakers. To reduce arc flash damage, Zone Selective Interlocking Protection (ZSIP) should be used. Example: The main breaker earth-fault element should coordinate with the downstream feeder earth-fault settings. For example, feeder breaker earth-fault set at 100 A with 0.1 sec delay, main breaker earth-fault element set at 200 A at 0.2 seconds and the e/f relay connected to the residually connected 3000/1 LV CTs monitoring the transformer output can be set at 300 A or 500 A at 0.3 seconds. Alternatively, a CT can be mounted on the Neutral to Ground bus and connected to the earth-fault relay set at 300 A at 0.3 seconds.

The HV side will have phase-over-current condition due to LV ground fault. The earth-fault function on the 6.6kV breaker feeding the transformer will need to be set to suit the HV side earthing. If 6.6kV source is also solidly grounded, then residually connected 200/1 HV CTs can be set at 20A at 0.2 seconds to provide transformer primary winding earth-fault protection.

LV FEEDER

Q. We have an arrangement of a 11kV/0.415kV transformer feeding a LV (415V) switchboard. Total load around 280kVA, with most of the three-phase motors, started DOL with few on VSD. I am proposing to use a MCCB as incomer with shut trip. It will provide thermal/magnetic protection. Do you think earth-fault and under-voltage protections are necessary for this configuration? What is the best way of achieving earthfault protection, economically as well e.g., CB-CT, residual CTs? What should be the settings for both earth-fault and under-voltage relays in that case?

A. Before you select earth-fault protection you need to decide the system earthing for the 415V supply. Conventionally, it would be solidly grounded but then you will have to trip when an earth-fault happens and subject yourself to severe arc flash hazards. If instead you apply High Resistance earthing, then power flow to the motors can be maintained even when there is an earth-fault and there are no arc flash hazards associated with ground faults. For the size of the transformer and the load, a 2A let-through, 230V, neutral earthing resistor would be sufficient. Occurrence of an earth fault can now be detected by simply monitoring the voltage to ground from each phase or by monitoring the current through the resistor by a sensor and an earth-fault relay. This relay can be set for 1A pick up. This would be quite economical.

If you decide not use high-resistance grounding and instead opt for solid grounding, then you could choose an earth-fault relay setting of 100A. This can be obtained through earth-fault element on the incomer MCCB which has built in CTs and a loose neutral sensor. Time delay setting should be as low as possible to reduce the fault damage, about 0.1 to 0.5 seconds. There are time-current coordination issues with load-side protective devices that you will need to consider to avoid nuisance tripping the MCCB, another problem with SG systems. The under-voltage function needs to be set for 80% of the nominal. With a large percentage of the loads being motors under single phasing condition, the open phase will regenerate and would be difficult to detect if the under-voltage setting is below 80%.

ZONE SELECTIVE INTERLOCKING

Q. How can Zone Selective Interlocking reduce the arc flash hazard from ground faults?

A. Arc flash hazard is quantified by the incident energy released in an arc flash at a particular location, expressed in calories per centimeter squared, as determined by an arc flash hazard analysis. The incident energy is proportional the length of time the arcing fault persists; hence arc flash hazard can be reduced by lowering time delay settings of the phase and ground fault overcurrent protective devices.

Continuity of service is important in many plants, and is maximized by time-current coordination of the phase overcurrent devices and ground fault devices. Where coordination does not exist, a breaker further upstream will trip first, knocking out more of the plant than was necessary. In extreme cases the plant main breaker will trip. The drawback of time-current coordination is that extra time delay is required on upstream protection devices. More damage is tolerated from upstream arcing faults in the interests of service continuity. Today there is increased awareness of arc flash safety; engineers and electricians are taking a second look at these tripping time delays upstream in the distribution system. Arc flash safety now overrides service continuity on switchboards that require inspection while energized.

Zone Selective Interlocking (ZSI), also known as Zone Selective Instantaneous Protection (ZSIP), offers an excellent solution to this problem. It improves arc flash safety upstream in the plant distribution system without affecting service continuity. ZSI is applied both to phase overcurrent devices (on the short-time protection function), and to ground fault protective devices. It is available on electronic trip units and relays of circuit breakers.

With ZSI, a breaker which senses a fault will trip with no intentional time delay unless it receives a restraint signal from the breaker immediately downstream; if so restrained, the breaker will wait to time out before tripping. The downstream breaker only sends a restraint signal upstream if it also senses the fault, i.e. only for faults located downstream of both breakers. For the fault at point Y, the sub-feeder breaker will restrain the feeder breaker; and the feeder breaker will restrain the main breaker. Hence the main and feeder will wait to time out. In the meantime, the sub-feeder breaker will clear the fault.

Zone selective interlocking has been available for decades, but has not been widely used because time-current coordination was deemed safe enough; damage upstream in the distribution system was a tolerable trade-off.

However, the push today for increased arc flash safety means that shorter trip times will be used. The cost of the ZSI twisted pair control wiring between switchboards, panel boards, and motor control centers will now be considered a worthwhile investment because it improves arc flash safety without compromising service continuity.

SENTRI

Sentri

Arc Flash Mitigation

ZSIP Selective Instantaneous Protection

40 trip levels from 100 mA up to 1200A

HRG DC POWER

Q. Are there disadvantages to utilizing a high resistance grounding scheme on 4000 A 1000V DC switchgear? Does this class of DC gear have arc-flash hazards the same as AC switchgear?

A. No, I do not see any disadvantages in high resistance grounding 1000Vdc switchgear. Where would you apply the high resistance grounding? Is center tap available to allow +/- 500V? This would be the most convenient place to apply HRG and you can monitor the system for ground faults. Yes, Arc Flash Hazard exists in the 1000V DC systems as well and can be quite severe because of low source impedance.

ARC FLASH AND HRG

Q. What about existing installations? Would just installing HRG alone solve possible risks? What else should we consider in an industrial installation? Please advise.

A. HRG will limit ground fault currents to a low value. You should have an arc flash hazard assessment performed so you know what the hazards are. You should acquire the appropriate PPE and insure you have good training programs and safety policies. This is just a start.

Q. Are you kidding? How can you ensure your electrician ONLY drops his screwdriver between one phase and ground? The other 2 phases are only inches away! This is why IEEE 1584 and NFPA70E base everything on 3-phase bolted faults! Am I wrong?

A. Correct the other two phases are inches away. I go to many conferences and I hear stories of people who are racking in breakers with a misaligned stub and it caused a ground fault and an arc flash. Another case had someone testing voltage with a meter and the probe slipped and caused a ground fault and an arc flash. These arc flash incidents could have been avoided with a HRG system. The operator, wearing the appropriate PPE, would have been alarmed that a ground fault occurred, rectified the situation and most importantly hugged his wife and kids when he went home instead of the grim reality that did occur.

Now I cannot guarantee that electrical accidents will only affect a single phase and ground. There will be incidents that will involve other phases and ground or all three phases, but you should be wearing the appropriate PPE for that. We are not stating that you need to wear less PPE, just because you have a high resistance grounded system. I can guarantee that if you are working on an electrical system with no faults on it and accidentally contact a single phase to ground, you will walk away and the equipment can be put back into service. No one cannot guarantee the same thing with a solidly grounded system.

If I had the choice, I would prefer the added insurance with a high resistance grounded system. But the choice in the end is yours and you are gambling with a lot more than just an opinion.

Falcon

Optical Arc Detection

Photoelectric Technology

Trips in less than 1ms

Q. I would say that use of HRG will greatly reduce the risk of arcing faults on a 480V system, since the large majority of faults begin life as a line-to-ground fault. But what the others are saying is that it does NOT reduce the hazard that can exist for a three-phase arcing fault, so the required PPE is still based on the worst-case three phase fault. This is pretty clearly addressed in IEEE 1584. There is still an arc-flash hazard since the HRG has no effect on phase-phase or three-phase faults.

A. You are correct. Arc flash calculations are based on the arc flash current, time, distance and bolted fault data. There is no way that the grounding system can reduce the arc flash hazard analysis. The only thing a high-resistance grounding system can do is limit the fault current of a single phase to ground fault. Now that the fault current is limited to 5 A., the probability of that fault escalating to a phase to phase fault or a three phase fault is greatly reduced. In contrast a single phase to ground fault in a solidly grounded system has the highest probability of escalating to a three phase fault. The Red Book is stating that most faults in the electrical industry start of as ground faults. The probability of that fault escalating into a three-phase fault in a solidly grounded system is high, whereas the probability of that fault escalating into a three-phase fault in a high-resistance grounded system is low. If the Statement 7.2.2 is interpreted this way, then the statement remains true.

Q. I have a transfer switch with two breakers, as my main service disconnect. Power is through a 480V transformer/generator. Can I use one HRG for both?

A. There are two methods of inserting a single HRG System with 2 sources. You can create another neutral on the common bus that is fed both sources and ground that new neutral with a resistor to limit the fault current. This way it doesn't matter which source is on, the system will be protected.

You can tie both neutrals together and ground it through a resistor. This method is problematic as the voltage of one neutral may elevate to 277V with respect to ground even though it is not connected directly to the system. For example, if the transfer switch is on transformer and you are servicing the generator and a ground fault occurs, then the votage on the generator will rise to 277V, unless more costly switches are placed to isolate the neutrals under certain system conditions.

Q. I don't understand the quote, "There is no arc flash hazard, as there is with solidly grounded systems, since the fault current is limited to approximately 5 A." There is still phase-to-phase arcs that have just as high arc flash hazard. Can you please explain?

A. According to IEEE 1584, using High Resistance Grounding System increases the Incident Energy by approximately 30%. This is the only mathematical proof we have that High Resistance Grounding works. Now according to the Red Book 7.2.2 and the Green Book we can reduce the number of Incidences that an Arc Flash may occur. The purpose of IEEE 1584 is to calculate the Incident Energy in an Arc Flash. We can use the information form the Red, Green, Buff Books to reducce the number of incidences.
An Arc Flash can occur on a High Resistance Grounded System. When it does, we can calculate the Incident Energy that we need to protect ourselves from, and wear the appropriate PPE. High Resistance Grounding reduces the probability of a single phase fault escalating to a three phase fault.

Q. Acknowledged that phase to ground faults have much lower fault current with HRG. However, with no reduction in severity of phase-phase faults, does the Arc Flash PPE category decrease?

A. The equation for calculating Incident Energy from IEEE 1584 is as follows;
$\lg E_n = K1 + K2 + 1.0811 \lg I_a + 0.0011G$
Where,

- E_n is the incident energy (J/cm) normalized for time and distance
- K1 is -0.792 for open configuration (no enclosure) and;
  is -0.555 for box configuration (enclosed equipment)
- K2 is 0 for ungrounded and high-resistance grounded systems and;
  is -0.113 for grounded systems
- G is the gap between conductors (mm)

As you can see the only term that differentiates the grounding is K2.

K2 can be either 0, for ungrounded and high-reistance grounded systems, or -0.113 for solidly grounded systems.
If everything else is identical then the term $\lg E_n$ for high-resistance grounded system is 0.113 more than a solidly grounded system.
And since $E_n = 10^{\lg E_n}$ then the incident energy for a high-resitance grounded system or an ungrounded system is 29.7% greater than for a solidly grounded system. According to IEEE 1584, you need to wear PPE with a higher degree of protection due to the high-resistance or ungrounded system.

Q. Since HRG does not reduce L-L fault current, does it meet the legal and safe intent of all arc flash reduction requirements?

A. Making a statement that HRG will eliminate arc flash would be criminal. No one at this stage can state that they can eliminate arc flash hazards. But HRG can be used with other protection systems to reduce the probability of an arc flash.

Q. If a solidly grounded system is coordinated based on safety and arc flash currents in mind and not the continuous operation of equipment isn't the solidly grounded system a better method because the fault is isolated immediately? In this case, it does not matter if whether the fault is a ground fault or a phase-to-phase fault.

A. The fault can only be isolated immediately if it is detected. In a properly coordinated electrical system intentional time delays are placed where the fault current is the greatest. In order for the protective relays to detect an arcing fault, there must be a current greater than the set point of the protective and it must persist for a time greater than the time delay of the protective relay. Arcing currents are lower than bolted fault currents. It is possible for a low level arcing ground fault to be present on the system and go undetected. This arcing current can propagate into a phase-to-phase or a three-phase fault quickly. In a high resistance grounding, the arcing ground fault will not propagate into a phase-to-phase or three-phase fault.

Q. On its most basic level, is this the same principle as a GFCI outlet in a residential application?

A. No, I would equate a GFCI with a fuse. If the leakage current is greater than 5 mA then the fuse, GFCI would open clearing the fault from the system. High Resistance Grounding actually limits the fault current to a desired value. The GFCI does not limit, it only detects and isolates.

Q. For HRG installations, is it essential to run equipment grounding conductors inside the conduit (versus using the conduit for just a ground conductor)?

A. The installation does not have to be different than any other installation. If the code allows you to use the conduit as a bonding conductor then it would be allowed in a HRG installation.

Q. Why does the NEC not require detection on ungrounded systems?

A. NEC 250.21(B) ground detectors. Ungrounded alternating current systems as permitted in 250.21(A)(1) through (A)(4) operating at not less than 120V and not exceeding 1000V shall have ground detectors installed on the system. So, ground detectors are required on ungrounded systems. The problem is that there are no efficient ways to find the ground fault when it occurs. Ground defects are voltage based. You measure the voltage with respect to ground. The voltage on the faulted phase will decrease to 0V. The voltage on the un-faulted phases will increase to near the full line-to-line potential. So you now know that you have a fault on “C” phase. You have no way of finding and importantly clearing that fault other than cycling every breaker or switch in the plant until it is found. Normally, facilities choose the ungrounded system to avoid outages. The only way to find the fault is with an outage, temporary as it might be., maintenance personnel are the only ones that lose in the situation. You can’t find the fault unless you cycle the breakers and you can cycle the circuit breakers because you need continuity of power. I have stated that most ungrounded facilities I have visited have a ground fault. The maintenance electricians always have more important issues to work on, so they wait for the second fault to clear the system. This is unacceptable but allowed.

Q. HRG- isn’t second fault at 480V not 277V and greater energy than at 277V?

A. The second ground fault, if it is on a different phase will be a phase-to-ground-to-phase fault. I would not say that there is more energy in the second fault as far as the IEEE 1584 is concerned as it uses a voltage of 0.48kV to calculate the fault energy. The attractive part of your question is the second fault. You will know when you are at risk of the second fault, because you would have had a first fault and you are looking for it. I have had systems that are very complex and I can find the fault within an hour. In solidly grounded systems there is no warning. You do not know when you are at risk. We also have products that isolate the second fault should it occur. This is done on a priority level. The two faulted feeders communicate with each other and determine which one should trip based on the priority that the user programs into them.

Q. What about healthcare applications? Recommended?

A. We have installed many HRG systems in hospitals. In fact, hospitals were the preferred customer base for our DSP product. This particular product afforded the user the luxury of tripping on the second fault should one occur.

Q. What should be considered when retrofitting 5kV systems from LRG to HRG systems?

A. When converting any system from LRG (low-resistance grounded) to HRG the main thing to consider is the sensitivity of the protection system. If your protection is set up to detect a 200A, 400A ground fault, it may not have the sensitivity to pick up a 5A, or 10A ground fault. This can be easily overcome. Similarly, for converting an ungrounded system to a HRG system you must ensure that you can detect a fault when one occurs.

Q. What about existing installations? Is just installing HRG that we solve possible risks? What else should we consider in an industrial installation?

A. HRG will limit ground fault currents to a low value. You should have an arc flash hazard assessment performed so you know what the hazards are. You should acquire the appropriate PPE and insure you have good training programs and safety policies. This is just a start.

Q&A

Gemini

- Dual path current limiting resistor
- Redundant fail-safe resistor circuit
- Integral ground fault relay
- Integral ground monitoring relay
- Fault location through pulsing
- Harmonic filter and time / current adjustments to reduce false trips

STANDARD

DSP-OHMNi

- Monitors and protects up to 50 feeders on one relay
- 1^{st} Fault Alarm, 1^{st} Fault Trip or 1^{st} Fault Time Delay Trip
- Resistor Monitoring Module
- Selective Instantaneous Feeder Trip on 2^{nd} ground fault

STANDARD

Sentinel

- Current limiting resistor
- Voltage and current sensing
- Integral ground fault relay
- Integral ground monitoring relay
- Fault location through pulsing
- Harmonic filter and time / current adjustments to reduce false trips
- Inrush detection restraint
- Multi-feeder protection
- Second fault protection
- MODBUS for remote monitoring

PREMIUM

Gardian

HRG reduces the frequency of arc flash incidents and optical detection reducing impact, all in one.

ULTRA PREMIUM

GARD

Unparalleled Protection

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