White Paper
August 2017

Improve Plant Safety through Ground System Testing, Analysis, and Maintenance

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Wide availability and strong historical performance means electrical distribution and safety issues sometimes go unnoticed. Upper-level managers, however, must understand the risks posed by aging infrastructure and changes to facilities. Lives and property are endangered by incomplete or outdated knowledge and lack of correction.

As background, voltage determines the amount of current generated in a circuit. Higher voltage means greater current. Current is the source of damage to people and equipment. Three factors determine the level of damage: amount of current, path of current, and duration of current. Although no actions can eliminate the risks completely, properly installed and maintained grounding can mitigate the risks and reduce the potential for injury, damage, and expense.

I recently visited a plant where welding in a certain area required significant workarounds. Investigation showed that, in some areas, the building steel carried a low-level current that magnetized the I-beams. Equipment was tested yearly and maintained to meet code, but study revealed variations in the earth potential across areas within the plant. This variation in ground potentials could result in catastrophic damage to personnel or equipment.

Any difference in the resistance between adjacent grounding points could lead to a fault-induced voltage difference between adjacent equipment/structural components on the surface. The condition can produce circulating current between equipment and could kill a worker that accidentally bridges adjacent areas. The problem in this case was with the in-ground components to which the equipment grounds were tied. Although the problem was significant, after much discussion, upper management decided to delay the fixes.

What is Grounding: Risks Related to Grounding System Failure

Grounding is the creation of a low-resistance path from equipment or electrical supply lines to ground and carries current from the point of a ground fault on a wiring system back to the electrical supply source. Resistance must be low enough that the ground current produced by the fault rises rapidly to trip the protective device quickly, clear the fault, and protect the person or equipment.

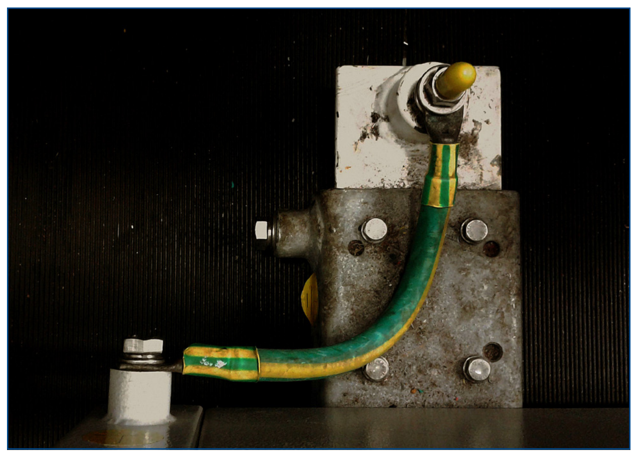

Fig. 1 Typical equipment ground connection

Bonding is a term associated with grounding and is accomplished by linking two structural conductors, such as a tank and a pipe. By connecting all metal elements that (during normal operations) should not carry current, bonding brings the conductors to the same electrical potential and safer conditions.

A current path is any route that current can take. This could be metal raceways, cable sheaths, electrical equipment, or other electrically conductive materials, such as metallic water or gas piping, steel-framing members, metal ducting, reinforcing steel, or the shields of communications cables. Electric force, by its nature will take the path of lowest resistance to ground, even if that path is through people, building steel, or equipment.

A failed grounding system can cause:

- Injury or death
- Extreme equipment damage
- Legal and financial risks

OSHA's general regulation states employers must provide a safe workplace and comply to NEC Article 250, which addresses bonding and grounding of electrical systems. Although few regulations cover maintenance and testing, any hazard resulting from an inadequate design, ineffective testing, or lack of maintenance can result in severe sanctions and penalties. Because grounding is primarily for safety, the "grandfather clause" does not apply.

Unseen Risks Might Cause Public Safety Issues

Cities/towns and manufacturing facilities in the US are supplied primarily by incoming power from a utility, at voltage levels including 2.5KV, 13.2KV, 72KV, or 138KV. Usually, the power goes to a step-down transformer or a series of transformers that provide the actual working voltages. Large transformers often are found outside in switchyards and can be surrounded by various switching devices. Safety regulations require the yards be isolated and access restricted to limit public or unauthorized exposure to the hazards.

Yard and structure inspections must be considered when discussing grounding. With the higher voltages and currents present in the overhead cables and busses, there is the possibility of induced current in the fence, gates, and other structural steel. If, for instance, the fence around a switchyard was not grounded, a very large voltage could develop in the fence itself by induced current. A person could come into contact with it simply by touching the fence. This is called touch potential, and it can be deadly.

If a line falls to the land and the protection circuit does not trip, the land itself can present a voltage differential (the force causing current). Linemen working on downed power lines have an awkward, hopping way of walking where only one foot is on the ground at any point other than right beside each other and touching. Alternately, they shuffle without ever allowing their feet to lose contact with each other. The odd dance is lifesaving and is due to the possibility of step potential, the voltage drop across the land itself between contact points (their feet). The current resulting from this can, and has, killed.

All yard and fence structures must be grounded, and a flexible bonding strap must assure gate grounding. Transformer cases and other yard assets must be grounded. All future inspections must include the ground system.

Fig. 2 Fence and gate with flexible ground connections

Positive Results of an Effective Ground-Fault Current Path

An effective ground-fault current path, developed as a low-resistance route to clear a ground fault, must:

- Provide a path for fault current lower in resistance than people, to save lives.
- Reduce voltage stress on electrical insulation, giving longer insulation life for components such as motors and transformers.
- Help reduce fire potential.
- Stabilize voltage and help reduce damage from lightning and fault currents.
- Reduce threat to solid state/digital systems — extremely sensitive to voltage transients, variations, and electrical noise — improving their service life and reliability.

How Grounding Fails

The earth itself has variations in its ability to provide a safe dissipation path When evaluating a grounding system, consider that safe dissipation paths are determined, in part, by soil composition and conditions.

- **Composition:** Clay, sand, or rocks in the soil increase the resistance. Moist, loamy soil decreases it. For example, soil containing a high percentage of clay can be an insulator. Sandy soil is an insulator when dry, and loamy soil can be a slightly better insulator.
- **Condition:** Wet and dry cycles can cause air gaps to develop in the soil, compromising contact with buried electrodes. Also, ground water incursion from surrounding areas can alter the pH of the soil, which affects the corrosion rate of grids, rods, and steel building pilings. Seismic activity, water-table cycles, or equipment vibration can cause conductor breaks or sand migration through soil, collecting around buried objects and changing contact resistance.

Equipment grounds reduce induced voltages on metal parts from nearby power lines and distribution equipment, and help prevent damage from arcing within buildings/structures.

Substation Ground Grid Designed for Compliance

Before the 1960s the design criterion of substation grounding or earthing systems was “low-earth resistance.” (Earth Resistance< 0.5 ohms for High Voltage installations).

During 1960s, the new criteria for the design and evaluation of substation earthing system were evolved particularly for EHV AC and HVDC Substations. The new criteria are:

- Low Step Potential
- Low Touch Potential
- Low Earth Resistance

The conventional “low earth resistance criterion” and low current earth resistance measurement continues to be in practice for substations and power station up to and including 220 kV.

Equipment with the potential for static buildup requires grounding. Static buildup develops due to the friction of moving material and can happen on equipment such as tanks, vessels, and piping. Bonding and grounding help drain off static electricity charges before flashover potential is reached.

Electrical power systems, like the secondary winding of a transformer, are grounded to limit the voltage induced by lightning, line surges, or unintentional contact by higher-voltage lines. Secondary grounds also stabilize the return path for single phase loads. If the contact resistance of an electrode to the earth is high, very little fault current can return by that path, and the circuit protection device may not open to clear a ground fault. Then all metal parts associated with the electrical installation, metal piping, and structural building steel could become — and remain — energized. These risks can be mitigated with a separate, dedicated earth grounding connection that is installed correctly, tested effectively, and maintained.

Ground System Testing, Analysis, and Maintenance

Aging infrastructure places increased importance on addressing the design and maintenance of grounding systems. Companies and municipalities must:

- Perform baseline earthing tests, calculate the total earth resistance for each system, and analyze the results to determine your risk exposure.
- Deal with any risks identified, retest and establish a corrected baseline, and develop a program of procedural compliance and system testing to avoid future risks.

These two tasks can be broken into several activities:

Testing the grounding hub — Most industries test equipment grounds annually. Each grounding "hub" must be tested verifying an adequately low resistance ground and low differentials.

Fig. 3 Top of grounding rod at grade

The top of the ground post is the hub, which may also be a ground plate/strip in a building. These will be connected to a buried rod, plate, loop, or grid made of steel. At specific places, a connection point is brought to the surface for equipment ground attachment. If individual ground rods are used, they must be made of approved material and sufficiently long to meet regulations. They must be linked into a loop by connecting cables or tested more frequently to verify a sufficiently low resistance differential.

Any resistance differential between adjacent grounding points must be investigated and corrected because it sets up a fault induced difference between adjacent assets on the surface, which can be fatal. In-ground components, cables, and connections can suffer corrosion and physical damage negating any protection.

Measuring conditions — Years ago, ground resistivity was tested using a megger (Megaohm range ohmmeter) and a grounding rod at some distance from the test point. Although it was the best method available at the time, results were inconsistent and this is no longer sufficient. There are now testers than can be used specifically for this purpose.

Be aware that using earthing and ground test equipment requires knowledge and training, usually supplied by the manufacturer. There are also computer programs available for recording, tracking/trending, and analyzing your system conditions. If a facility or municipality doesn't decide to expend the resources to do the testing in-house, there are various electrical testing/certification companies which can be contracted to perform the tests, analyze the results, and advise in required risk mitigation.

Analyzing conditions — Analysis and review should be done by qualified engineers. Any grounding system should be tested at installation, not only for efficient grounding, but for differential between it and any adjacent systems. All results must fall within the parameters stated in the National Electric Code.

Keep in mind that the limits stated in the NEC are for TOTAL resistance to a "proven" ground. Because different segments of the grounding circuits are tested separately, the measurements must be combined and correctly calculated for each path — and still meet the stated minimum. These calculations can be complicated for distribution systems, involving length and diameter of ground conductors, parallel paths, and potential fault current levels. Electrical engineering personnel must be involved in and responsible for the accuracy of any analysis.

Differences exist in ground conductor types (e.g., copper bar, stranded copper, copper clad, and braids). Qualified engineers must determine the appropriate application.

Monitoring load changes — Any upgrading or additions to electrical loads could mean that the grounding system must be strengthened. The conductor size, connection type, length, and rod dimensions (if applicable) should be recorded for every system part. Good records can mitigate the necessity of digging up ground components to check for sizing each time changes are made to the system they protect.

Performing baseline and scheduled tests — Most companies have a program already in place to test equipment grounds, usually once a year. The other parts of the system do not require annual testing. After an initial baseline measurement is established, testing frequency can be set with consideration to soil pH, soil material makeup, wet/dry cycling, and average historical in-ground corrosion rates for the probe or grid installed.

A five- to ten-year comprehensive test schedule might be reasonable for ground grids or loops, depending on the conditions. If individual ground rods are used near equipment, and not connected to a loop, more frequent testing should be done to verify that dangerous differentials have not developed between adjacent or nearly adjacent equipment. Corrosion monitoring might be needed for grid systems and ground rods.

Make sure that tests are performed after any extreme ground fault occurrence, such as a lightning strike, fire, or explosion. Even if the protection did its job, it is wise to ensure that your protection is uncompromised.

Including a master equipment list (MEL) for proof of compliance — Keep in mind that an OSHA inspector might ask to see inspection records for only equipment grounds, but the client is responsible for guaranteeing that the ground systems they connect to are proven effective to the required minimum. Be careful though, because if an organization cannot verify that the grounding system is effective, they are not in compliance. Best practice is to include grounding systems and components in the MEL. Inclusion in your CMMS system can provide a comprehensive record of efforts to (as OSHA requires) provide a safe workplace.

Ground testing parameters and dealing with the results — Earth ground testing itself must be done with care. Concerns when performing grounding testing include the identification of all metallic items underground, any static or equipment grounds which may interfere with readings, and identification/mitigation of potential sources of stray voltages from operating systems (even building utilities).

Any Reliability Program Must Include a Grounding Program

When a problem is found during a grounding test, it must be corrected in a timely manner. To be aware of a problem — and not correct it — is a serious violation of OSHA regulations. Ignorance of a deficiency is not considered an acceptable reason either, if an injury occurs. Any plant, corporation, or municipality must do whatever is required to find and eliminate these hazards. It all falls under the OSHA General Clause: it is the owner's responsibility to know.

Plants and towns sometimes pave or build over the access points to grounding components (grid/loop connections and cables). These must be found, made accessible, labeled, and tested.

There is a commonly held belief that building steel pilings are sufficient for grounding purposes. Building steel, even as driven pilings, must still be tested for efficient and consistent grounding. Soil conditions, corrosion, and physical damage can happen to pilings as well as grids and rods.

Fig. 4 Building steel used as grounding hub

Complete the Review to Save Lives and Equipment

Any reliability program must address the awareness and mitigation of potential risks to both the public and employees. A grounding compliance program should be established and enforced to ensure a safe environment for employees and contractors. These grounding procedures should address standard work rules such as:

- Don't work on ungrounded equipment
- Always work between grounds
- Report known or suspected problems
- Remove and re-connect grounding elements, during other work in area
- Maintain proper records of portable ground use and testing

Whether you have in-house electrical maintenance or rely on vendor expertise, there are various consultant resources available to advise and assist you on evaluation, requirements, and implementation. But your responsibility is unavoidable.

Due to the age-related nature of these failures, the longer you have gone without an incident, the higher the probability is that you will experience one. Don't wait for an employee to be seriously injured by bridging between two insufficiently grounded areas in your plant. Don't wait for the death of a passer-by who touches a fence (Touch Potential), or walks over a utility manhole cover (Step Potential).

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