Grounding & Bonding

Ten years ago it would have been rare for anyone to talk about the importance of low resistance grounding and bonding except where mainframe computer systems, telecommunications equipment or military installations were being discussed. Today, we live in a world controlled by microprocessors so low resistance grounding is now critical and is a popular topic of conversation.

The electrical grounding system in most facilities is the electrical service entrance ground. In the past it was often "OK" to just meet the minimum requirements of the National Electrical Code (NEC). Today, the requirements of the NEC should only be the starting point for grounding systems and bonding.

The primary focus of the NEC is life safety and proper equipment operation. The NEC and most local codes call for the installation of one or two 8- 10' ground rods with the intention of the ground rods net total resistance being no more than 25 Ohms. The NEC does not address the grounding or bonding requirements of sensitive networked systems or the testing of grounding systems. The NEC does not call for what is known as "low resistance electrical grounding". These specifications are most often those of equipment manufacturers, power quality consultants or electrical engineers familiar with sensitive equipment's grounding requirements.

The evolution of microprocessors and networking is the root cause of today's keen interest in grounding. The continued growth of networked systems and equipment is the focus of the need for low resistance grounding as well as the associated power quality issues. The microprocessor has evolved from the transistor to integrated circuits with millions of transistors in packages considered impossible only a few years ago. These new packaged transistors commonly known as computer chips operate on 3 or 5 volts DC (direct current) and are very sensitive to the problems resulting from high resistance or bad grounds. The problems associated with grounds is better left to other areas of this report, but remember, for the proper operation of networked microprocessors a low resistance "clean" ground is required.

Ground, by most electrical or electronic definitions, is "0" reference. More formal definitions are: The position or portion of an electric circuit that is at zero potential with respect to earth, and, A large conduction body, such as the earth, used as a return for electric currents which has an arbitrary zero potential.

Ground to an electrical system should "0" potential and be designed to be a highly conductive path for electrical energy. The resistance of the path to this "0" reference must be low, of sufficient ampacity and capable of handling a broad frequency spectrum of energy.

Today, the most common specification where sensitive equipment is involved is for the ground field (rods, grids, plates, etc.) to be a maximum of 5 Ohms of resistance or lower. Many military and critical communications sites specify substantially below 1 Ohm. If sensitive equipment is to be installed it is very important for the grounding system to be compatible with the equipment requirements.

Most commercial buildings are specified with a NEC or other code ground and not to low resistance standards. The resistance of this code ground is intended to be 25 Ohms or less, but is rarely tested. To verify the resistance of ground, it is most often tested with instruments using the fall-of-potential method by a trained technician.

In lightning prone areas ground should be tested more frequently than most commercial installations that require only annual testing. Location of electrical panels, equipment to be grounded and other factors must enter into the calculation of the required wire size. The calculation of conductor size and installation method is best left to engineers or professionals in the field of grounding.

Grounding is the backbone of effective protection of all networked systems. AC power, security, life safety, computer, video, satellite, telecommunications, etc. systems all rely on ground for operation. In addition, the protective devices used to protect these systems such as UPS systems, power conditioners, voltage regulators, surge suppressors, etc., will be rendered ineffective if connected to improper wiring or defective grounding.

Electrical distribution systems are solidly grounded to limit voltage to ground during normal operation and to prevent excessive voltage due to lightning, line surges or unintentional contact with higher voltage lines during normal operation. In all cases, the grounding electrode system is required to be common and solidly bonded to each system per the NEC.

National Electrical Code (NEC) Grounding Requirements

Code requires the grounding of one current carrying conductor in a distribution system where voltages are between 50 and 1000 volts or where one of the service conductors in not insulated. The grounded conductor is identified either by a white or light gray color at termination points and is typically referred to as the neutral conductor. The equipment-grounding conductor is a non-current carrying conductor *whose primary function is safety*. The conductor must have adequate ampacity and low enough impedance to actuate over current protection devices (circuit breakers or fuses), on the supply side of a circuit should an ungrounded conductor come in contact with any exposed metal part of the distribution system or equipment. *Both the neutral and equipment-grounding conductor is bonded together at a single point* via a bonding jumper. (Most often this is the main disconnect or the neutral/ground service entrance bonding buss bar.) This point is also bonded to Earth via the grounding electrode conductor that bonds the system to the grounding electrode system. The panel that houses the bonding jumper (or bonding buss bar) is called the main panel (main distribution panel) or can be the service entrance main disconnect. All subsequent panels and disconnects fed from this point are referred to as sub-panels, distribution panels or disconnects.

Single point bonding at the service entrance is critical to life safety and is required by code (NEC). It can occur more than once between a service entrance and the first panel housing a disconnecting device such as a fuse or circuit breaker; however, this is still considered a single location. Neutral and ground can only be re-bonded on the outputs of separately derived systems such as transformers, generators, and some UPS systems. The most important aspect of a single point of bonding is that it keeps current off the equipment-grounding conductor.

Electrical panels are typically supplied with a bonding jumper in the form of a screw that bonds the neutral bus to the panel case. If the electrician installing the panel fails to remove the screw prior to completion of the installation, the equipment-grounding conductor on the supply side of the panel will carry objectionable neutral current. Accidental bonding within building distribution or branch circuitry will cause neutral current to flow in the grounding system. Building steel, water piping and most other metal conductive systems that are required by code to be bonded to the ground will also carry this current. (Reference: Intersystem Ground Noise)

Inter-system ground noise results from current flow on the ground conductor. This ground noise occurs because of the impedance differences in the different components of ground within the building. Accidental neutral to ground bonding also makes it impossible to predict and/or defend against the effects of lightning induced currents within a building. Any current on ground will divide into the lowest impedance path back to the service entrance ground placing different parts of the ground system at different voltage potentials. (Reference: Ground loops)

Grounding Requirement

The NEC requires the path back to ground from circuits, equipment and exposed metal enclosures:

1. **be permanent, reliable, and continuous.**
2. **have sufficient capacity to conduct safely any fault current likely to be imposed on it: and**
3. **have sufficient low impedance to limit voltage to ground and:**
4. **to facilitate the operation of the circuit protective devices in the circuit.**

All the components that form a ground conductor for a given circuit; i.e.: panels, raceway, conduit, wires, clamps, fittings, brackets, etc., must be able to carry fault currents capable of tripping the circuit protective devices (breakers or fuses) feeding the ungrounded conductors in that circuit without causing significant heating in any of those components.

It is very common for problems to arise over time with all of the above requirements. These potential problems can be divided into five areas.

1. **<u>Materials</u>: Ground continuity must be maintained through what can be hundreds or thousands in large buildings, of components that may be of many types of material. i.e.: Steel raceway, electrical panels, disconnects, transformers, conduit, flexible conduit, fittings, connectors, bushings, etc. In addition many of these have coatings which can be made of dozens of different materials.**

2. **<u>Initial Workmanship</u>: Depending on the quality, initial design, material selection and workmanship the trouble free life of the buildings electrical distribution system can vary dramatically.**

3. **<u>Subsequent Work or Equipment Additions</u>: Modifications and additions to the electrical distribution system are common several years after a building has been completed. Modifications that do not follow the guidelines of the NEC and good grounding principles can impose problems to the properly installed portion.**

4. **Age: Without preventive maintenance and testing an electrical distribution system will deteriorate dramatically. Over time, components will wear out, fail, overheat, etc. If appropriate corrective action is not taken the result is system deterioration, rust, corrosion, painting, and inappropriate circuit usage which will all take their toll. Renovations and improper maintenance of internal systems such as heating ventilation and air conditioning equipment can cause significant electrical distribution system problems. i.e.: If the building does not have adequate and positive ventilation of conditioned air, then condensation can form on the metallic portions of the electrical distribution system and cause significant corrosion. This will result in continuity loss and lowered ampacity of the electrical distribution system.**

5. **Not directly related to the NEC, but significant none the less, is building usage. It is common for a building to have several owner or tenants over its normal life. The usage of these tenants is likely to have changed from the initial construction. i.e.: Microprocessor usage today vs. the use of typewriters and adding machines in 1970. The needs and requirements of the electrical distribution system have changed dramatically, but has the system been updated to meet the needs of these devices? Has the grounding ever been tested or updated?**

Sufficient capacity (ampacity) can only be ensured via testing, however, there is no requirement in the code with respect to testing the adequacy of a ground circuit after the initial installation. It may only take a single faulty joint in a long circuit to eliminate the ability for a breaker or fuse to trip during a fault. It may only take one lightning strike to "glaze" the ground rod(s) and render them ineffective or increase their resistance significantly. The safety issue is that faulty joints can burn open and leave the exposed parts of the equipment at this short at a high voltage with respect to Earth. This leaves a shock hazard for operators of equipment and renders equipment protective devices useless. Remember, impedance will also be affected by the composition, length of the different components, the quality of the hardware and the workmanship to join them, maintenance issues aside.

Surge suppression technology installed on a defective circuit may not only fail to perform as expected, but can also redirect harmful energy into the protected load. At a minimum, high impedance ground will negatively affect surge suppression technology to some degree.

Grounding Electrodes and Grounding Electrode Conductors

A low impedance connection to Earth is necessary to prevent excessive voltages due to lightning. This connection to Earth is provided by a grounding electrode system.

Where available, all of the following must be bonded together to form a grounding electrode system:

1. **Metal underground water pipe that is in direct contact with earth for ten feet or more.**
2. **The metal frame or structural members of the building.**
3. **Concrete encased electrodes. Reinforcing bars or rods not less than 20 feet long and not less than ½ inch in diameter.**

4. **Ground Ring. A copper conductor, not smaller than No. 2 copper and at least 20 feet long that is buried not less than 30 inches deep, which encircles the building.**

When none of the above electrodes are available, or when only a water pipe is available, made electrodes such as copper clad ground rods must be driven to supplement the grounding electrode system. ***Multiple electrodes must be bonded together regardless of their distance apart.***

Once the individual components of the grounding electrode system have been bonded together, a single grounding electrode conductor serves to bond the electrical system to the ground conductor (neutral) and the equipment grounding conductor of one or more services feeding a building. (It is important to note that neutral is utility ground.) ***Individual services for a single building cannot reference different grounds.*** **Size and requirements for all grounding components are specified in sections 250 and 800-820 in the NEC.**

A common mistake in both the computer and telecommunications industries is to drive separate ground rods as an attachment point to earth for an "isolated ground" with no connection back to the building service entrance neutral to ground bond point. This lack of bonding is a clear violation of the NEC and actually significantly increases the risk of damage due to lightning.

Telephone communication lines and CATV coax cable (cable TV) lines are required by code to make connections to the building grounding electrode system. Phone systems require primary lightning protection equipment at the service entrance. (FCC required) If a separate ground rod is driven for convenience during the installation of the discharge equipment, this rod must be bonded to the building electrode system with an adequate conductor. Cable and satellite coax cable shields, as well as metal support structures, must also be bonded to the building electrode system at their point of entry into the building. Again, any separate ground rods driven for the purpose of grounding this equipment must be bonded to the building electrode system with a minimum of a No.6 copper wire. When determining Bonding and grounding, always refer to sections 250 and 800-820 in the NEC.

Supplemental Ground Rods

Equipment installers are allowed by code to supplement the existing ground system by driving additional ground rods and bonding these rods via a supplemental grounding electrode conductor to the chassis of the equipment. This is very common for phone switching equipment. Several references state that this can be done to help reduce noise, however, Code demands that this can only be done when the existing circuit, which feeds that device, is properly grounded.

The reason for this allowance in the code is to provide for the installation of supplemental ground rods for outside structures that are electrically connected to the AC power supply of a building. A good example of where supplemental ground rods can help a facility would be parking lot lights. The supplemental ground rods dissipate to Earth a direct lightning strike rather than have it migrate to the building ground. If a supplemental rod is driven for a piece of equipment that is housed within the building, the existing circuit ground serves as the bond between the supplemental rod and the building grounding electrode system. This would seem to be in conflict with the section of the NEC that states that any additional rods be bonded with a minimum of a No. 6 copper conductor. In the

case of the supplemental rod, the existing equipment grounding conductor for the circuit serves as the bond between the two ground systems and need not be a No. 6 copper conductor. The risk here is that the supplemental rod can be a source of lightning energy rather than an aid. Ground loops can develop between different ground potentials. While meeting the letter of the code, it is still a formula for disaster for the connected networked equipment. (Reference: Ground Loops) All ground rods should be bonded properly to form a single reference, as you don't want to develop a voltage potential across the building as a result of a lightning hit.

The reason for and the necessity to bond individual grounds or ground electrodes is simple. Soil is an extremely poor conductor and lightning energy that is conducted into it generates rings of voltage potentially around the point where the lightning strikes the Earth. Ground rods in different locations can be thousands of volts apart from each other. If these rods are not solidly bonded, this voltage potential may attempt to equalize in the piece of equipment where there are two grounds, or over the conductors between them. In the most basic installation, the most common examples of this are phone and modem damage or cable TV tuner damage. In the world of microprocessors, this is damage to networked equipment coming in on the data ports. This action is referred to as a *difference in potential* or a *ground loop*.

Network and Communications Cables

The installation configuration of network and communications cables and the quality of workmanship used to install them relate directly to the connected equipment's ability to survive severe transients. The relationship between these cables and ground is also critical to the survival of the connected equipment as well. Different cabling platforms have different characteristics and different levels of immunity to disturbances on ground.

1. **Unshielded twisted pair Ethernet cable and network cards has no ground connections and a 1500-volt isolation specification between any cable pin and any part of the card.**
2. **Coax Ethernet has no physical connection between the cable and the card unless a grounded terminator makes an intentional connection. Coax also has a 500-volt isolation specification between both the center pin and any part of the card that comes into contact with the motherboard of the computer.**
3. **Token ring cabling has no isolation specification and may or may not make any direct connection with the computer chassis depending on whether a shielded cable is used.**
4. **RS-232, 422, 432, AUI, serial and parallel cables all carry one or more ground pins and consequently have no isolation between the cabling and computers or peripherals that interconnect.**

There is always a risk of bridging two branch circuits with the ground on one of these cables. Any significant difference in the impedance of the two AC grounds can induce current flow in network cable ground that, at the least, can potentially destroy the cards at either end. For this reason fiber optic cables are preferred when the possibility of difference in ground impedance (ground loop) may be present. Optical isolation often will not carry the data line transmission speed, but in installations were it will, optical isolators are an inexpensive solution to difference in ground impedance.

Grounding & Soil Conditions

Ground grids are installed in soil and the composition of the soil (soil type, salt content and moisture content) will effect the resistance of the ground grid. In addition the life of the ground grid will be determined by the pH factor of the soil. Soil pH is a measure of the acidity or alkalinity of the soil.

Most ground grid materials are composed of copper, copper plated steel, and zinc plated steel, steel, stainless steel or aluminum. Acidic soils will easily eat away both copper and zinc, yet they will be are stable in alkaloid soils. Aluminum is unaffected by acidic soils; but it is etched by alkaloids. A very basic soil test can be performed using some soil with distilled water (equal parts) in a pool/spa water strip pH tester. It is simple yet effective test and the equipment cost is minimal.

Aside from the pH of the soil, its water and salt content determine the conductivity. The more salts, the less water required to reach a specific conductivity. Like all partial conductors, the resistance value is measured in ohmmeters or ohm-cm.

Soil resistively can be measured using four-point fall of potential equipment. This testing is best left to a trained, experienced technician with calibrated equipment.

Grounding Verification and Testing of Proper Grounding

There is no verification process required by NEC for checking the quality of a grounding system during or after installation. At best the code specifies adequate materials and encourages good workmanship with phrases like "connections must be wrench-tight". The inspection process involved in obtaining a sign-off to achieve an occupancy permit for a building is typically a visual inspection only. Inspection after walls have been closed in can be almost impossible; depending on the material employed to build a ground system.

The proper testing of a grounding electrode system for resistance involves two steps. The ground grid (ground rods, bonding, etc.) is tested for resistance to Earth. The branch circuits are tested for resistance at the outlets.

The ground grid (rods) should be tested using the fall-of-potential method by a trained, experienced, skilled technician. The equipment used must be in current calibration and the equipment manufacturer instructions must be followed. A professional should be contracted to perform this testing.

Standards for the "net" resistance of the ground grid will vary. The preferred specification for sensitive equipment is less than 5 Ohms and a lower resistance is better. The NEC call for a 25-Ohm resistance but does not require testing or take into consideration the needs of sensitive equipment.

Branch circuit resistance testing can be completed using a SureTest® branch circuit analyzer model ST-1D or ST-THD. These testers will also perform a number of other tests to analyze the circuit's ability to carry a load properly. One such test is that for an isolated ground circuit, very often critical for sensitive equipment. The advantage of these testers is their ability to test a live circuit. Most other testing of circuits require they be disabled and the equipment disconnected.

In older (pre microprocessor) buildings conduit was often used as the ground conductor. This method of ground is completely unacceptable for sensitive equipment. The joint work, age, corrosion and dozens of other factors render these ground systems ineffective. Current NEC does not allow conduit ground as an acceptable practice. Using a copper wire as a conductor for ground is infinitely more desirable due the fact that terminations of the copper wire occur inside the metal or plastic work boxes that house receptacles and switches, making the joints assessable.

Standards for branch circuits are clear and have been defined by IEEE (Institute of Electrical & Electronic Engineers) and the NEC.

Measuring a Ground Connection

Ground connections have to be good connections and measuring them can be accomplished with standard low range meters. One such instrument is a Fluke Model 8012A with option 01 can measure down to .001 ohm, (one milliohm). This meter provides the capability to zero out the lead resistance with a front panel control.

Note: Sites with phone system batteries use +48 volts to ground and you may experience a slight problem in making resistance measurements. It is not uncommon for the meter to read negative ohms. This is due to the return currents causing a voltage drop across the ground connection being measured. Reversing the meter leads will make the reading positive. The true reading is the algebraic sum of the two readings.

Grounds and Frequency

The true resistance of a ground connection in an AC power system is the most important measurement, but the inductive value of the ground path can play a critical role. Radio frequency energy and the fast rise time of a lightning strike event require low inductance ground paths. Cellular Phone and radio towers are struck more often than most structures, as they are tall and made of conductive metal. The energy in a lightning strike is broad-spectrum energy. When high frequency energy travels on a conductor it travels on or near the surface of the conductor. This is called the "skin effect" and is the tendency of high frequency energy to only be conducted on or near the surface of the conductor. Below this surface, the majority of the conductor material is not used. This means that connections or conductors that do not have a large surface area will be more inductive and have higher impedance (resistance) to the flow of high frequency currents.

Ground Conductor Size and Type

The NEC outlines ground conductor requirements to meet code. The size of the conductor is outlined in detail and the ampacity of the conductor is a function of size. The type of conductor is not outlined in the NEC. Where ever possible when high frequency energy is to be handled it is preferable to use stranded conductor vs. solid conductor. The surface area of a stranded conductor is greater than that of a solid conductor and therefore it is better able to handle high frequency energy. A ground conductor can not be too large and in the case of ground conductors, bigger is better.

Grounding and Dissimilar Metals

The use of dissimilar metals should be avoided if possible. Where it is not possible to avoid their connection it is important to take steps to prevent corrosion or electrolysis between the dissimilar metals.

When making low impedance connections which could be of dissimilar metals it is important to use a joint compound such as T&B's Kopr-shield CP-8 (for copper joints) or Alumashileld (for aluminum joints). This will prevent corrosion and should also be practiced when connections will be exposed to moisture.

Shared Neutral & Ground Conductors

Neutral is the drain to the phase conductor just as the phase is like the water faucet is the supply pipe in a water system and the drain is the disposal pipe. That means that neutral is the power (utility) company ground.

Shared neutrals in branch circuits meets the NEC, but not recommended when sensitive equipment is used. It is also not recommended when the circuit is powering non-linear loads. Non linear loads are "switch mode power supplies" as found in computers and other microprocessor products.

The theory behind using shared neutrals is valid only with linear loads. Linear loads have a unity power factor while switch mode loads do not. In theory a three-phase system is balanced as each phase voltage is 120 degrees behind (lagging) the phase before it. Phase currents are separated by 120 degrees as well. If each phase is carrying equal current (10 amps as an example), the equivalent currents will cancel each other as they combine at the neutral for return to the source. The result can be mathematically and algebraically shown to result in no (0 amps) of neutral current.

In reality the previous example assumes the electrical system is powering linear loads that the system is resistive in nature, that it is operation at unity power factor, and further, that the system operates in a state of equilibrium. In the real world, three phase systems are never in this state even though electricians do their best to balance loads. Elevators, compressors, and air handlers cycle in their operation. Computers, lights, copy machines, etc. are constantly being turned on or off. These changing conditions create natural imbalances in the three-phase distribution system. As soon as currents become unbalanced cancellation of neutral currents cease. As neutral current begins to flow, physical laws take over and the flow through the impedance of the neutral conductor creates a voltage drop that can be measured with reference to ground. The amplitude of the voltage will be directly proportional to the amount of neutral current flow and the impedance of the neutral conductor. Result, Neutral to ground voltage often called common mode voltage.

Branch circuit length, induced and conducted voltages all impact neutral to ground voltages, but the most common cause is outlined above. Sharing neutrals where switch mode power supplies are involved is not recommended because they are such a contributor to the imbalance. Neutral to ground (common mode) events can cause significant disruption to the operation of microprocessor based equipment. These devices constantly measure logic voltage against the "zero voltage reference"

of life safety ground. The microprocessor expects to see less than .5 volts between neutral and ground.

It is common practice and meets the NEC to have shared ground and neutral conductors in 120-volt branch circuits (most cases). It is not good practice to have shared conductors for several reasons. Those that relate to the neutral and ground conductor will be explained briefly.

The ground conductor (not neutral) is the life safety and equipment chassis ground reference for the standard (120-volt) branch circuit. Other equipment uses ground as the "neutral" or drain wire is for the 120-volt branch circuit. Single-phase (208 & 240 volt) equipment is often wired; phase (hot), phase (hot) & ground. The efficiency of the equipment will determine how much of the energy is not used by that equipment. The unused energy uses the ground wire as the drain. This resulting energy dumped on the ground wire can have a very negative effect on sensitive equipment relying on the same ground. Noise, stray voltages and other anomalies are not good for sensitive networked equipment.

Isolated Ground Circuits

The below standards should be a guide to the proper installation of branch circuits. The wire size, outlet type, etc., should be selected to meet the NEC and the equipment requirements. The below standards are for 120VAC 15 ampere and 20-ampere branch circuits. All low voltage circuits should meet the grounding requirements below.

Branch Circuit Standards

Description	***Normal Range***	***Comments***
Line Voltage	**108 – 132**	**Low or high voltage will harm equipment.**
% Voltage Drop @ 15 Amp. Load	**<5.0%**	**NEC Part. 210-19, FPN 4. Excessive voltage drop can cause fires. (test for 15 amp. Circuit)**
% Voltage Drop @ 20 Amp. Load	**<5.0%**	**NEC Part. 210-19, FPN 4. Excessive voltage drop can cause fires. (test for 20 amp. Circuit)**
Voltage between Neutral & Ground	**< .5 Volts**	**Higher voltages upset microprocessor operation. Can often be noise.**
Phase Conductor Impedance	**<.25 Ohms**	**IEEE recommends less than .25 Ohms from any outlet to the building entry.**
Neutral Conductor	**<.25 Ohms**	**IEEE recommends less than .25 Ohms from any outlet to the building entry.**
Ground Conductor Impedance	**<.25 Ohms**	**IEEE recommends less than .25 Ohms. Critical for proper operation of surge protection devices.**