5 Grounding and Bonding

5.1 INTRODUCTION

What do the terms *grounding* and *bonding* mean? Quite often the terms are mistakenly used interchangeably. To reinforce understanding of the two concepts, the definitions given in Chapter 1 are repeated here: *Grounding* is a conducting connection by which an electrical circuit or equipment is connected to earth or to some conducting body of relatively large extent that serves in place of earth. *Bonding* is intentional electrical interconnecting of conductive paths in order to ensure common electrical potential between the bonded parts.

The primary purpose of grounding and bonding is electrical safety, but does *safety* cover personal protection or equipment protection, or both? Most people would equate electrical safety with personal protection (and rightfully so), but equipment protection may be viewed as an extension of personal protection. An electrical device grounded so that it totally eliminates shock hazards but could still conceivably start a fire is not a total personal protective system. This is why even though personal safety is the prime concern, equipment protection is also worthy of consideration when configuring a grounding system methodology.

With the advent of the electronic age, grounding and bonding have taken on the additional roles of serving as reference planes for low-level analog or digital signals. Two microelectronic devices that communicate with each other and interpret data require a common reference point from which to operate. The ground plane for such devices should provide a low-impedance reference plane for the devices, and any electrical noise induced or propagated to the ground plane should have very minimal impact on the devices. So far we have identified three reasons for grounding and bonding. One point that cannot be stressed enough is that nothing that we do to grounding and bonding should compromise personal safety. It is not uncommon to see modifications to the grounding of an electrical system for the sole purpose of making equipment function properly at the expense of safety. Such actions contradict the real reason for grounding a system in the first place.

5.2 SHOCK AND FIRE HAZARDS

Grounding and bonding of electrical devices and systems are vital to ensuring that people living or working in the environment will be adequately protected. We will start by looking into why personal safety is dependent on grounding and bonding. Table 5.1 is a list of physiological hazards associated with passage of electrical current through an average human body. It is obvious that it does not take much current to cause injury and even death. The resistance of an average human under conditions when the skin is dry is about 100 kΩ or higher. When the skin is wet,

TABLE 5.1
Effect of Current Flow Through Human Body

Current Level	Shock Hazard
100 μA	Threshold of perception
1–5 mA	Sensation of pain
5–10 mA	Increased pain
10–20 mA	Intense pain; unable to release grip
30 mA	Breathing affected
40–60 mA	Feeling of asphyxiation
75 mA	Ventricular fibrilation, irregular heartbeat

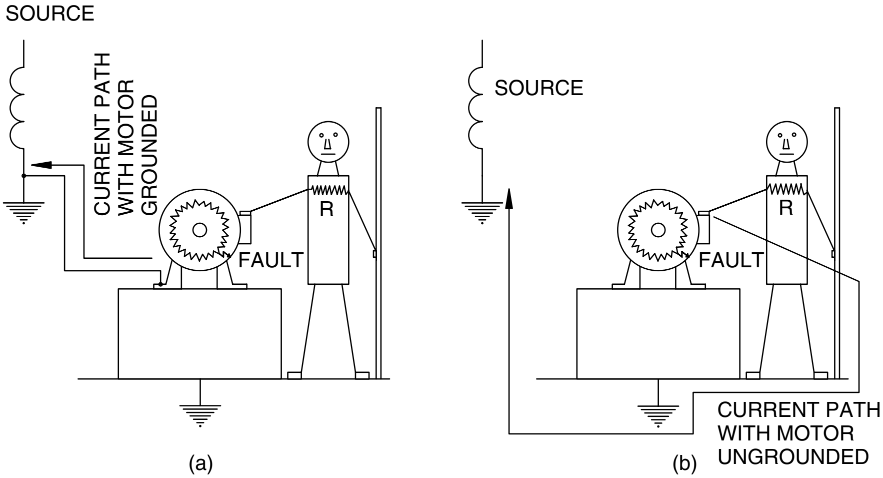

FIGURE 5.1 (a) Current flow when motor frame is grounded. (b) Current flow when motor frame is ungrounded.

the resistance drops to 10 kΩ or lower. It is not difficult to see how susceptible humans are to shock hazard.

Figures 5.1a and 5.1b illustrate what would happen if a person came in contact with the frame of an electric motor where, due to insulation deterioration, a 480-V phase is in contact with the frame. Figure 5.1a is the condition of the frame being bonded to the service ground terminal, which in turn is connected to the building ground electrode. If the power source feeding the motor is a grounded source, this condition in all likelihood would cause the overcurrent protection (such as the fuse or circuit breaker) to operate and open the circuit to the motor. If the power source feeding the motor is an ungrounded source (such as a Δ-connected transformer), no overcurrent protection is likely to operate; however, the phase that is contacting the frame will be brought to the ground potential and the person touching the frame is not in danger of receiving an electric shock.

On the other hand, consider Figure 5.1b, where the motor frame is not bonded to a ground. If the source feeding the motor were a grounded source, considerable leakage current would flow through the body of the person. The current levels can reach values high enough to cause death. If the source is ungrounded, the current flow through the body will be completed by the stray capacitance of cable used to connect the motor to the source. For a 1/0 cable the stray capacitance is of the order of 0.17 μF for a 100-ft cable. The cable reactance is approximately 15,600 Ω. Currents significant enough to cause a shock would flow through the person in contact with the motor body.

5.3 NATIONAL ELECTRICAL CODE GROUNDING REQUIREMENTS

Grounding of electrical systems is mandated by the electrical codes that govern the operation of electrical power systems. The National Electrical Code (NEC) in the U.S. is the body that lays out requirements for electrical systems for premises. However, the NEC does not cover installations in ships, railways, or aircraft or underground in mines or electrical installations under the exclusive control of utilities.

Article 250 of the NEC requires that the following electrical systems of 50 to 1000 V should be grounded:

- Systems that can be grounded so that the maximum voltage to ground does not exceed 150 V
- Three-phase, four-wire, Wye-connected systems in which the neutral is used as a circuit conductor
- Three-phase, four-wire, Δ-connected systems in which the midpoint of one phase winding is used as a circuit conductor

Alternating current systems of 50 to 1000 V that should be permitted to be grounded but are not required to be grounded by the NEC include:

- Electrical systems used exclusively to supply industrial electric furnaces for melting, refining, tempering, and the like
- Separately derived systems used exclusively for rectifiers that supply adjustable speed industrial drives
- Separately derived systems supplied by transformers that have a primary voltage rating less than 1000 V, provided all of the following conditions are met:
  - The system is used exclusively for industrial controls.
  - The conditions of maintenance and supervision ensure that only qualified personnel will service the installation.
  - Continuity of control power is required.
  - Ground detectors are installed in the control system.

Article 250 of the NEC also states requirements for grounding for systems less than 50 V and those rated 1000 V and higher; interested readers are urged to refer to the Article.

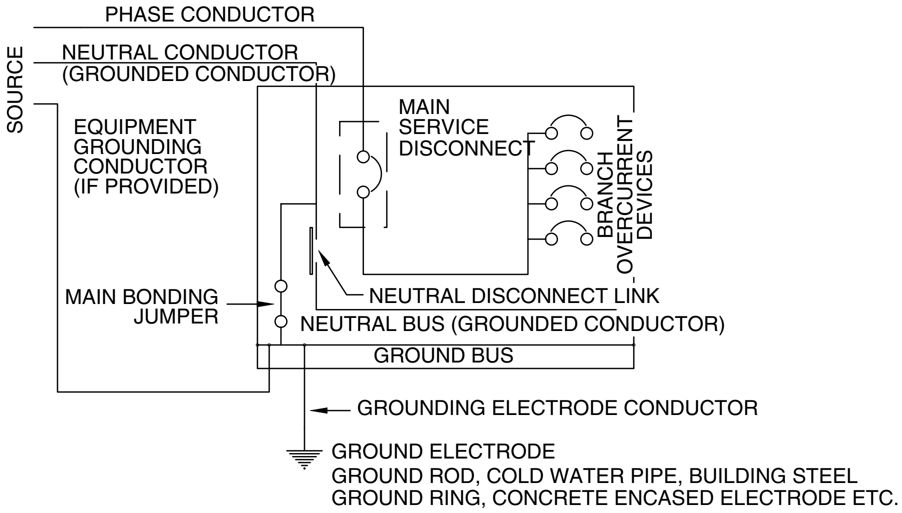

FIGURE 5.2 Main service switchboard indicating elements of a ground system.

5.4 ESSENTIALS OF A GROUNDED SYSTEM

Figure 5.2 shows the essential elements of a grounded electrical power system. It is best to have a clear understanding of the components of a ground system to fully grasp the importance of grounding for safety and power quality. The elements of Figure 5.2 are defined as follows:

Grounded conductor: A circuit conductor that is intentionally grounded (for example, the neutral of a three-phase Wye connected system or the midpoint of a single-phase 240/120 V system)

Grounding conductor: A conductor used to connect the grounded circuit of a system to a grounding electrode or electrodes

Equipment grounding conductor: Conductor used to connect the non-current-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both at the service equipment or at the source of a separately derived system

Grounding electrode conductor: Conductor used to connect the grounding electrode to the equipment grounding conductor, the grounded conductor, or both

Main bonding jumper: An unspliced connection used to connect the equipment grounding conductor and the service disconnect enclosure to the grounded conductor of a power system

Ground: Earth or some conducting body of relatively large extent that serves in place of the earth

Ground electrode: A conductor or body of conductors in intimate contact with the earth for the purpose of providing a connection with the ground

5.5 GROUND ELECTRODES

In this section, various types of ground electrodes and their use will be discussed. The NEC states that the following elements are part of a ground electrode system in a facility:

- Metal underground water pipe
- Metal frame of buildings or structures
- Concrete-encased electrodes
- Ground ring
- Other made electrodes, such as underground structures, rod and pipe electrodes, and plate electrodes, when none of the above-listed items is available.

The code prohibits the use of a metal underground gas piping system as a ground electrode. Also, aluminum electrodes are not permitted. The NEC also mentions that, when applicable, each of the items listed above should be bonded together. The purpose of this requirement is to ensure that the ground electrode system is large enough to present low impedance to the flow of fault energy. It should be recognized that, while any one of the ground electrodes may be adequate by itself, bonding all of these together provides a superior ground grid system.

Why all this preoccupation with ground systems that are extensive and interconnected? The answer is low impedance reference. A facility may have several individual buildings, each with its own power source. Each building may even have several power sources, such as transformers, uninterruptible power source (UPS) units, and battery systems. It is important that the electrical system or systems of each building become part of the same overall grounding system. A low impedance ground reference plane results from this arrangement (Figure 5.3). Among the additional benefits to the creation of a low-impedance earth-ground system is the fact that when an overhead power line contacts the earth, a low-impedance system will help produce ground-fault currents of sufficient magnitude to operate the overcurrent protection. When electrical charges associated with lightning strike a building and its electrical system, the lightning energy could pass safely to earth without damaging electrical equipment or causing injury to people. It is the author's personal experience that a lack of attention to grounding and bonding has been responsible for many preventable accidents involving equipment and personnel.

5.6 EARTH RESISTANCE TESTS

The earth resistance test is a means to ensure that the ground electrode system of a facility has adequate contact with earth. Figure 5.4 shows how an earth resistance tester is used to test the resistance between the ground grid and earth. The most common method of testing earth resistance is the fall of potential test, for which the earth resistance tester is connected as shown in Figure 5.4. The ground electrode of the facility or building is used as the reference point. Two ground rods are driven as indicated. The farthest rod is called the current rod (C_2), and the rod at the

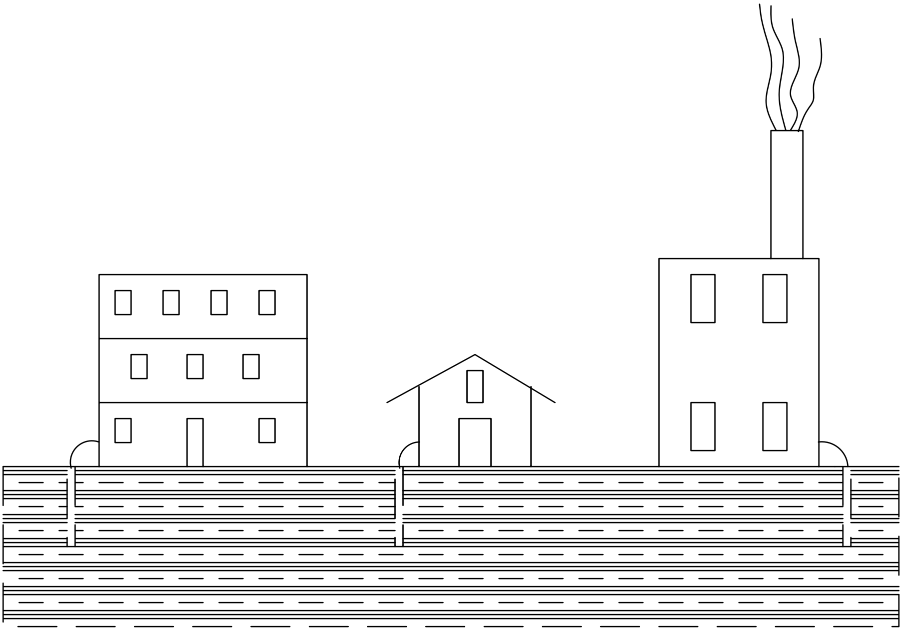

FIGURE 5.3 Low-impedance ground reference, provided by the earth, between several buildings in the same facility.

intermediate point is the potential rod (P_2). A known current is circulated between the reference electrode and the current rod. The voltage drop is measured between the reference ground electrode and the potential rod. The ground resistance is calculated as the ratio between the voltage and the current. The tester automatically calculates and displays the resistance in ohms. The potential rod is then moved to another location and the test repeated. The resistance values are plotted against the distance from the reference rod. The graph in Figure 5.4 is a typical earth resistance curve. The earth resistance is represented by the value corresponding to the flat portion of the curve. In typical ground grid systems, the value at a distance 62% of the total distance between the reference electrode and the current rod is taken as the resistance of the ground system with respect to earth.

The distance between the reference electrode and the current rod is determined by the type and size of the ground grid system. For a single ground rod, a distance of 100 to 150 ft is adequate. For large ground grid systems consisting of multiple ground rods, ground rings, or concrete-encased systems, the distance between the reference ground electrode and the current rod should be 5 to 10 times the diagonal measure of the ground grid system. The reason is that, as currents are injected into the earth, electrical fields are set up around the electrodes in the form of shells. To prevent erroneous results, the two sets of shells around the reference electrode and the current electrode should not overlap. The greater the distance between the two, the more accurate the ground resistance test results.

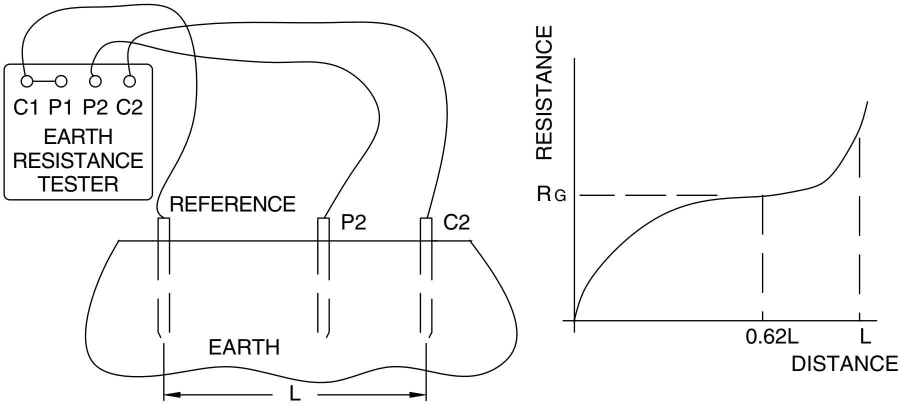

FIGURE 5.4 Ground resistance test instrument and plot of ground resistance and distance.

Article 250, Section 250-56, of the NEC code states that a single ground electrode that does not have a resistance of 25 Ω or less must be augmented by an additional electrode. Earth resistance of 25 Ω is adequate for residential and small commercial buildings. For large buildings and facilities that house sensitive loads, a resistance value of 10 Ω is typically specified. For buildings that contain sensitive loads such as signal, communication, and data-processing equipment, a resistance of 5 Ω or less is sometimes specified.

Earth resistance depends on the type of soil, its mineral composition, moisture content, and temperature. Table 5.2 provides the resistivity of various types of soils; Table 5.3, the effect of moisture on soil resistivity; and Table 5.4, the effect of temperature on soil resistivity. The information contained in the tables is used to illustrate the effect of various natural factors on soil resistivity. Table 5.5 shows the changes in earth resistance by using multiple ground rods. Note that, to realize the full benefits of multiple rods, the rods should be spaced an adequate distance apart.

TABLE 5.2
Resistivities of Common Materials

Material	Resistivity Range (Ω-cm)
Surface soils	100–5000
Clay	200–10,000
Sand and gravel	5000–100,000
Limestone	500–400,000
Shales	500–10,000
Sandstone	2000–200,000
Granite	1,000,000
Tap water	1000–5000
Seawater	20–200

TABLE 5.3
Effect of Moisture on Soil Resistivity

Moisture Content (% by weight)	Resistivity (Ω-cm) Top Soil	Resistivity (Ω-cm) Sandy Loam
0	1000×10^6	1000×10^6
2.5	250,000	15,000
5	165,000	43,000
10	53,000	22,000
15	21,000	13,000
20	12,000	10,000
30	10,000	8000

TABLE 5.4
Effect of Temperature on Earth Resistivity[a]

Temperature °C	Temperature °F	Resistivity (Ω-cm)
20	68	7200
10	50	9900
0	32 (water)	13,800
0	32 (ice)	30,000
–5	23	79,000
–15	5	330,000

[a] For sandy loam, 15.2% moisture.

TABLE 5.5
Change in Earth Resistance with Multiple Ground Rods

Number of Ground Rods	Distance between Rods[a] D = L (%)	D = 2L (%)	D = 4L (%)
1	100	—	—
2	60	52	50
3	42	37	35
4	35	29	27
5	28	25	23
10	16	14	12

[a] One ground rod of length L is used as reference.

5.7 EARTH–GROUND GRID SYSTEMS

Ground grids can take different forms and shapes. The ultimate purpose is to provide a metal grid of sufficient area of contact with the earth so as to derive low resistance between the ground electrode and the earth. Two of the main requirements of any ground grid are to ensure that it will be stable with time and that it will not form chemical reactions with other metal objects in the vicinity, such as buried water pipes, building reinforcment bars, etc., and cause corrosion either in the ground grid or the neighboring metal objects.

5.7.1 Ground Rods

According to the NEC, ground rods should be not less than 8 ft long and should consist of the following:

- Electrodes of conduits or pipes that are no smaller than 3/4-inch trade size; when these conduits are made of steel, the outer surface should be galvanized or otherwise metal-coated for corrosion protection
- Electrodes of rods of iron or steel that are at least 5/8 inches in diameter; the electrodes should be installed so that at least an 8-ft length is in contact with soil

Typically, copper-clad steel rods are used for ground rods. Steel provides the strength needed to withstand the forces during driving of the rod into the soil, while the copper coating provides corrosion protection and also allows copper conductors to be attached to the ground rod. The values indicated above are the minimum values; depending on the installation and the type of soil encountered, larger and longer rods or pipes may be needed. Table 5.6 shows earth resistance variation with the length of the ground rod, and Table 5.7 shows earth resistance values for ground rods of various diameters. The values are shown for a soil with a typical ground resistivity of 10,000 Ω-cm.

TABLE 5.6
Effect of Ground Rod Length on Earth Resistance

Ground Rod Length (ft)	Earth Resistance (Ω)
5	40
8	25
10	21
12	18
15	17

Note: Soil resistivity = 10,000 Ω-cm.

TABLE 5.7
Effect of Ground Rod Diameter on Earth Resistance[a]

Rod Diameter (inches)	% Resistance
0.5	100
0.75	90
1.0	85
1.5	78
2.0	76

Note: Soil resistivity = 10,000 Ω-cm.

[a] Resistance of a 0.5-inch-diameter rod is used as reference.

5.7.2 PLATES

Rectangular or circular plates should present an area of at least 2 ft^2 to the soil. Electrodes of iron and steel shall be at least 1/4 inch in thickness; electrodes of nonferrous metal should have a minimum thickness of 0.06 inch. Plate electrodes are to be installed at a minimum distance of 2.5 ft below the surface of the earth. Table 5.8 gives the earth resistance values for circular plates buried 3 ft below the surface in soil with a resistivity of 10,000 Ω-cm.

5.7.3 GROUND RING

The ground ring encircling a building in direct contact with the earth should be installed at a depth of not less than 2.5 ft below the surface of the earth. The ground ring should consist of at least 20 ft of bare copper conductor sized not less than #2 AWG. Typically, ground rings are installed in trenches around the building, and wire tails are brought out for connection to the grounded service conductor at the service disconnect panel or switchboard. It is preferred that a continuous piece of wire be

TABLE 5.8
Resistance of Circular Plates Buried 3 Feet Below Surface

Plate Area (ft^2)	Earth Resistance (Ω)
2	30
4	23
6	18
10	15
20	12

Note: Soil resistivity = 10,000 Ω-cm.

TABLE 5.9
Earth Resistance of Buried Conductors

Wire Size (AWG)	Resistance (Ω) for Total Buried Wire Length				
	20 ft	40 ft	60 ft	100 ft	200 ft
# 6	23	14	7	5	3
# 1/0	18	12	6	4	2

Note: Soil resistivity = 10,000 Ω-cm.

used. In large buildings, this might be impractical. If wires are spliced together, the connections should be made using exothermic welding or listed wire connectors. Table 5.9 provides the resistance of two conductors buried 3 ft below the surface for various conductor lengths. The values contained in the table are intended to point out the variations that may be obtained using different types of earth electrodes. The values are not to be used for designing ground grids, as the values are apt to change with the type of soil and soil temperatures at the installation.

5.8 POWER GROUND SYSTEM

A good ground electrode grid system with low resistance to earth is a vital foundation for the entire power system for the facility. As we mentioned earlier, the primary objective of power system grounding is personal safety, in addition to limiting damage to equipment. When a ground fault occurs, large ground return currents are set up which causes the overcurrent protection to open and isolate the load from the power source. In many cases, the phase overcurrent protection is depended upon to perform this function during a ground fault. Article 250-95 of the NEC (1999) requires ground fault protection for solidly grounded Wye-connected electrical services of more than 150 V to ground, not exceeding 600 V phase-to-phase, for each service rated 1000 A or more. This requirement recognizes the need for ground fault protection for systems rated greater than 150 V to ground because of the possibility of arcing ground faults in such systems. Arcing ground faults generate considerably lower fault currents than bolted ground faults or direct short circuits between phase and ground. The possibility of arcing ground faults in systems rated less than 150 V to ground should be acknowledged, and ground fault protection against low-level ground faults should be provided for the power system. The ground fault protection is set at levels considerably lower than the phase fault protection. For instance, a 1000-A-rated overcurrent protection system may have the ground fault protection set at 200 A or lower. The setting of the ground fault device depends on the degree of protection required, as this requirement is strictly ground fault protection for equipment.

As indicated in Table 5.1, it takes very little current to cause electrical shock and even loss of life. This is why ground fault circuit interrupters (GFCIs) are required by the NEC for convenience outlets in certain areas of homes or facilities.

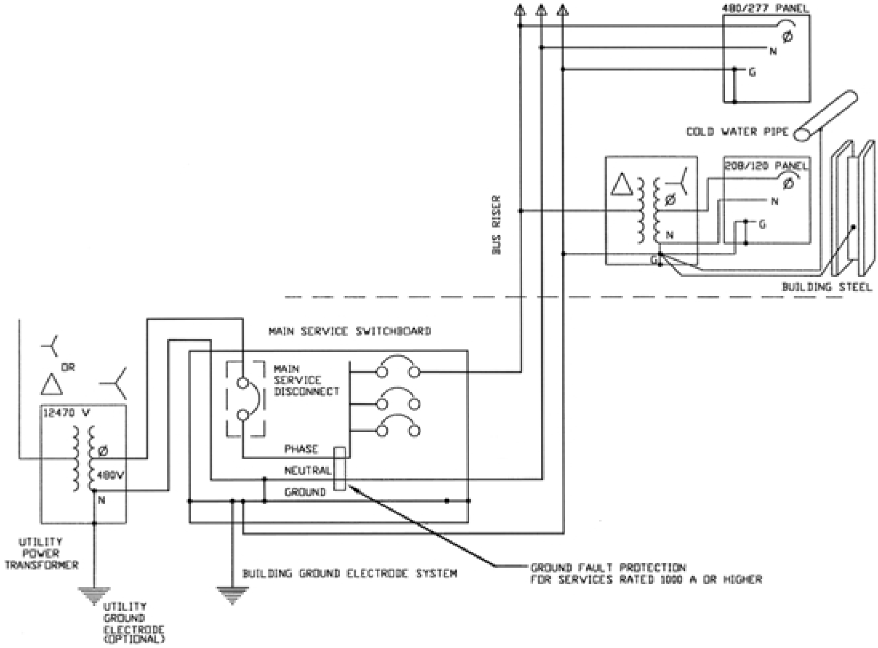

FIGURE 5.5 Typical power system grounding scheme.

GFCI protection is set to open a circuit at a current of 5 mA. The GFCI is not intended for equipment protection but is strictly for personal protection. Figure 5.5 illustrates a typical facility power-grounding scheme.

5.9 SIGNAL REFERENCE GROUND

Signal reference ground (SRG) is a relatively new term. The main purpose of the signal reference ground is not personal safety or equipment protection but merely to provide a common reference low-impedance plane from which sensitive loads may operate. Why is SRG important? Figure 5.6 depicts two low-level microcircuits sharing data and power lines. What makes this communication possible is that both devices have a common reference signal, the ground. If the reference ground is a high-impedance connection, voltage differentials may be created that would affect the point of reference for the two devices, so lowering the impedance between the reference points of the two circuits lowers the potential for coupling of noise between the devices.

When we mention low impedance, we mean low impedance at high frequencies. For power frequency, even a few hundred feet of wire can provide adequate impedance, but the situation is different at high frequencies. For example, let us consider

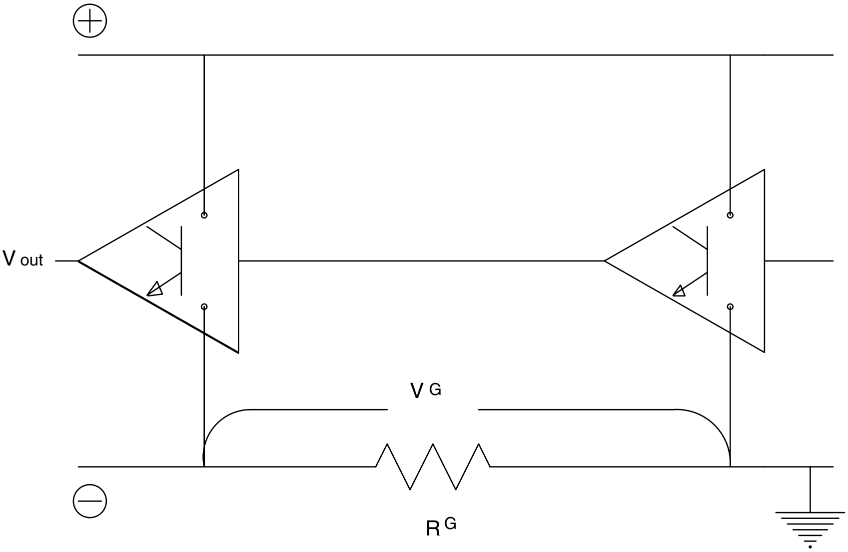

FIGURE 5.6 Ground potential difference due to excessive ground impedance.

a situation when two devices are connected to a 10-ft length of #4 copper conductor ground wire:

The DC resistance of the wire is = 0.00025 Ω
The inductive reactance at 60 Hz = 0.0012 Ω
Inductive reactance at 1 MHz ≅ 20 Ω

If a noise current of 100 mA at 1 MHz is to find its way into the ground wire between the two devices, the noise voltage must be 2 V, which is enough to cause the devices to lose communication and perhaps even sustain damage, depending on the device sensitivity. This example is a simple situation consisting of only two devices; however, hundreds and perhaps thousands of such devices or circuits might be present in an actual computer or communication data center. All these devices require a common reference from which to operate. This is accomplished by the use of the SRG.

As noted above, the main purpose of the SRG is not electrical safety, even though nothing that we do to the ground system should compromise safety; rather, the SRG is a ground plane that provides all sensitive equipment connected to it a reference point from which to operate without being unduly affected by noise that may be propagated through the SRG by devices external or internal to the space protected by the SRG. What we mean by this is that noise may be present in the SRG, but the presence of the noise should not result in voltage differentials or current loops of levels that could interfere with the operation of devices that use the SRG for reference.

The SRG is not a stand-alone entity; it must be bonded to other building ground electrodes such as building steel, ground ring, or concrete-encased electrodes. This requirement permits any noise impinging on the SRG to be safely conducted away from the SRG to building steel and the rest of the ground grid system.

5.10 SIGNAL REFERENCE GROUND METHODS

The SRG can take many forms, depending on the user preference. Some facilities use a single conductor installed underneath the floor and looped around the space of the computer center. While this method is practical, it is limited in functionality due to the large impedances associated with long wires, as mentioned earlier. Larger computer data centers use more than one conductor but the limitations are the same as stated above. A preferred SRG consists of #2 AWG or larger copper conductor laid underneath the floor of the computer or communication center to form a grid of 2 × 2-ft squares (Figure 5.7). By creating multiple parallel paths, the impedance for the reference plane is made equal for all devices and circuits sharing the SRG. If the impedance is measured at any two nodes of the SRG and plotted against frequency, the shape of the frequency characteristics would appear as shown in Figure 5.8. The impedance vs. frequency graph should appear the same across any two sets of nodes of the SRG, as this is the main objective of the SRG.

Some installations use copper strips instead of circular conductors to form the grid. Other facilities might use sheets of copper under the floor of the computer center as the SRG. Constructing an SRG with a continuous sheet of copper creates a reference plane made up of infinite parallel paths instead of a discrete number of parallel paths as with SRGs made up of circular wires. The SRG is also bonded to the building steel and the stanchions that support the raised floor of the computer center. Such an arrangement provides excellent noise immunity and allows the creation of a good reference plane for the sensitive circuits. Figure 5.9 depicts how an SRG for a large-sized computer center might be configured. Some installations use aboveground wiring methods instead of a raised-floor configuration. The principle behind the configuration of the SRG does not change whether the ground

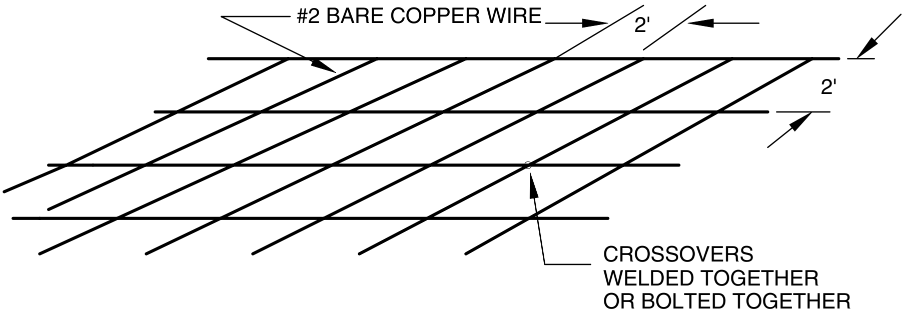

FIGURE 5.7 Typical 2 × 2-ft signal reference ground arrangement.

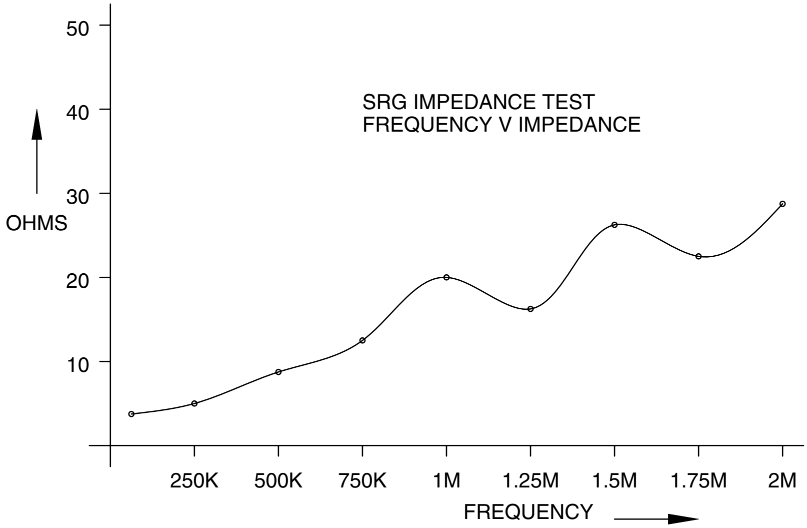

FIGURE 5.8 Typical signal reference ground frequency vs. impedance characteristics.

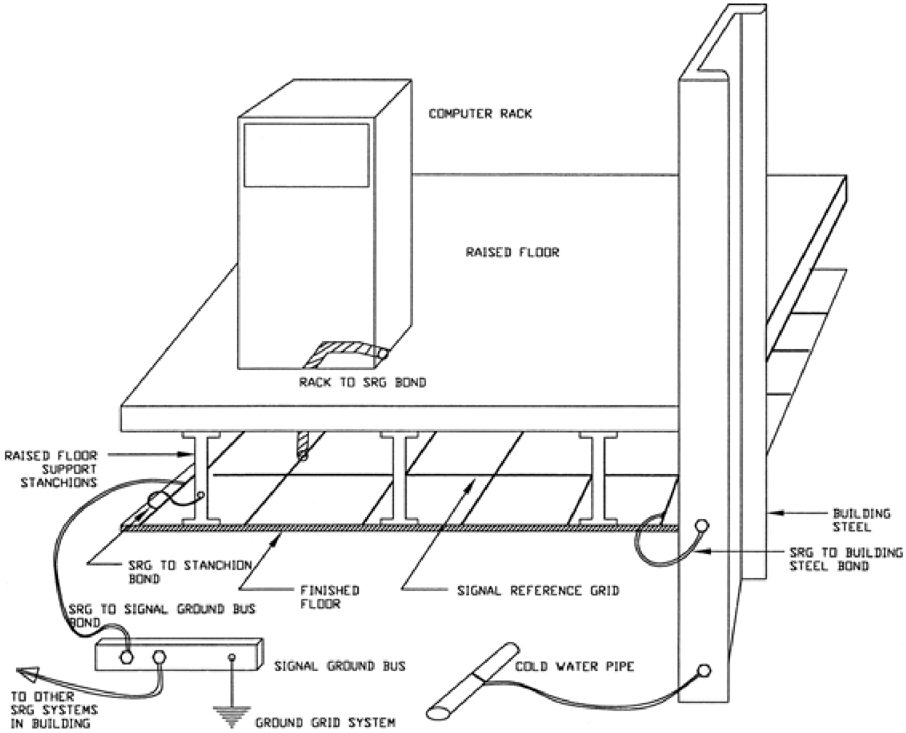

FIGURE 5.9 Typical computer and communication facility data center grounding and bonding.

reference plane is below ground or above ground. It is important that all noise-producing loads be kept away from the SRG. If such loads are present, they should be located at the outer periphery of the data center and bonded to the building steel, if possible.

5.11 SINGLE-POINT AND MULTIPOINT GROUNDING

With multipoint grounding, every piece of equipment sharing a common space or building is individually grounded (Figure 5.10); whereas, with single-point grounding, each piece of equipment is connected to a common bus or reference plane, which in turn is bonded to the building ground grid electrode (Figure 5.11). Multipoint grounding is adequate at power frequencies. For typical power systems, various transformers, UPS systems, and emergency generators located in each area or floor of the building are grounded to the nearest building ground electrode, such as building steel or coldwater pipe. Generally, this method is both convenient and economical, but it is neither effective nor recommended for grounding sensitive devices and circuits. As we saw, the primary purpose of grounding for sensitive equipment is the creation of a reference plane. This is best accomplished by single-point grounding and bonding means. The SRG must also be bonded to the building ground electrode to ensure personal safety.

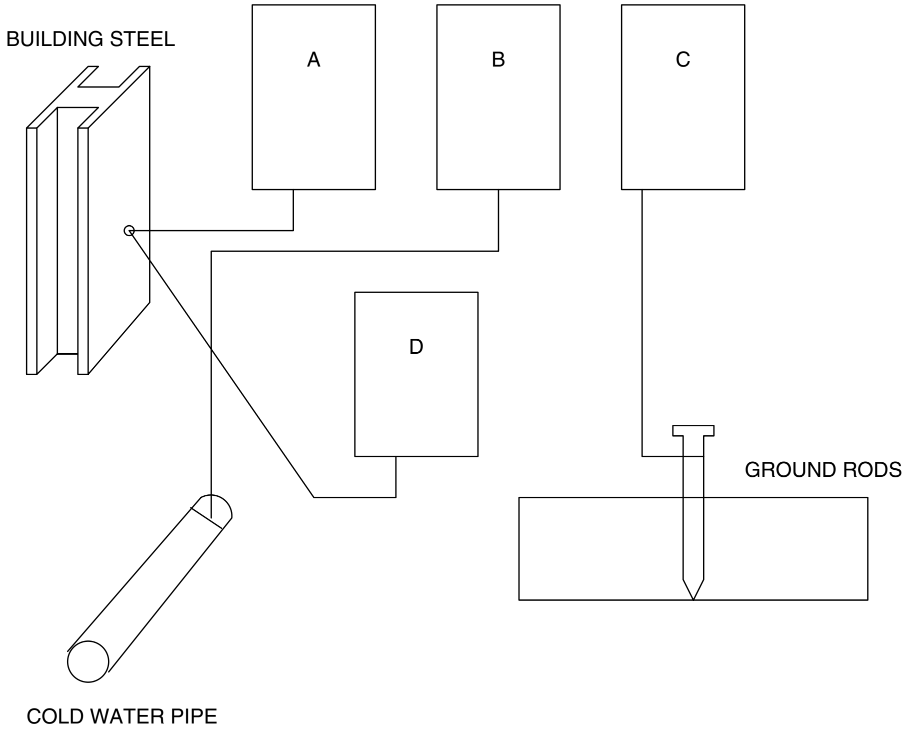

FIGURE 5.10 Multipoint ground system.

5.12 GROUND LOOPS

In Chapter 1, a ground loop was defined as a potentially detrimental loop formed when two or more points in an electrical system that are normally at ground potential are connected by a conducting path such that either or both points are not at the same potential. Let's examine the circuit shown in Figure 5.12. Here, the ground plane is at different potentials for the two devices that share the ground circuit. This sets up circulation of currents in the loop formed between the two devices by the common ground wires and the signal ground conductor. Such an occurrence can result in performance degradation or damage to devices within the loop. Ground loops are the result of faulty or improper facility wiring practices that cause stray currents to flow in the ground path, creating a voltage differential between two points in the ground system. They may also be due to a high-resistance or high-impedance connection between a device and the ground plane. Because the signal common or ground conductor is a low-impedance connection, it only takes a low-level ground loop potential to cause significant current to flow in the loop. By adhering to sound ground and bonding practices, as discussed throughout this chapter, ground loop potentials can be minimized or eliminated.

Problems due to ground loops can be difficult to identify and fix. The author has observed many instances where well-trained personnel have attempted to fix

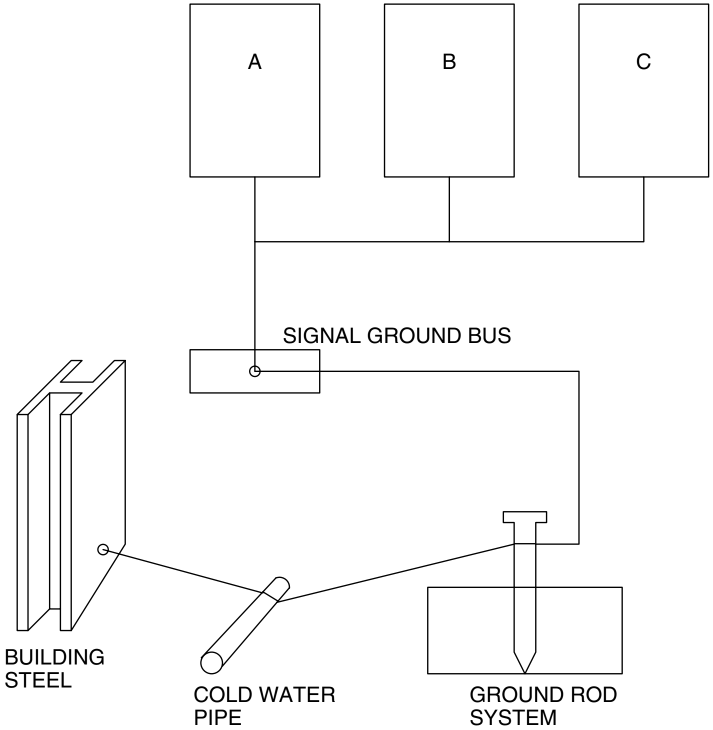

FIGURE 5.11 Single-point grounding of sensitive equipment.

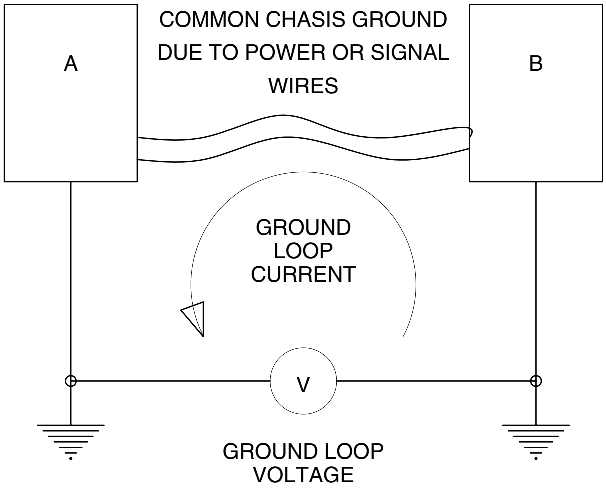

FIGURE 5.12 Ground loop voltage and current.

ground loop problems by removing the ground connections or ground pins from power and data cords. In all of these cases, relief, if any, has been minimal, and the conditions created by these actions are nothing short of lethal. This is what we mean by the statement that nothing that we do to grounding and bonding should make the installation unsafe.

5.13 ELECTROCHEMICAL REACTIONS DUE TO GROUND GRIDS

When two dissimilar metals are installed in damp or wet soil, an electrolytic cell is formed. If there is an external connection between the two metal members, a current can flow using the electrolyte formed by the wet soil which can cause deterioration of the anodic (+) member of the metal pair (Figure 5.13). The figure depicts the copper water pipes and ground rings bonded to the building steel or reinforcing bars in the foundation. This configuration results in current flow between the members. Over the course of time, the steel members that are more electropositive will start to disintegrate as they are asked to supply the electrons to support the current flow. If not detected, the structural integrity of the building is weakened. By suitably coating the steel or copper, current flow is interrupted and the electrolytic action is minimized.

Table 5.10 lists the metals in order of their position in the galvanic series. The more positive or anodic metals are more active and prone to corrosion. In some installations, to prevent corrosion of a specific metal member, sacrificial anodes are installed in the ground. The sacrificial anodes are more electropositive than the metals they are protecting, so they are sacrificed to protect the structural steel.

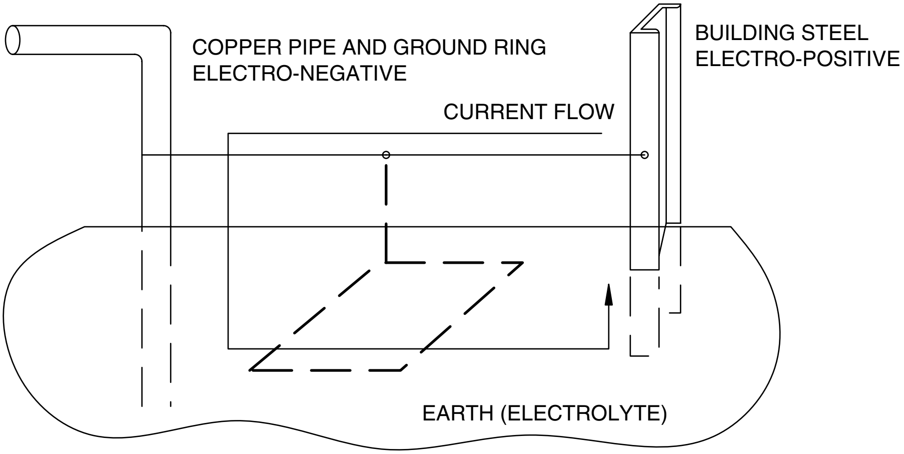

FIGURE 5.13 Metal corrosion due to electrolysis caused by copper and steel in the earth.

TABLE 5.10
Electromotive Series of Metals

Metal	Electrode Potential (V)
Magnesium	2.37
Aluminum	1.66
Zinc	0.763
Iron	0.44
Cadmium	0.403
Nickel	0.25
Tin	0.136
Lead	0.126
Copper	–0.337
Silver	–0.799
Palladium	–0.987
Gold	–1.5

5.14 EXAMPLES OF GROUNDING ANOMALIES OR PROBLEMS

5.14.1 Loss of Ground Causes Fatality

Case

At a manufacturing plant that used high-frequency, high-current welders for welding steel and aluminum parts, one of the welders took a break outdoors on a rainy day. When he walked back into the building and touched one of the welding machines to which power was turned on, he collapsed and died of cardiac arrest.

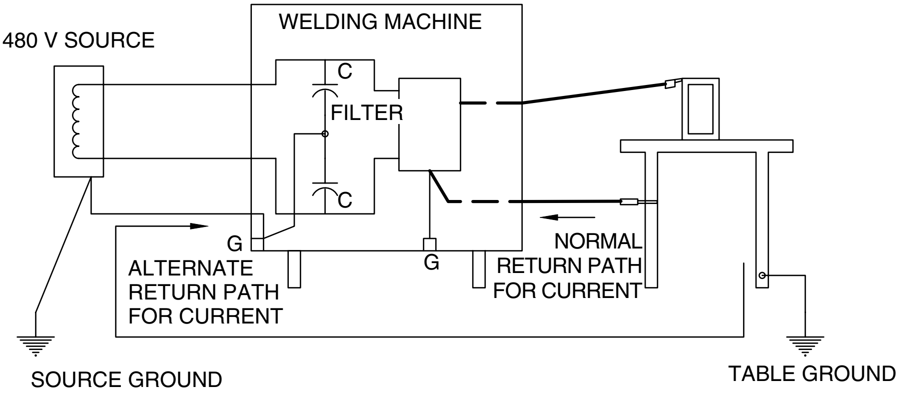

FIGURE 5.14 Example of grounding problem resulting in a fatality.

Investigation

Figure 5.14 shows the electrical arrangement of the equipment involved in this incident. The welding machine operated from a 480-V, one-phase source fed from a 480Y/277 secondary transformer. The input power lines of the machine contained a capacitance filter to filter high-frequency noise from the load side of the machine and to keep the noise from being propagated upstream toward the source. The return current for the welded piece was via the ground lead of the machine. Examination of the power and ground wiring throughout the building revealed several burned equipment ground wires. It was determined that due to improper or high-resistance connections in the return lead of the welder, the current was forced to return through the equipment ground wire of the machines. The equipment ground wires are not sized to handle large currents produced by the welding machine. This caused the equipment ground wire of the machine (and other machines) to be either severely damaged or totally burned off. As the center point of the capacitive filter is connected to the frame of the welding machine, the loss of ground caused the frame of the machine to float and be at a potential higher than the ground. When the operator touched the machine, he received a shock severe enough to cause cardiac arrest. The fact that he was exposed to moisture prior to the contact with the machine increased the severity of the hazard.

5.14.2 Stray Ground Loop Currents Cause Computer Damage

Case

In a commercial building, computers were burning up at an alarming rate. Most of the problems were found at the data ports.

Investigation

Wiring problems were found in the electrical panel supplying the computers, such as with the neutral wires in the ground terminal and ground wires in the neutral terminal. This configuration caused a portion of the neutral return current of the load

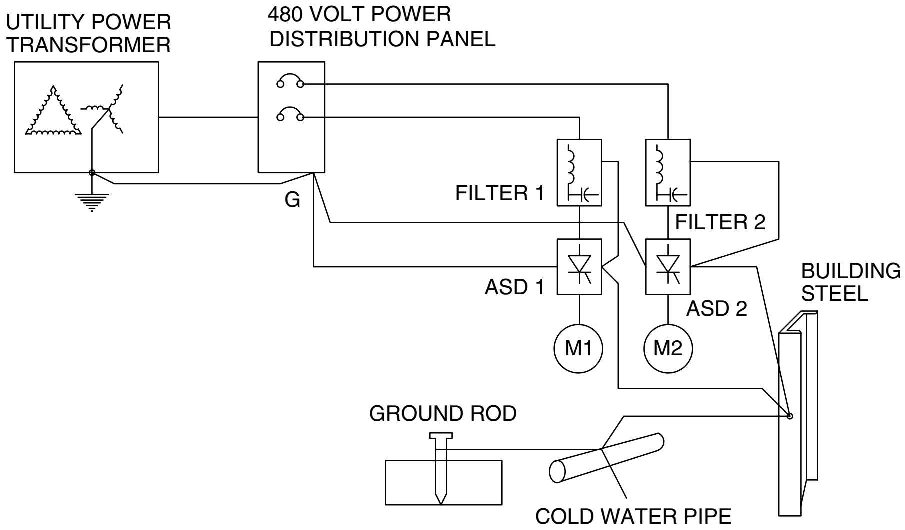

FIGURE 5.15 Adjustable speed drive grounding deficiencies, resulting in shutdowns and down time, reconfigured to correct the problem.

circuits to return via the equipment ground wires and other grounded parts such as conduits and water pipes. The current was also high in harmonic content, as would be expected in such an application. The flow of stray ground currents caused ground potential differences for the various computers that shared data lines. Resulting ground loop currents resulted in damage to data ports, which are not designed or intended to carry such currents. Once the wiring anomalies at the power distribution panel were corrected, computer damage was not experienced.

5.14.3 GROUND NOISE CAUSES ADJUSTABLE SPEED DRIVES TO SHUT DOWN

Case

In a newspaper printing facility, two adjustable speed drives (ASDs) were installed as part of a new conveyor system to transport the finished product to the shipping area. The ASDs were shutting themselves off periodically, causing papers to back up on the conveyor and disrupting production.

Investigation

Figure 5.15 depicts the electrical setup of the ASDs. The electrical system in the facility was relatively old. The drives were supplied from a switchboard located some distance away. Tests revealed the presence of electrical noise in the lines supplying the ASDs. Even though the drives contained line filters, they were not effective in minimizing noise propagation. The conclusion was that the long length of the ground return wires for the drives presented high impedance to the noise, thereby allowing it to circulate in the power wiring. To correct the situation, the ASDs and the filters were bonded to building steel located close to the drives. The building steel was also bonded to the coldwater pipe and ground rods installed for this section of the power system. This created a good ground reference for the ASDs and the filter units. Noise was considerably minimized in the power wires. The drives operated satisfactorily after the changes were implemented.

5.15 CONCLUSIONS

A conclusion that we can draw is that grounding is not an area where one can afford to be lax. Reference is fundamental to the existence of stability. For electrical systems, reference is the ground or some other body large enough to serve in place of the ground, and electrical stability depends on how sound this reference is. We should not always think of this reference as a ground or a ground connected to the earth. For the electrical system of a ship, the hull of the ship and the water around the ship serve as the reference. For aircraft, the fuselage of the aircraft is the reference. Problems arise when we do not understand what the reference is for a particular application or we compromise the reference to try to make a system work. Either condition is a recipe for problems. Grounding is the foundation of any electrical power, communication, or data-processing system; when the foundation is taken care of, the rest of the system will be stable.