Principles of Electrical Grounding

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Abstract:

This is a discussion of the basic principles behind grounding systems and how grounding is related to safety and the effective operation of circuit protection devices such as fuses and circuit breakers. The discussion moves quickly from a basic study of grounding to simple examples of a single building installation and onto facilities with multiple buildings and structures. Finally the discussion will briefly cover grounding as it applies to lightning protection and the control of static electricity.

Introduction:

Grounding to most engineers, technicians and electricians is a simple subject and little attention is paid to it other than knowing that something is required. To some people there are grounds and then there are “Clean Grounds”. Thirty years ago when computers were relatively new, there were many approaches to grounding, particularly for electronics and computers. Some of these approaches established what was called a “Clean Ground” which was often isolated from the power grounds.

Many of these ideas have been proven to be ineffective and sometimes dangerous to equipment and personnel. As frequencies became higher and higher (computer speeds faster and faster) research accelerated into the subject of grounding, shielding, EMI, lightning protection and static electricity. The research resulted in the basic science behind grounding. This subject is not as simple as once thought and one needs a clear understanding of the basic principles.

First, the ground or grounding of a circuit is a misnomer. For most purposes the term means earthing or connecting the circuit to earth. In actuality, it’s connecting the circuit to a common point of reference; for most systems that is the earth.

Grounding’s main purpose is to provide a common point of reference between various sources of electrical energy, i.e.

Different power systems	- Public Utilities, on-site generation, battery systems
Different voltage systems	- 138,000v, 13,800v, 480v, 120v, etc.
Different energy sources	- Electrical Energy, Lightning, Static Electricity, RF Energy

In any discussion of the grounding of electrical systems, particularly as it applies to power systems, there also needs to be a consideration of how the grounding system relates to overcurrent protection. They go hand in hand.

There are also a number of misconceptions that affect how a ground system works. The following facts are generally not known or are misunderstood.

The earth is NOT always a good ground.

What is acceptable at 60 Hz does not always work at high frequencies.

The interconnection of systems with even large conductors may be ineffective when installed improperly - ground loops around buildings and interconnecting buildings are not enough - the ground conductor must be run in a conduit with the phase conductors (ground conductors act as an inductor when outside of the conduit).

Circuit breakers and fuses, even though sized properly do not always protect.

Grounding shields can cause major problems. Most of the time ground only one end, but not always. Some circuits require both ends grounded.

New construction methods and materials are causing real problems - elimination of a structural element that has a secondary benefit as an electrical conductor is causing electrical problems.

An improperly installed lightning protection system can cause more damage then not having any lightning protection.

Safety:

In actuality, grounding's purpose is a lot more than providing a common point of reference. It is the key to SAFETY. That is, the protection of

Personnel

Equipment

Facilities

When considering protection of personnel, equipment and facilities against electrical hazards there is a NEED TO CONSIDER both Grounding and Overcurrent Protection and how they relate. They go hand in hand. A facility's electrical protection systems are intended to:

Protect Personnel from
  - Electrocution
  - Fire

Protect Equipment and Facility from
  - Failure
  - Fire

Protect Electrical Circuit from
  - Cable Failures

For the protection systems to do as intended, they must first work; and second they must work fast enough to eliminate or at least minimize damage. This is where proper grounding comes to play.

Another fact, which this author has observed, is that in most cases, accidents & failures occur because of **TWO** events or failures that exist at the same time. For example, a poor ground does not cause a problem in itself, but coupled with a short circuit, you have an accident. Likewise, an improperly installed ground system (with proper circuit protection) may not cause a problem until a short circuit occurs, the circuit breaker does not open, and the equipment is destroyed.

The reduction and potential elimination of many electrical problems is a function of proper grounding. Grounding is, in essence, the control of abnormal voltages or currents through the proper application of Ohm's Law:

$E = IR$ (Simplified Form)

$E = IR + jIX_C + jIX_L$

Grounding is the control or minimization of R in order to reduce the effects of E & I. Improper grounding can cause more harm than no grounding. Misunderstood grounding often leads to the installation of improper grounding systems that are either ineffective, or even worse, dangerous.

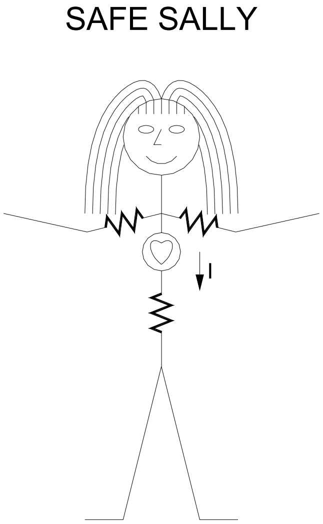
Electric Shock:

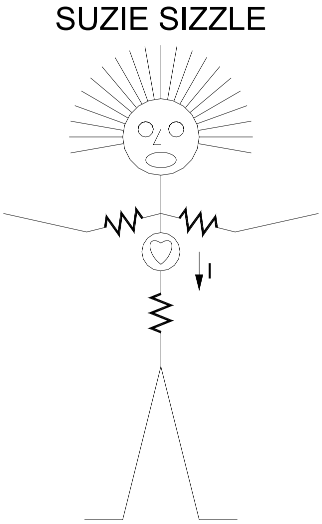
An electrical shock (electrocution) occurs when two portions of a person's body come in contact with electrical conductors of a circuit which is at different potentials, thus producing a potential difference across the body. The human body does have resistance and when the body is connected between two conductors at different potentials (voltage) a circuit is formed through the body and current will flow.

When the human body comes in contact with only one conductor, a circuit is not formed and nothing happens. When the human body comes in contact with circuit conductors, no matter what the voltage is, there is a potential for harm. The higher the potential difference the more the damage. The effect of an electrical shock is a function of what parts of the body come in contact with each conductor, the resistance of each contact point, the surface resistance of the body at the contact, as well as other factors.

When the electrical contact is such that the circuit path through the body is across the heart, you have the greatest potential for death. As shown in Figure 1, the human body's resistance varies from as low as 500 ohms to as high as 600,000 ohms. As the skin becomes moist, the contact resistance drops. If the skin is moist, due to sweat that contains salt, the resistance drops further. Figure 1 illustrates the amount of current that can flow through the human body at three different potential differences across the body. Also shown is the effect of different current levels, both AC and DC. The ultimate effect is fibrillation, which causes the heart to stop, and results in death.

When a high voltage such as 13,800v is involved, the body is literally cooked and, at times, explodes. Figure 1 also shows two stick figures, Safe Sally and Suzie Sizzle to illustrate how the human body can become electrocuted. The use of female names is only to provide names that are easy to remember and which rhyme with safe and sizzle and in no way intended to indicate that women are unsafe or more easily shocked.





HUMAN BODY

Z = 500 to 600,000 OHMS
(DEPENDS ON SKIN MOISTURE
AND OTHER FACTORS)

I = 250mA to 0.2mA
@ 120VAC
I = 550mA to 0.5mA
@ 277VAC
I = 960mA to 0.8mA
@ 480VAC

ELECTRIC SHOCK

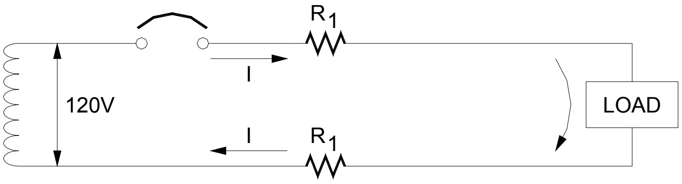
	AC @ 60Hz	DC
PERCEPTION LEVEL	1mA	2mA
NO-LET-GO LEVEL	15mA	300mA
FIBRILLATION LEVEL @ 0.2 SECONDS	500mA	500mA
FIBRILLATION LEVEL @ 0.5 SECONDS	75mA	400mA

~ FIGURE 1 ~

SHOCK001

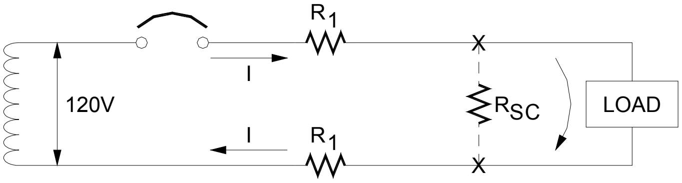
BASIC CIRCUIT

(PHASE-TO-PHASE or PHASE-TO-NEUTRAL)



$$I = \frac{E}{R_1 + R_L + R_1}$$

$$I \sim \frac{E}{R_L} \quad \text{(SIMPLIFIED)}$$



$$I = \frac{E}{2R_1 + \dfrac{R_{SC}R_L}{R_{SC} + R_L}}$$

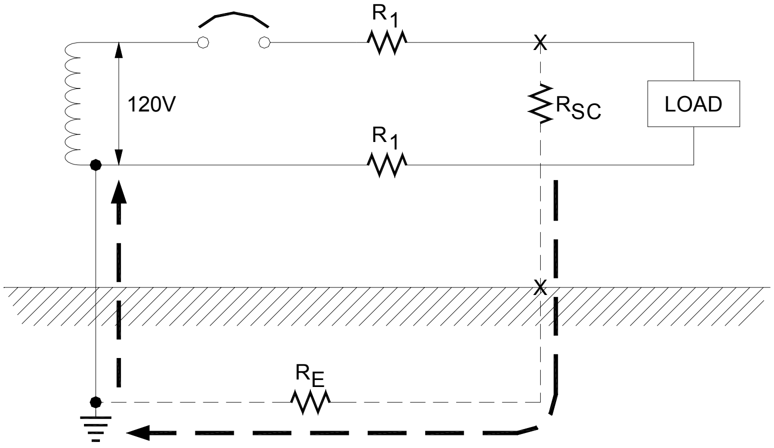
$$I \sim \frac{E}{R_L} \text{ or } \frac{E}{R_{SC}} \quad \text{(SIMPLIFIED)}$$

~ FIGURE 2 ~

SHOCK018

BASIC CIRCUIT

(PHASE-TO-GROUND)



$$I = \frac{E}{R_1 + R_{SC} + R_E}$$

IF 'R_{SC}' OR 'R_E' IS HIGH
THE CIRCUIT BREAKER
WILL NOT OPEN

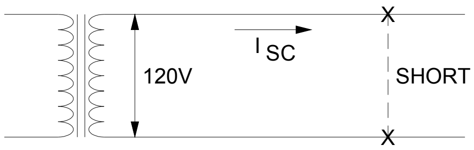
LOW 'R_{SC}' WITH HIGH 'R_E'
WILL CAUSE A FIRE

~ FIGURE 3 ~

SHOCK019

WHAT IS THE MAXIMUM CURRENT FLOW IN A SHORT CIRCUIT?

$$I_{SC} = I_{FLA} * \frac{100}{\% Z}$$



10KVA

$$I_{SC} = 83A * \frac{100}{1.6\%}$$

$$I_{SC} = 5{,}188 \text{ AMPS}$$

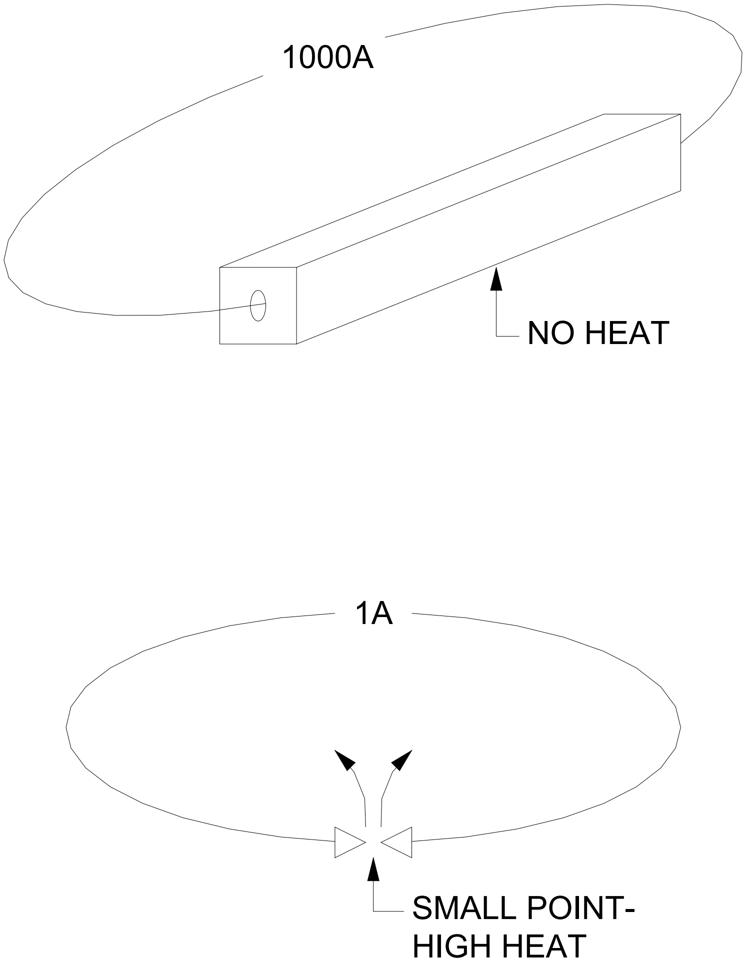
100KVA

$$I_{SC} = 830A * \frac{100}{1.6\%}$$

$$I_{SC} = 51{,}880 \text{ AMPS}$$

~ FIGURE 4 ~

SHOCK020



~ FIGURE 5 ~

SHOCK017

Short Circuits:

To analyze how an electrical shock occurs and how grounding is applied, you need to look at the circuit involved. Figure 2 illustrates the basic circuit that consists of a source, a transformer or generator for all AC circuits, circuit protection, conductors (R_1s), and a load (R_L). A short circuit is any unintended connection (R_{SC}) across the circuit conductors between the power source and the load. See the second circuit in Figure 2. Short circuits are classified as bolted shorts, momentary shorts, intermittent shorts, or high impedance shorts. A bolted short, which is rare, is a very low resistant connection such as two conductors being bolted together. Most shorts are high resistant shorts or they are momentary or intermittent. The high resistant short starts out as a high resistance or impedance connection, but usually progress to a low impedance connection.

In electrical systems, shorts are classified as phase-to-phase, phase-to-neutral, or phase-to-ground. Figure 2 shows a typical phase-to-phase or phase-to-neutral short. Figure 3 shows the basic phase-to-ground short. Most shorts are phase-to-ground and shorts which start as phase-to-phase or phase-to-neutral progress to a phase-to-ground short.

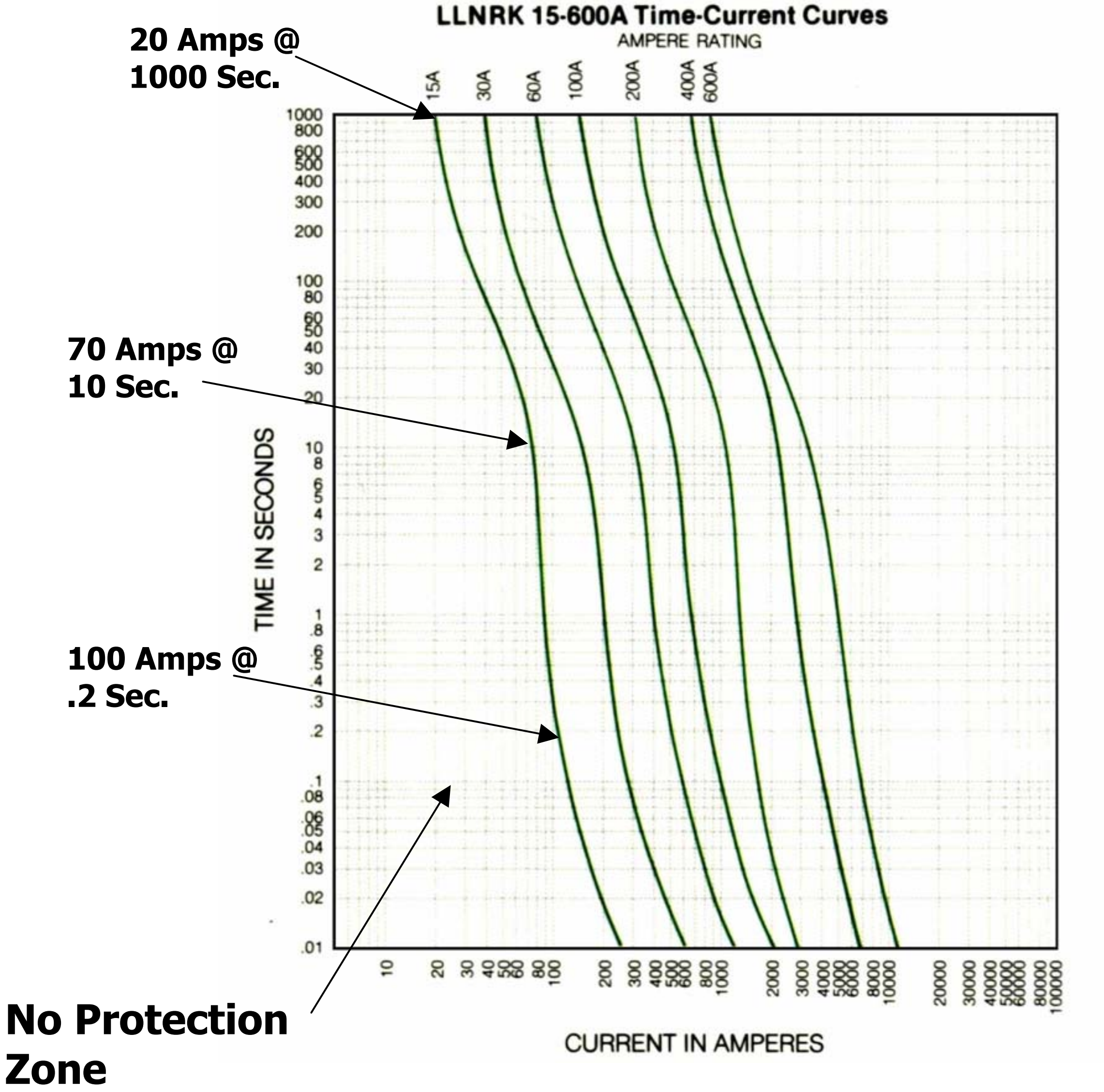
When considering short circuits and protecting against the damage they can cause, one needs to know what is the maximum amount of short circuit current that can flow in a given circuit. Is it infinity or some other amount? (Refer to Figure 4) When considering AC power systems, it's principally the impedance of the supplying transformer or generator which determines the amount of available short circuit current I_{SC}. Distance from the transformer or generator, lead length and conductor resistance reduce the amount of short circuit current that can flow. Any motors that are connected between the short circuit and the supplying transformer or generator act as generators and add to the short circuit current flow.

As we look at a short circuit, we need to consider the amount and type of damage a short circuit can cause. You might think that the bolted short circuit is the most destructive. In fact the bolted short which has the lowest impedance and can draw the most current, is often the least destructive. The simple arc can be very destructive by causing fires. Most arcs have a resistance of 0.5 to 1.0 ohms at 120 VAC. Thus, an arc can draw between 120 and 240 amps for a very short period of time. This can produce between 14,400 and 28,800 watts of heat. 20,000 watts will produce 1/16" diameter copper globules at >2500 EF flying in all directions. Thus, a fire starts.

What's important is the concentrated watt density for a unit of time. Figure 5 illustrates the point. 1000 amps through a large copper bar will not produce enough heat to do anything, yet an arc with very small contact area can produce >2500 EF copper globules. As another way of looking at this, consider the 5 watt Christmas tree light which is nothing more than a white hot glowing wire. The majority of the short circuits are these arcing faults that often are of low current flow and often result in a fire.

Short circuits, whether phase-to-phase, phase-to-neutral, or phase-to-ground are normally not bolted faults but are of relatively high impedance. Most 120 VAC circuits are protected by 15 amp fuses or circuit breakers. When a short occurs, you might think that the fuse or circuit breaker is going to protect and open the circuit. This is just not the case in many instances.

15 Amp Fuse Curve



20 Amps @ 1000 Sec.

70 Amps @ 10 Sec.

100 Amps @ .2 Sec.

No Protection Zone

Figure 6

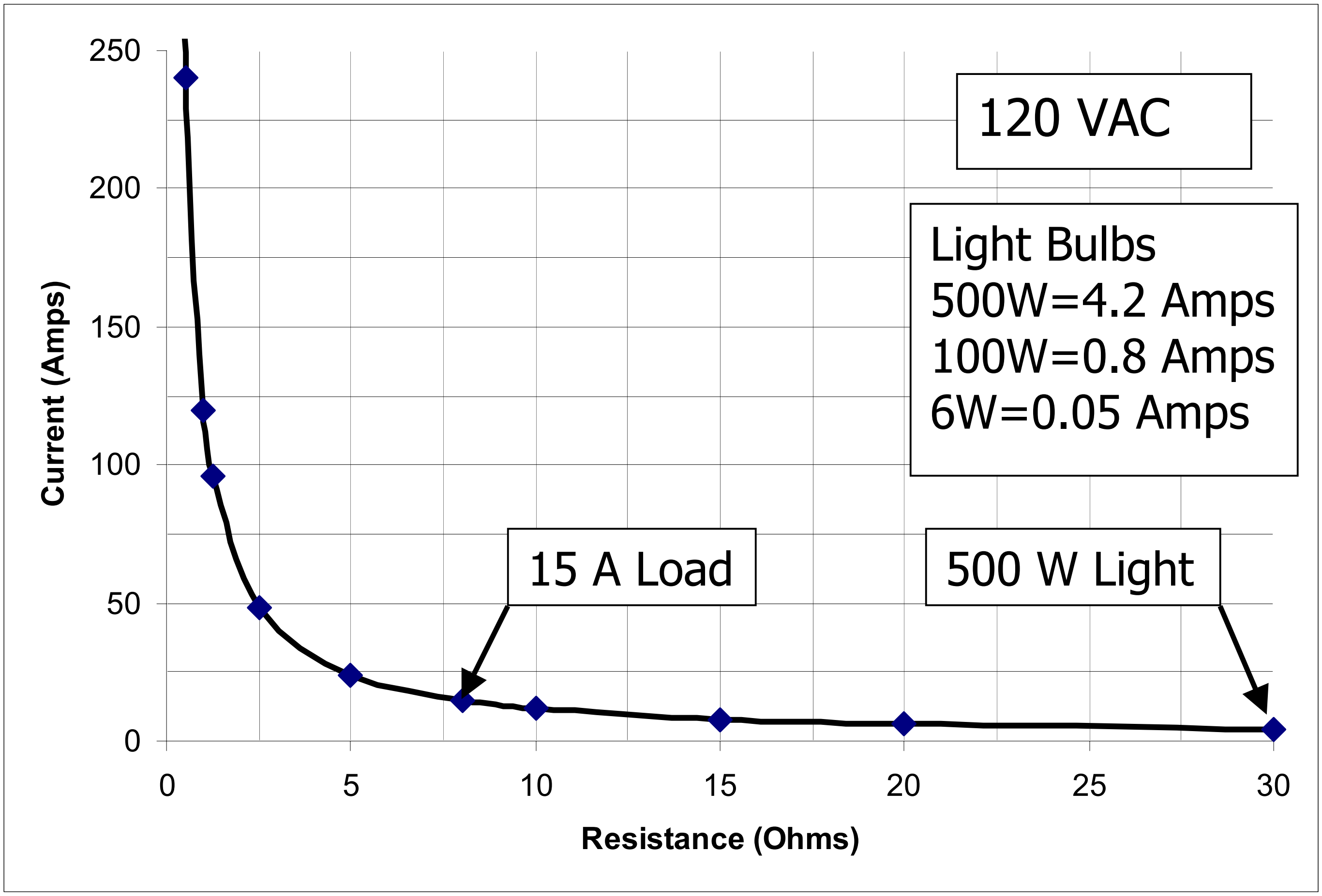
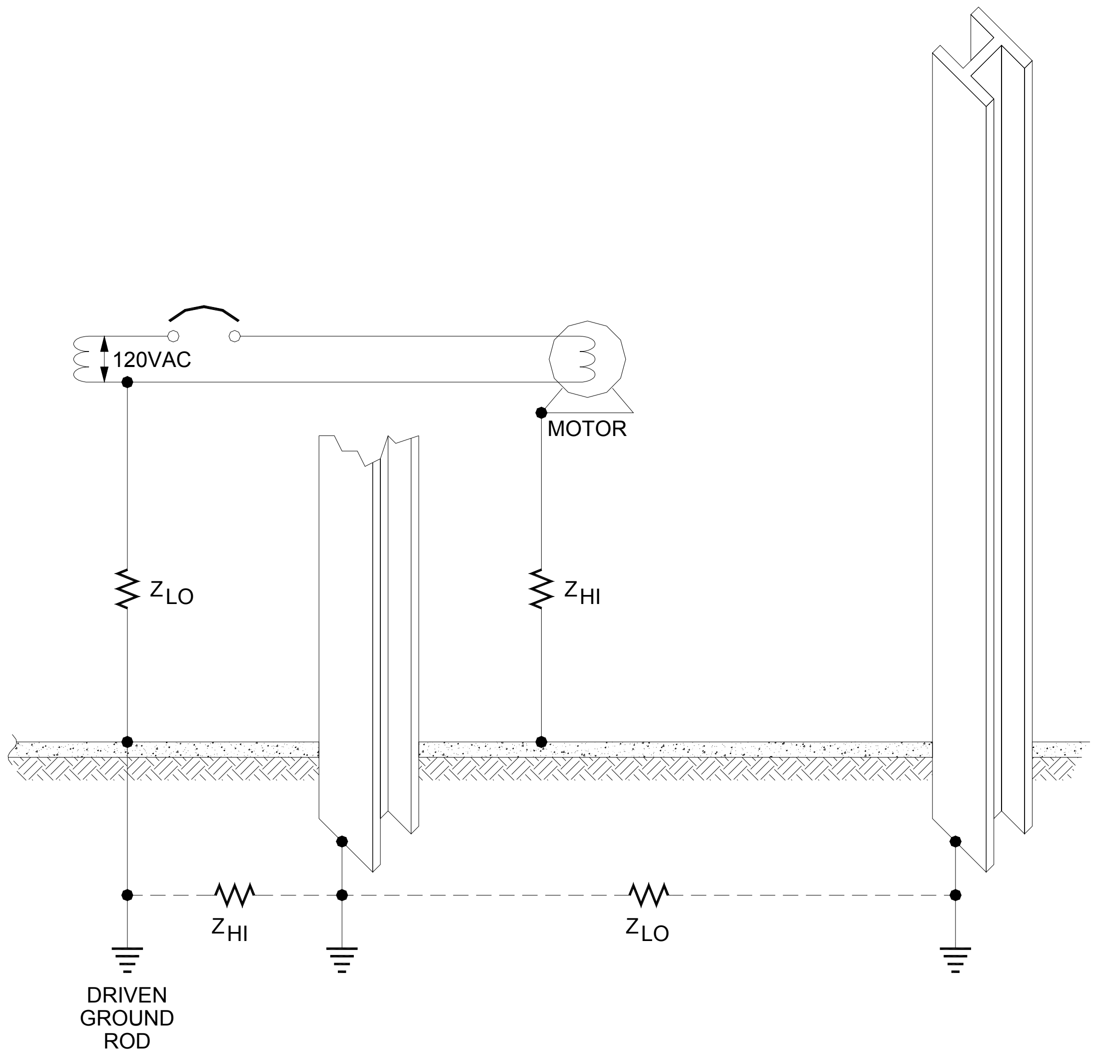
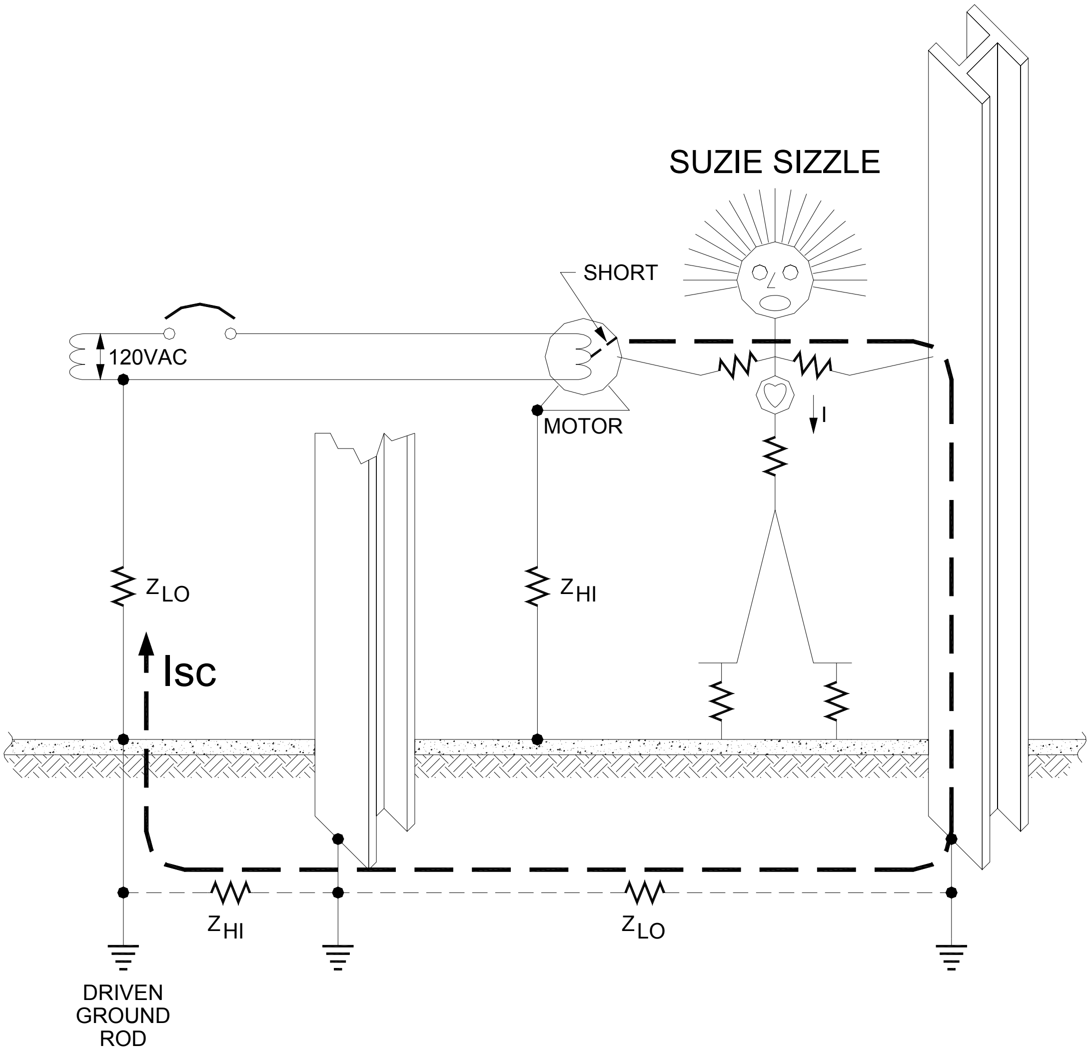

250
200
150
100
50
0
Current (Amps)
0
5
10
15
20
25
30
Resistance (Ohms)
120 VAC
Light Bulbs
500W=4.2 Amps
100W=0.8 Amps
6W=0.05 Amps
15 A Load
500 W Light

Figure 7



~ FIGURE 8 ~

SHOCK006



~ FIGURE 9 ~

SHOCK007

For the protective device to function, the short has to be at a sufficient current for a sufficient amount of time to be detected. For a 15 amp. protective device, this takes more than 15 amps of short circuit current. Figure 6 shows the time-current characteristics of a typical fuse. The left-most curve is for a 15-amp fuse. For the 15 amp fuse to open and clear the fault it requires a 100 amp short for 0.2 seconds, a 70 amp short for 10 seconds, or 20 amp short for 1000 seconds. An arcing circuit can be producing copper globules for a long time and not open the fuse. Figure 7 further illustrates the point.

The moral of this story is that overcurrent protection mainly protects against overloads and some types of short circuits. No matter how good an overcurrent protection system is, it won't always work. Since most short circuits progress into a phase-to-ground fault, ground fault protection has been the only system which will provide additional protection. A new device has just been introduced which will be required for bedroom circuits after the next edition on the National Electrical Code. This new device is the Arc-Fault Circuit Protector (AFCP). If this device proves out to work as advertised, it will greatly eliminate fires. For the next few years the AFCP will only be available in 15 and 20 amp sizes. This new device still requires grounding to be right. Thus, if grounding is not right, the protection system will not always work.

The Ground:

The word ground, as stated above, normally refers to connecting a portion of an electrical circuit to earth. There are a number of reasons to do this. First, our facilities and equipment are connected to earth in one manner or another since most materials are conductive to some extent. Also, the earth is fairly conductive under normal conditions.

Whether we like it or not, electrical circuits, nearby conductive materials, and the earth are connected together either intentionally, by accident or by nature through inductive and/or capacitive coupling. As the use of electricity spread after Thomas Edison invented the light bulb, many fires and accidents occurred. It was found that by connecting one point in each electrical circuit to a common reference point, the earth, potential differences between electrical systems could be controlled and electrical systems could be made safe.

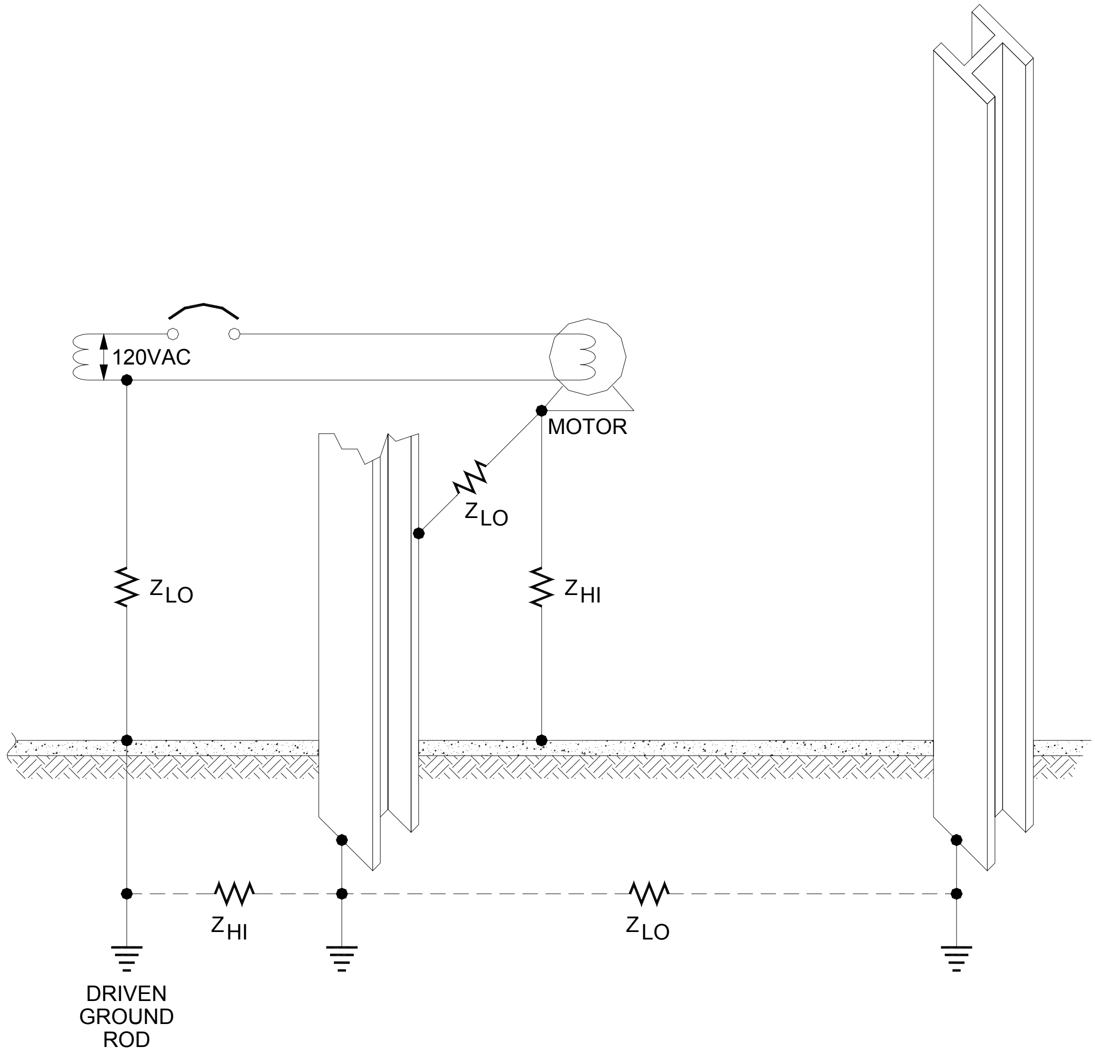
Figure 8 begins to illustrate how electrical systems can be made safe. We have used the example of a simple motor circuit to illustrate the basic principle. It must be understood that there are many ways an electrical system can fail: transformer winding can short out to the transformers case, motor winding can short to the motor housing, wires can short to each other or to their surroundings. Many moving items generate static electricity which must be dealt with. And it goes on and on. In figure 8 the transformer is shown to be connected to the earth through a low impedance connection Z_{LO}. This is an intentional ground which we normally provide, but could also be a high impedance connection. As shown in Figure 8 virtually everything is connected together.

Figure 9 illustrates what happens when a motor winding fails, shorts to its housing, and a person touches the motor housing while in contact with something else which is conductive, the I-beam. Suzie Sizzle becomes part of the circuit. Since impedances are high, the circuit breaker does not open. Figure 10 shows how the motor should have been installed with a ground connection to a steel column. In Figure 11 we again have the motor failure. This time we have Safe Sally.

The short circuit current is conducted away through the low impedance path. In this figure we illustrate another problem that of a high impedance connection between the building steel and the power ground. Sally will still be safe but the motor will fail. Due to the high impedance, the fault current will be low and the circuit breaker will not open. Since a part of the winding is shorted, the motor will overload and will heat up and may even catch fire. The high impedance shown is often what happens when we rely upon the earth to be a low impedance ground, which it's not always. The same situation happens when the transformer has a high impedance connection to earth.

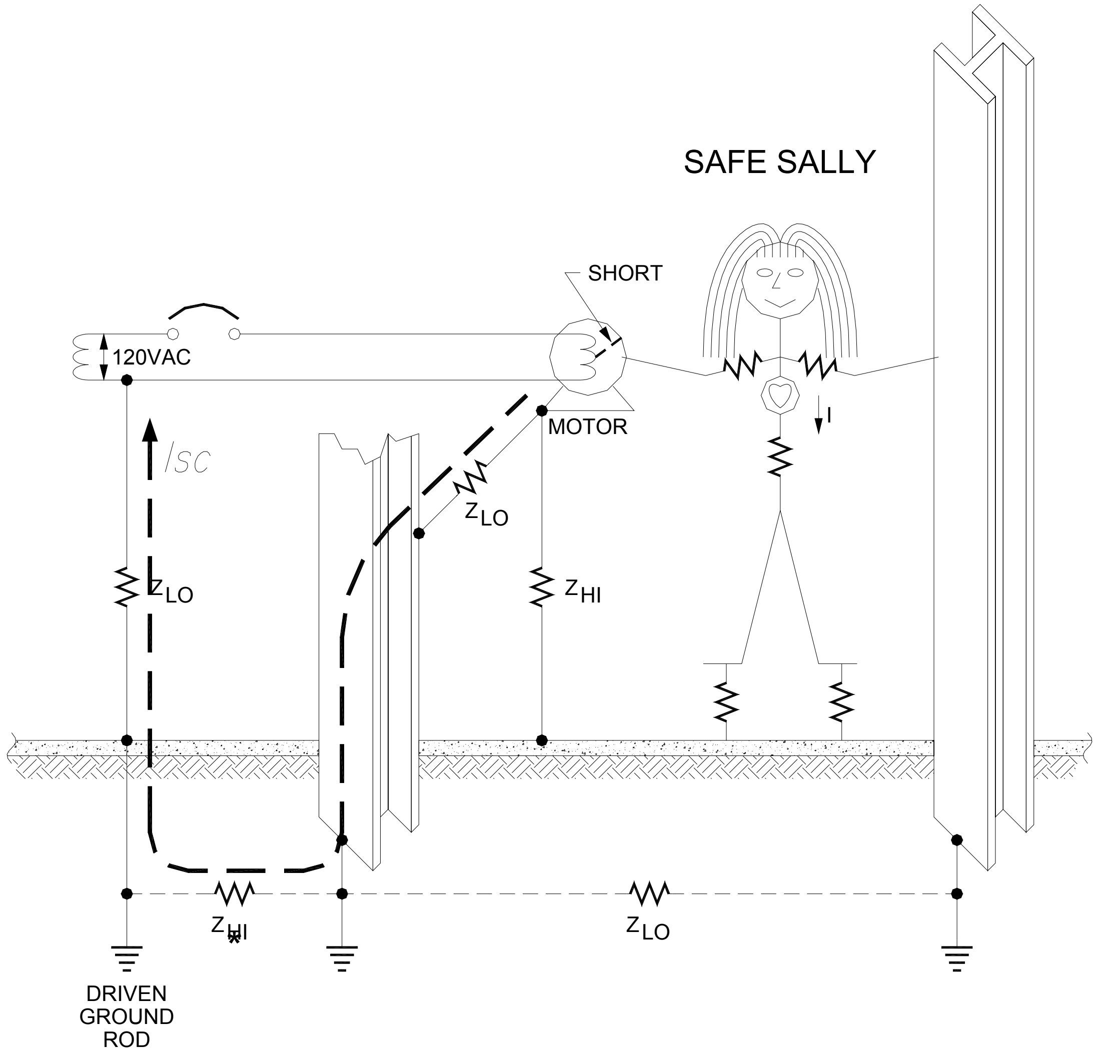
In most installations today, the circuit conductors are run in metal conduits to provide physical protection for the conductors, as shown in Figure 12. Normally the metal conduit is connected to earth and is often bonded to the ground system for the transformer. The motor is normally not directly connected to the metal conduit but rather is connected using a flexible connection that is often made of metal. Figure 13 illustrates what happens when the flexible connection breaks or makes a poor connection, as often happens. Figure 14 shows what happens if we connect the conduit directly to the motor.

Connections break due to vibration and movement of the motor. In Figure 15, two connections are added. First, the transformer is bonded to the building's structural steel. Second, the motor is also bonded to structural steel. In this example, Sally is Safe. Figure 16 shows the use of a bonding jumper and Figure 17 shows running a ground wire with the circuit conductors. Conduit connections, particularly the flexible conduit type, break far too often. The National Electrical Code requires either a bonding jumper around flexible connections to motors or a ground conductor be run with the phase conductors.



~ FIGURE 10 ~

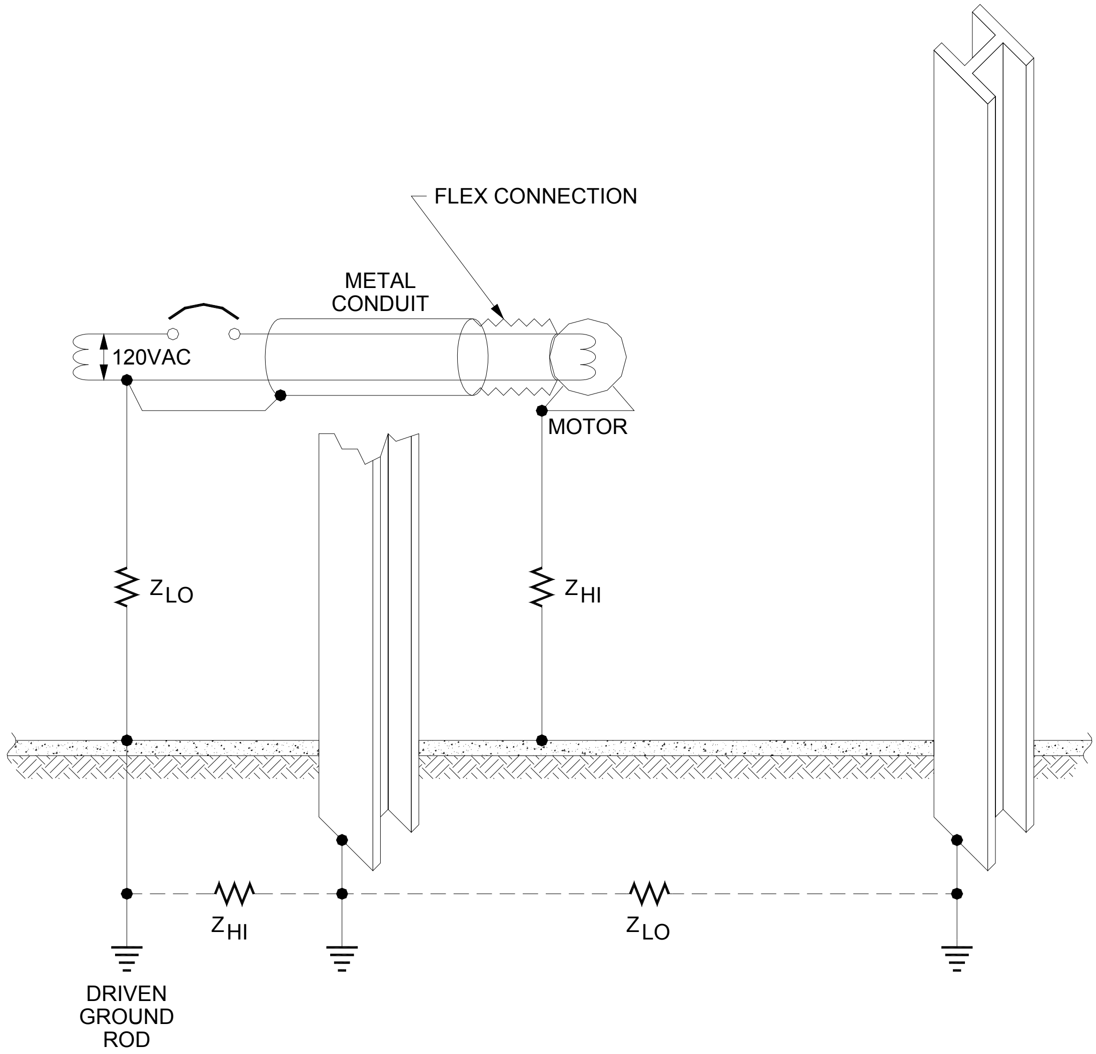
SHOCK008



HIGH EARTH RESISTANCE

~ FIGURE 11 ~

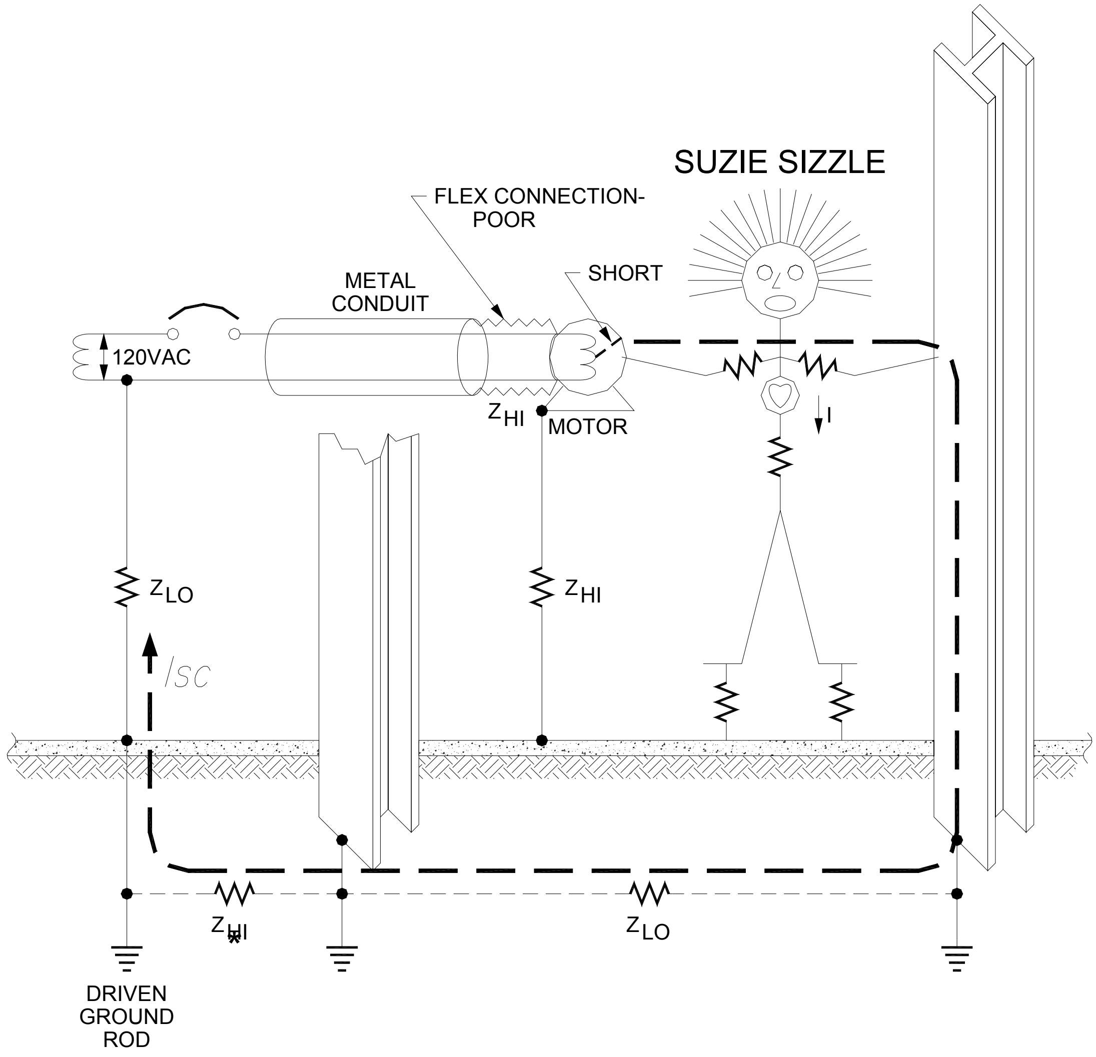
SHOCK009


FLEX CONNECTION
METAL
CONDUIT
120VAC
MOTOR
Z_{LO}
Z_{HI}
Z_{HI}
Z_{LO}
DRIVEN
GROUND
ROD

~ FIGURE 12 ~

SHOCK010

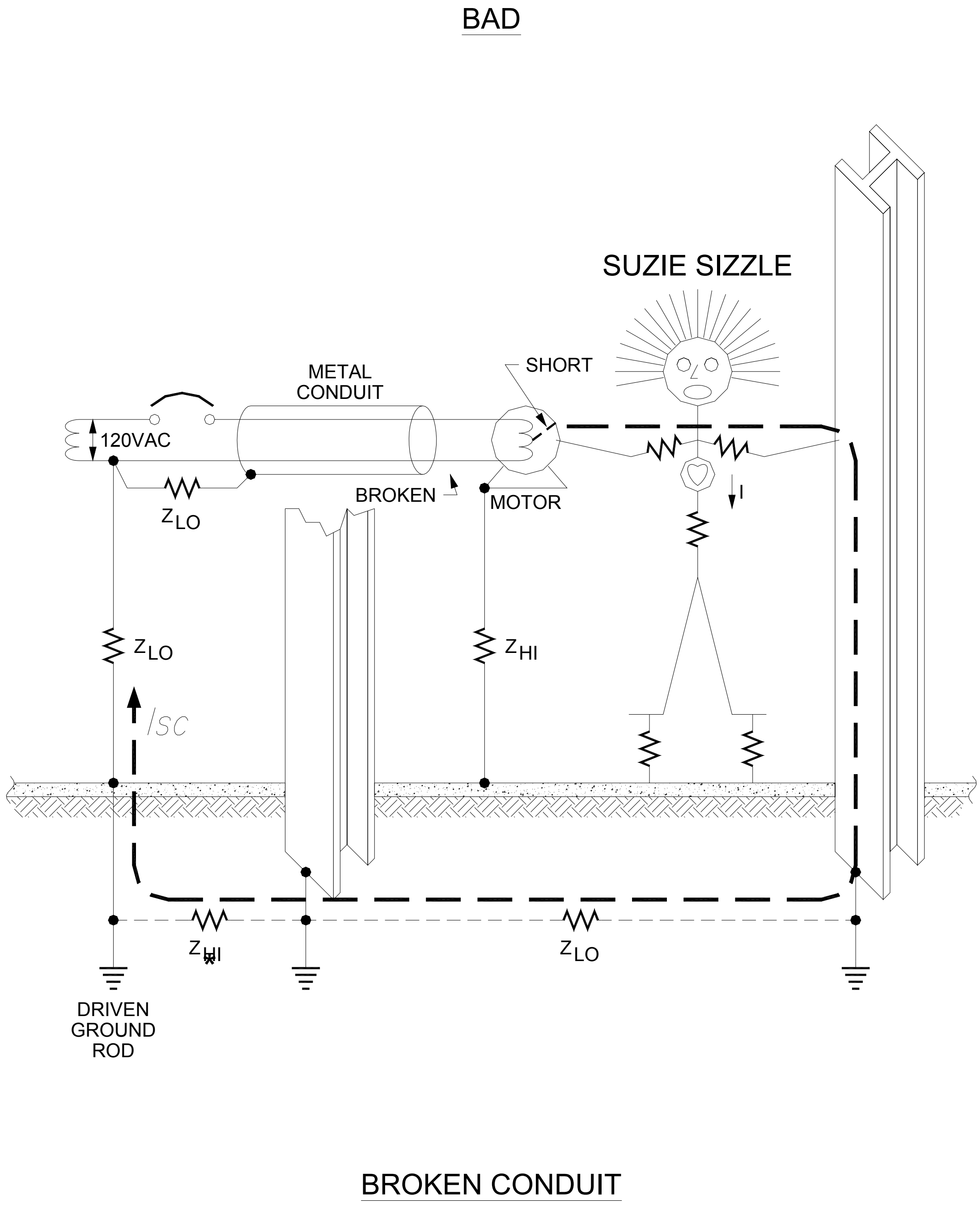
BAD



POOR CONNECTION

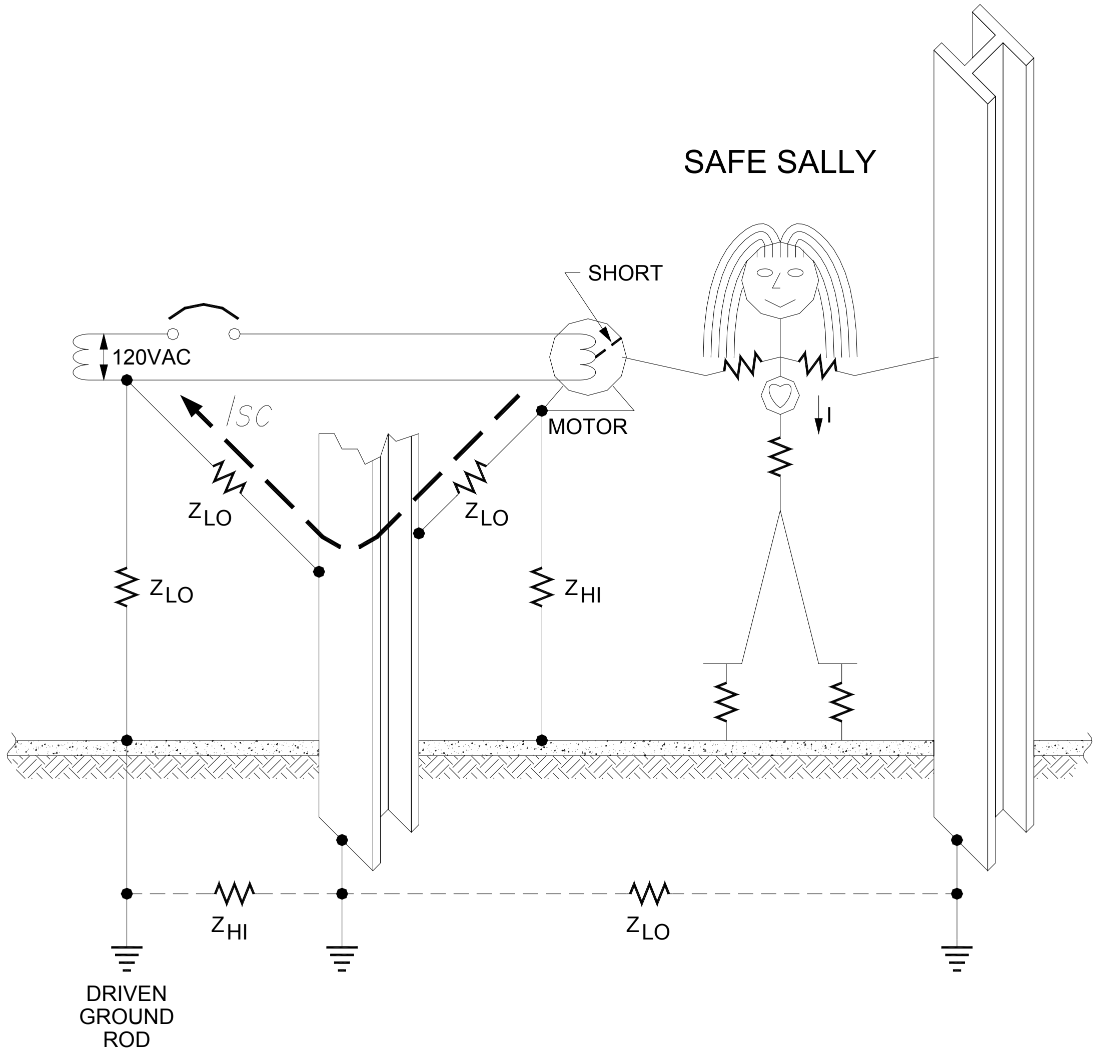
~ FIGURE 13 ~

SHOCK011


BAD
SUZIE SIZZLE
SHORT
METAL
CONDUIT
120VAC
Z LO
BROKEN
MOTOR
I
Z LO
Z HI
I SC
Z HI
Z LO
DRIVEN
GROUND
ROD
BROKEN CONDUIT
SHOCK012

~ FIGURE 14 ~

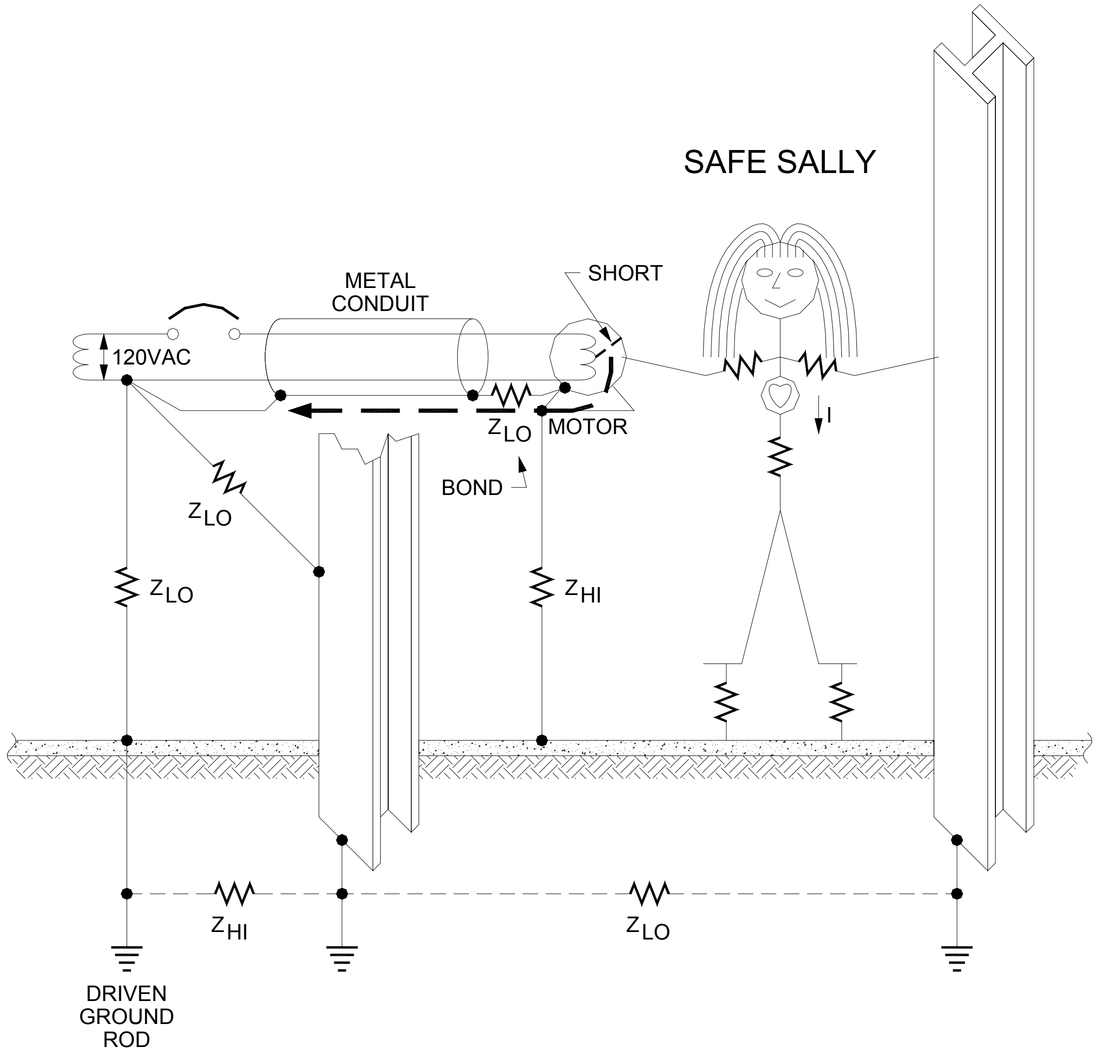
SAFE



LOW 'Z' RETURN
CONNECTION TO BUILDING STEEL

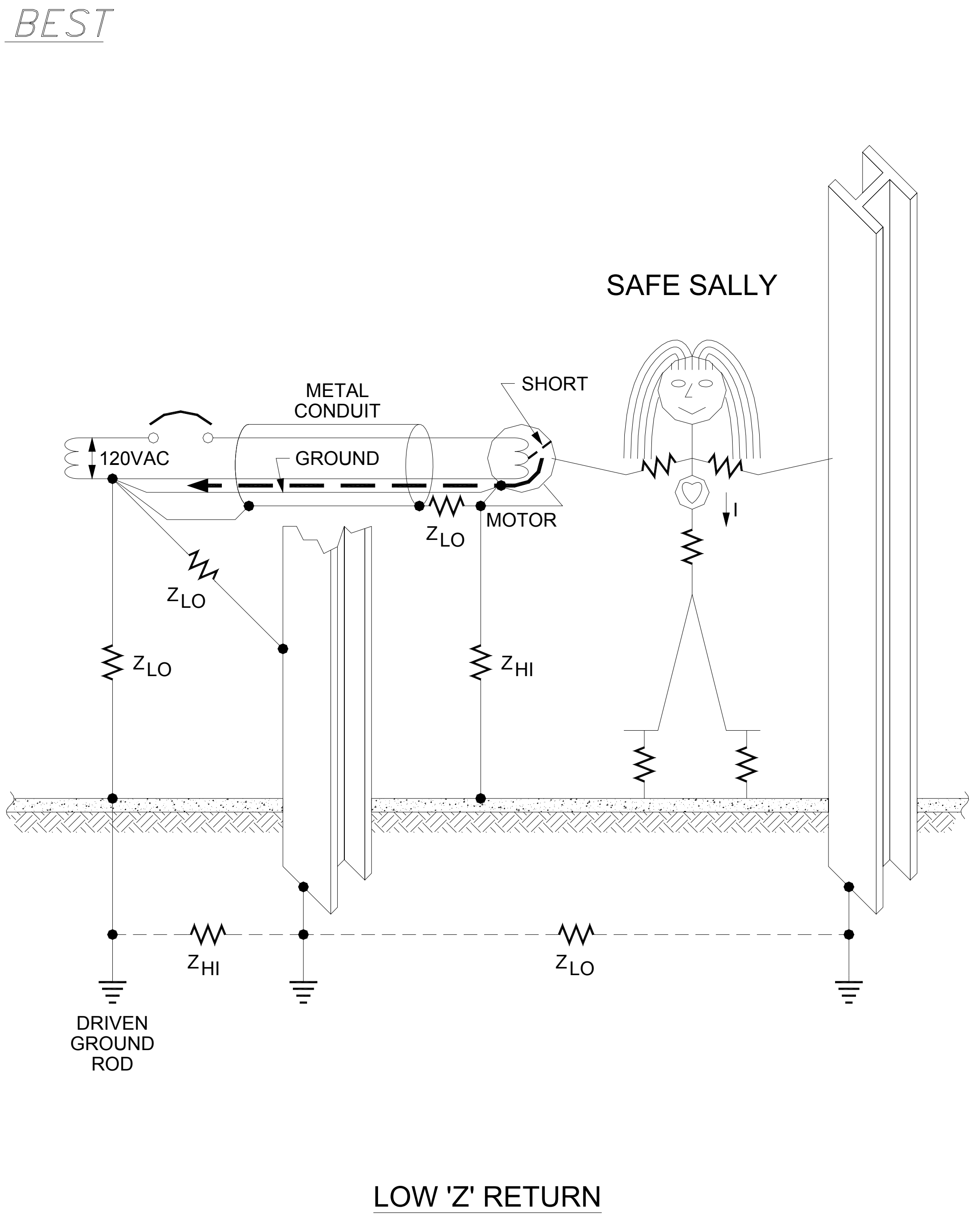
~ FIGURE 15 ~

SHOCK014



LOW 'Z' RETURN

~ FIGURE 16 ~


BEST
SAFE SALLY
METAL CONDUIT
SHORT
120VAC
GROUND
MOTOR
Z LO
Z LO
Z LO
Z HI
I
Z HI
Z LO
DRIVEN GROUND ROD
LOW 'Z' RETURN

~ FIGURE 17 ~

SHOCK016

The Power Source:

The National Electrical Code, Article 250 - “Grounding” dictates which systems are to be grounded and how they are to be grounded. For a ground system to be effective, LOW impedance paths are required. A good low resistance earth connection is important, but more important is a good equipotential plane. That is, all buildings and structures within a facility are bonded together through a low resistance path.

The National Electrical Code requires a LOW Impedance return path. The following sections define the requirements.

Article 110-10:	“Circuit Impedance and Other Characteristics. The overcurrent protective devices, the total impedance, the component short-circuit current ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical components of the circuit. . . . . .”
Article 250 -2(d):	“Performance of Fault Current Path. . . . sufficiently low impedance to facilitate the operation of the overcurrent devices under fault conditions. The earth shall NOT be used as the sole equipment grounding conductor or fault current path.”
Article 250-32(b):	“(b) Grounded Systems . . . (1) Equipment Grounding Conductors. An equipment grounding conductor as described in Section 250-118 shall be run with the supply conductors.....”

Definitions:

Grounded System - “A system of conductors in which at least one conductor or point (usually the middle wire or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through an impedance.”[1] Types of grounded systems: solid grounded, resistance grounded, impedance grounded.

Ungrounded System - “A system, circuit, or apparatus without an intentional connection to ground, except through potential-indicating or measuring device or other very-high-impedance devices.”[2]

Ground - “A conduction connection, whether intentional or accidental, between an electrical

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[1] IEEE Std. 142-1982 (Green Book)

[2] IEEE Std. 142-1982 (Green Book)

circuit or equipment and the earth, or to some conducting body that serves in place of the earth."[3]

Examples - Ground rods, water pipes, ufer grounds, equipotential plane

Grounded Conductor - (Neutral Conductor - White) " A system or circuit that is intentionally grounded."[4]

Grounding Conductor - (Ground - Green) "A conductor used to connect equipment or the grounded conductor of a wiring system to a grounding electrode or electrodes"[5]

Figure 18 shows several methods of grounding the typical three-phase system. For most applications, the transformer's secondary is a wye and is solidly grounded. For large facilities, it is sometimes important to provide a resistive connection to ground or even to use an inductor in this connection. This added resistance or impedance limits the amount of ground fault current on purpose. Normally this type of system also has ground fault monitoring. On occasions the secondary of a transformer is connected in a delta configuration as shown in Figure 19. The ungrounded system is acceptable in certain applications but the system does require continuous supervision.

The National Electrical Code defines how electrical systems are to be grounded. The various methods have changed over the years as experience is gained. Figure 20 shows the basic requirement. This figure shows a number of ways the transformer is grounded. It is important to note that ALL of these ground connections are REQUIRED, not just one connection.

The Single Building:

In illustrating why the National Electrical Code is written the way it is, the best example is a simple single structure or building. In the following illustrations both the single-phase system and the three-phase system are shown. The illustrations show a building with a transformer as its service, a main circuit breaker panel and a sub-panel which are normally some distance away. One of the main points in these figures is the connection between the main panel and the sub-panel which is often misunderstood.

It is important to note that the neutral conductor is intended to carry current, while the ground conductor is NOT intended to carry current except in a fault condition. Figure 21 shows an INCOMPLETE installation. When considering a short circuit, one needs to remember the basic circuit in Figure 2: all short circuit current flows back to the transformer. If this short circuit path has enough resistance, the short circuit current will be reduced and the circuit breaker or fuse may not respond at all or will only respond after a fairly long time. This may result in a fire or electrocution.

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[3] National Electrical Code

[4] National Electrical Code

[5] National Electrical Code

In Figure 21, a ground fault on the load side of the sub-panel will result in current flowing through the earth between the two ground rods. This is not a very effective return path. Figure 22 shows the required installation. Please note that a ground conductor MUST be connected between the two panels and that both panels are bonded to the ground. The neutral conductor must also be run if the system is a single phase system or if there are single-phase loads. Further note that the neutral terminal in the sub-panel is isolated from the panel; this is to keep unwanted currents from flowing through the ground conductor.

Multiple Buildings:

The multiple building or structure system is where most of the problems are found, particularly in older systems. Figure 23 shows examples of systems which are deficient. Again, ground faults in Building 2 MUST find a low impedance path back to the transformer in order for the circuit breaker to open and open fast enough. Figure 24 shows first that both buildings are required to be grounded. Second, that the neutrals in each building are bonded to the building's ground and that the neutrals are tied together between buildings. In Figure 24, the neutral conductors would be carrying current under a phase-to-ground short.

Figure 25 goes one step further, providing a ground conductor between each building. In this case, building no.2's neutral is isolated from ground. For a three-phase system, if there are only three phase loads, then the neutral conductors are not required. If there are single phase loads then BOTH the ground and the neutral conductor are REQUIRED. A very important point, which is often overlooked, is that this ground conductor MUST be run with the phase conductors in their conduit. A ground grid will not suffice. Having the ground conductor run away from the phase conductors will affect the overall impedance of the system and thus will slow down the system's response and possibly keep the circuit protection from opening. The external ground will act like a transformer and thus will add impedance to the circuit. This has been proven through tests.

Figure 26 shows a ground grid system covering the entire facility. This system is very important in establishing an equipotential plane. However, the main and sub-panel still requires a ground conductor run between them.

The Computer:

The grounding of computer systems and electronic systems is a subject all to its own and is not covered here to any extent. Several points are very important to consider. First, a properly installed computer ground system can be installed in full compliance to the National Electrical Code. Providing a separate grounding system for computers which is completely isolated from the power ground is ILLEGAL, dangerous, and is ineffective. Second, when looking at computer grounds, the frequency of signals is important. The resistance of conductors increases greatly as the frequency increases above 60 Hz.

Lighting Protection:

The damage caused by lightning can be very significant. There isn't a high degree of understanding of lightning and more research is needed. Lightning as we all know is of high energy. The lightning stroke has a very fast rise in current and much of what applies to high frequencies also applies to lightning due to the fast rise times.

Figure 27 illustrates what happens during a storm. Clouds travel across the earth's surface. Due to the movement of the moisture in the cloud against the air, electric charges build up. The bottom of the cloud becomes negatively charged while the building beneath the cloud becomes positively charged. The air between the cloud and the building acts as a large capacitor. When the voltage across this capacitor becomes higher that the insulation resistance of the air, a lightning strike occurs and high current begins to flow.

The lightning protection system in actuality is a lightning attractor. The lightning protection systems are metal rods which are connected to earth and are installed at the highest points of buildings. As a storm approaches as shown in Figure 28, a charged cloud moves across the earth, likewise a positive charge mass moves through the ground. When the gap between the two charges is reduced, such as when it passes over a building, you have as lightning strike. What the lightning protection system does is to short circuit these two charges in a controlled manner. The sharp pointed lightning rod, called an air terminal, emits charges. The idea is to dissipate as much of the charge as possible before the charge builds to the point where a very high energy lightning strike can occur.

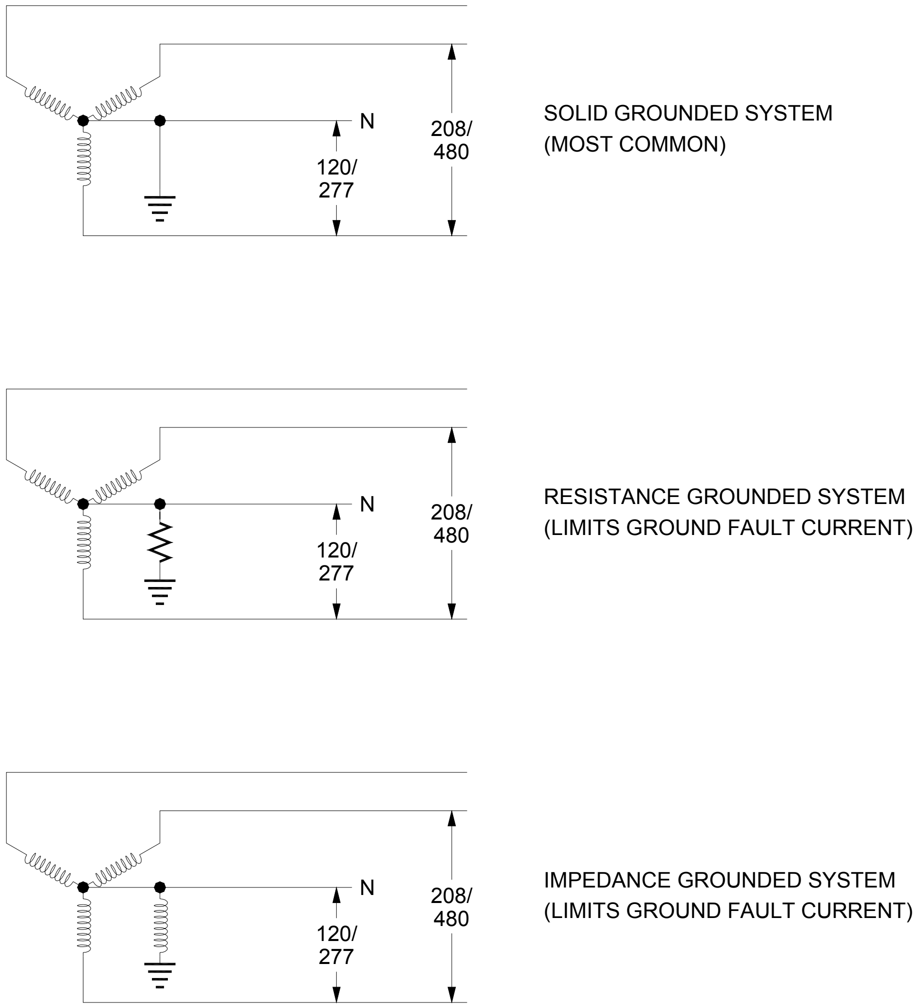
Another important fact is understanding the importance of this traveling charge mass. This charge mass produces a potential difference between interconnected buildings. Under normal conditions there is minimal potential difference between buildings. However, under storm conditions, this difference can increase to 50Kv which can damage interconnected equipment and conductor insulation. To protect against this kind of problem, all buildings must be connected together.

Many facilities rely upon the earth to interconnect buildings, however the earth's resistance varies greatly. One important factor in the earth's resistance is moisture. As more and more areas around buildings are paved over, the earth below drys out and its resistance increases. The interconnecting ground grid shown in Figure 29 forms a ground plane which is parallel to the earth. With this grid, the earth's resistance becomes less important. What is formed is an equipotential plane which reduces the earth's resistance and minimizes the potential difference between buildings.

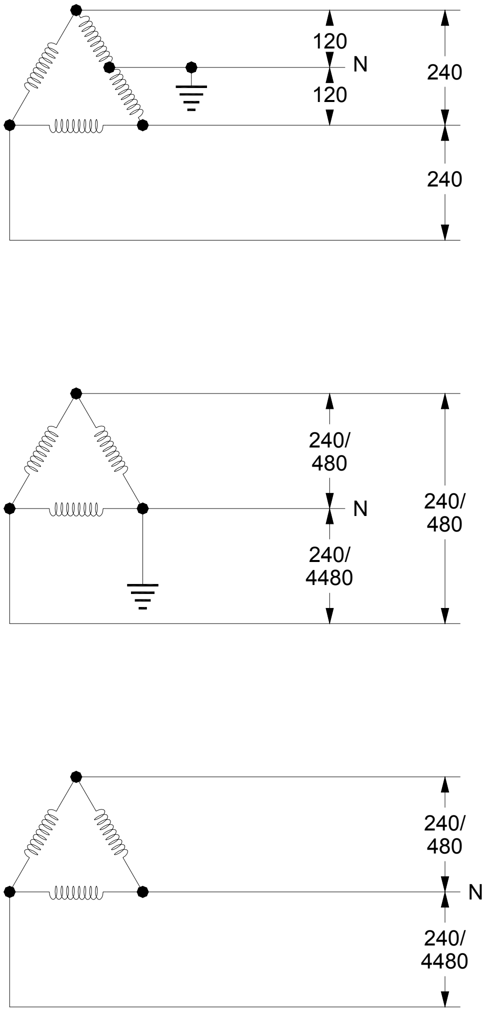
Mistakes in installing a lightning protection system can be serious and can do more harm then no system at all.

An IMPROPER Lightning Protection System will:
  A. Increase the potential of a lightning strike
  B. Can cause severe damage to property and injury to personnel

A PROPER Lightning Protection System will:
  A. Dissipate charge buildup - reducing the likelihood of a strike
  B. Control the flow of the strike's current away from key electrical systems


N
208/
480
120/
277
SOLID GROUNDED SYSTEM
(MOST COMMON)
N
208/
480
120/
277
RESISTANCE GROUNDED SYSTEM
(LIMITS GROUND FAULT CURRENT)
N
208/
480
120/
277
IMPEDANCE GROUNDED SYSTEM
(LIMITS GROUND FAULT CURRENT)
SHOCK024

~ FIGURE 18 ~

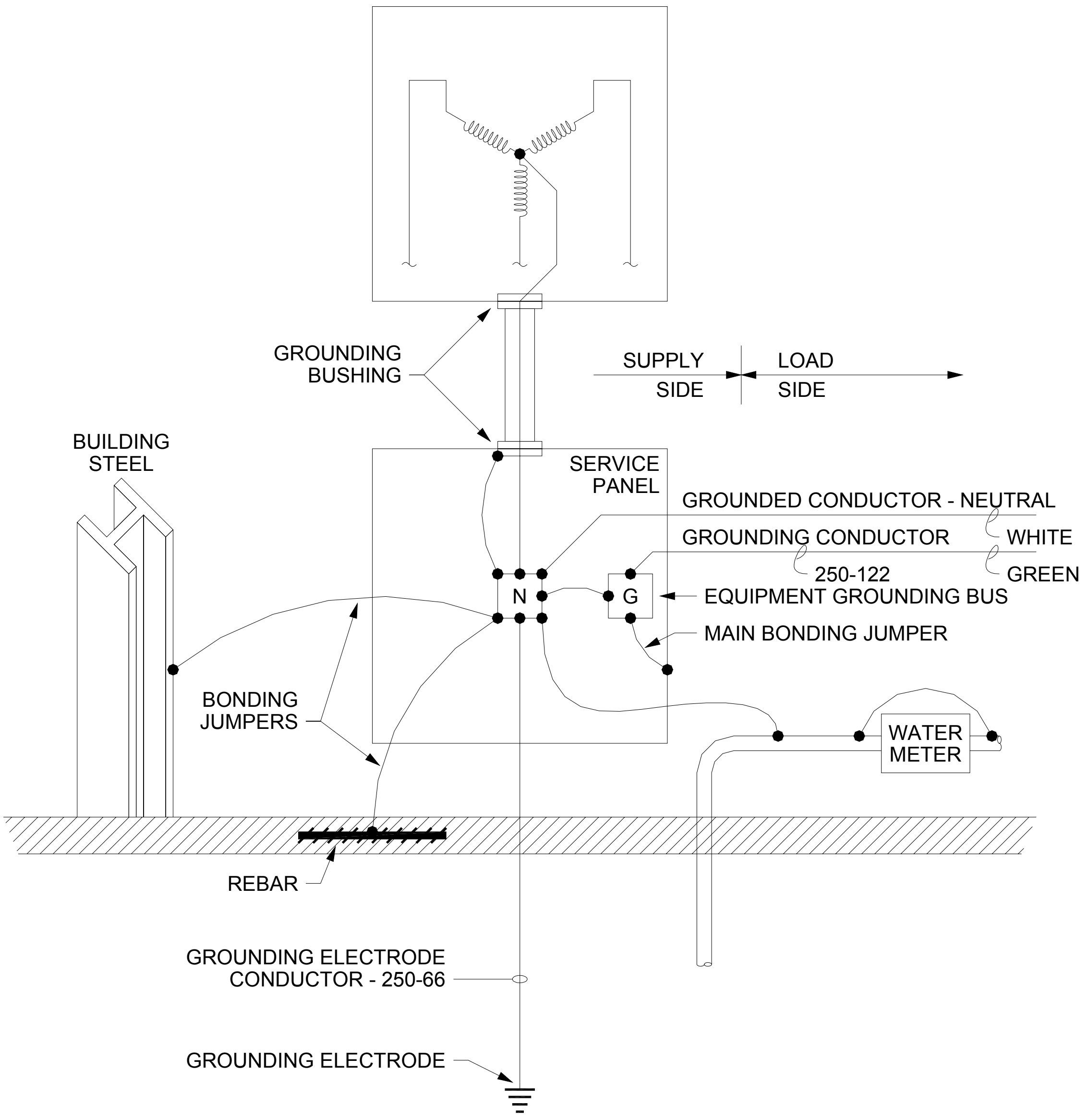


UNGROUNDED SYSTEM
(LIMITED APPLICATION-
MUST BE SUPERVISED)

~ FIGURE 19 ~

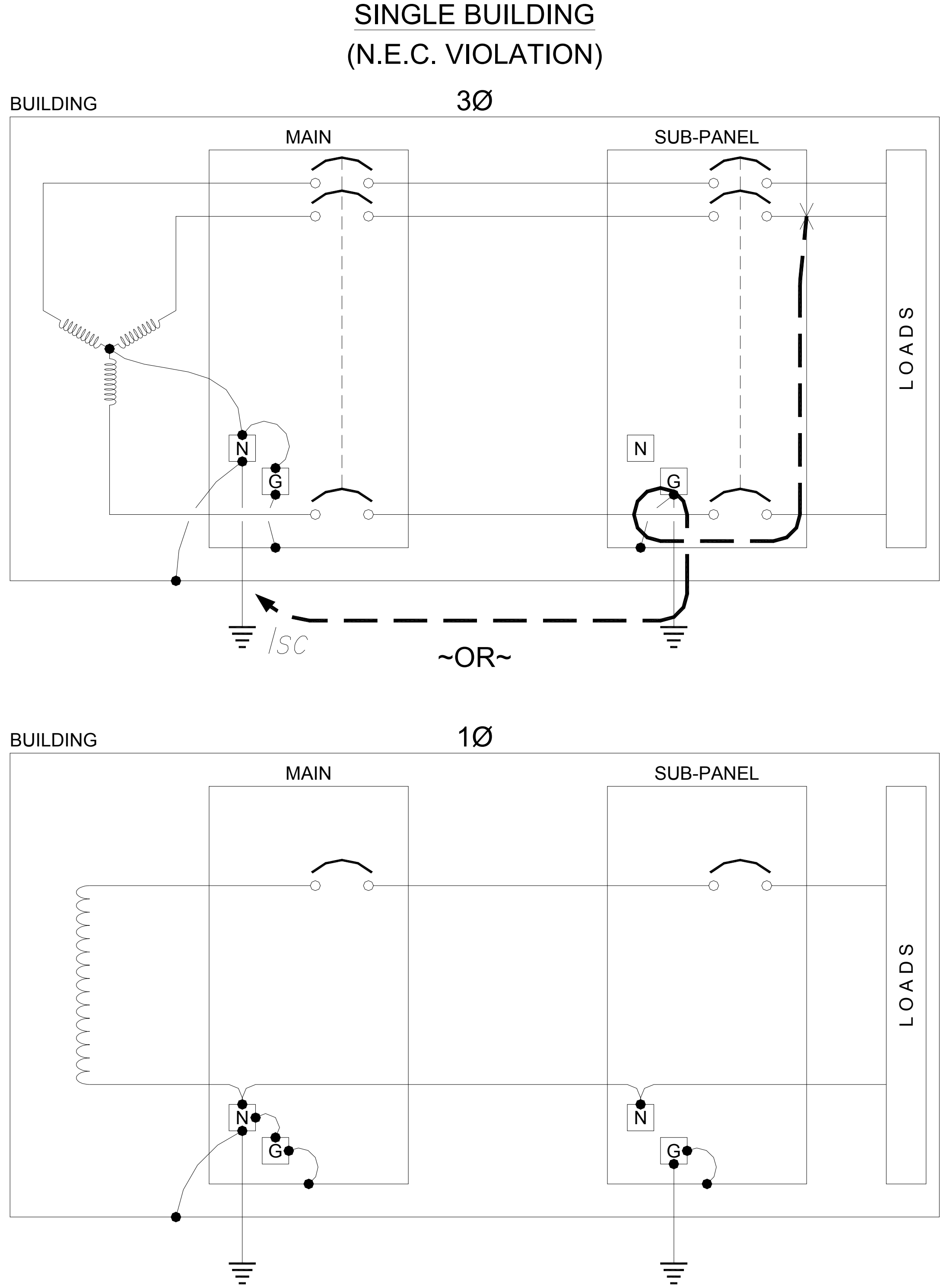
SHOCK025

GROUNDING ELECTRODE SYSTEM
N.E.C. 250-50



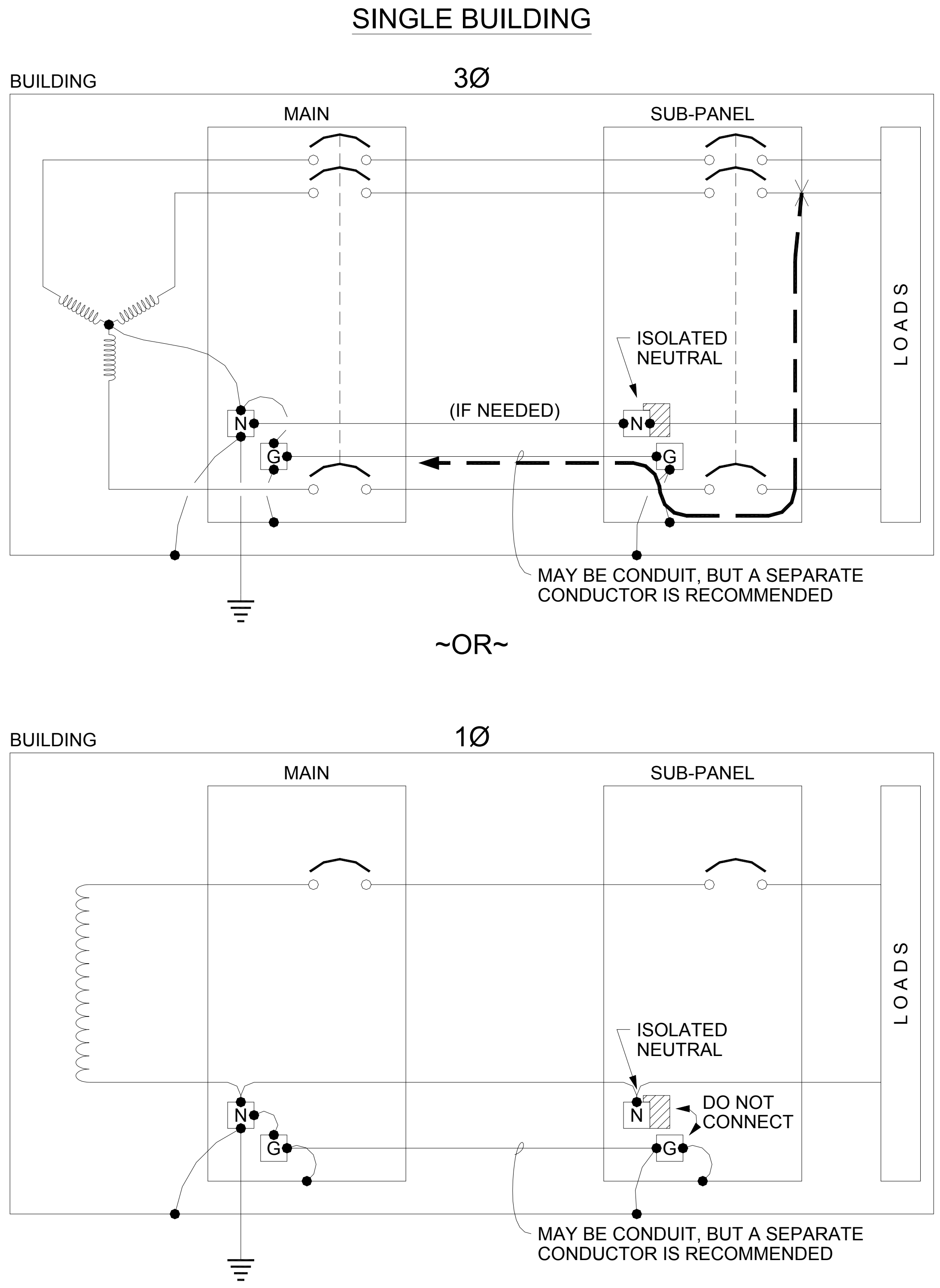
~ FIGURE 20 ~

SHOCK023

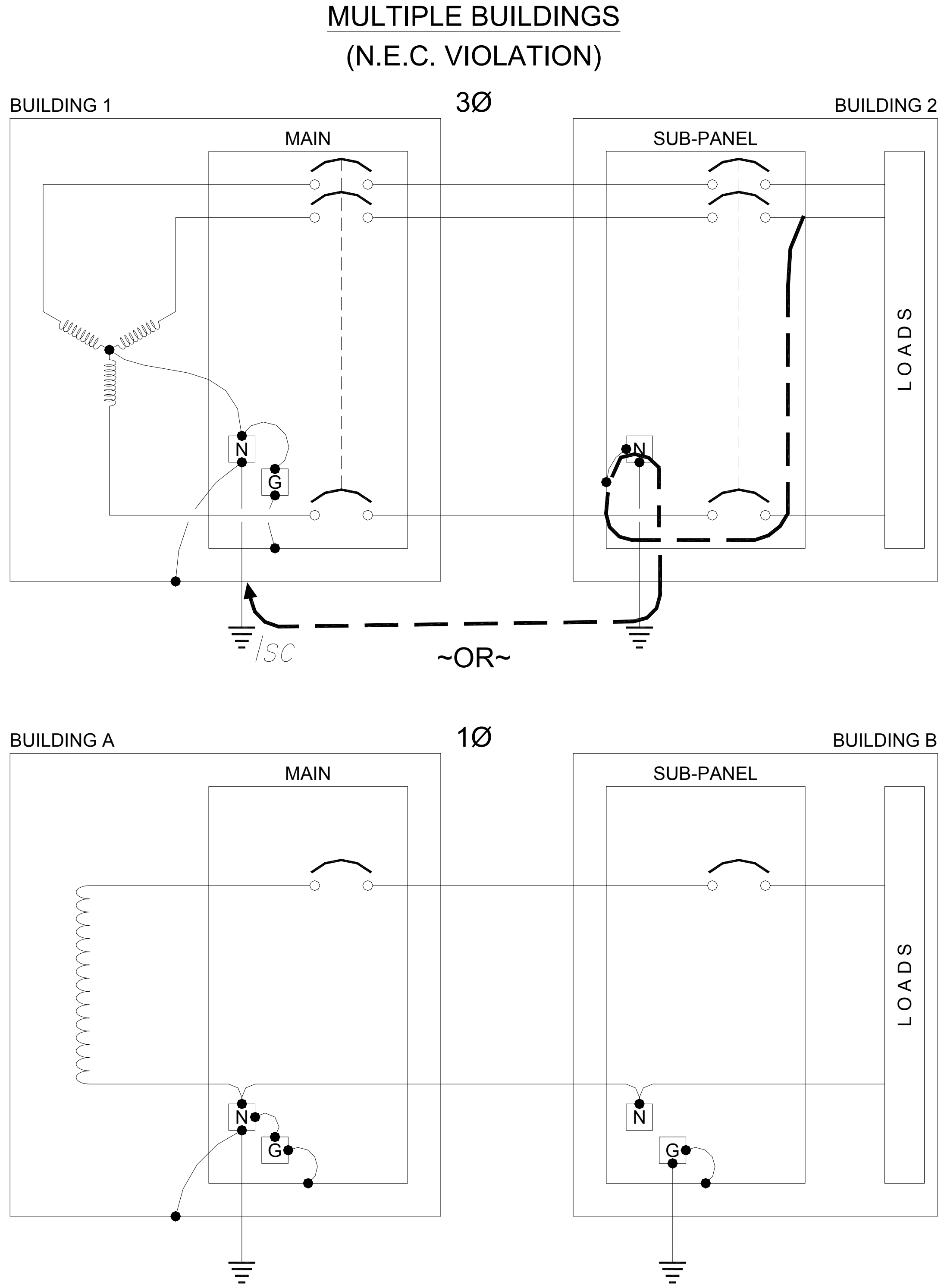

SINGLE BUILDING
(N.E.C. VIOLATION)
BUILDING
3Ø
MAIN
SUB-PANEL
LOADS
N
G
N
G
Isc
~OR~
BUILDING
1Ø
MAIN
SUB-PANEL
LOADS
N
G
N
G

~ FIGURE 21 ~

SHOCK004


SINGLE BUILDING
BUILDING
3Ø
MAIN
SUB-PANEL
LOADS
ISOLATED
NEUTRAL
(IF NEEDED)
N
G
N
G
MAY BE CONDUIT, BUT A SEPARATE
CONDUCTOR IS RECOMMENDED
~OR~
BUILDING
1Ø
MAIN
SUB-PANEL
LOADS
ISOLATED
NEUTRAL
DO NOT
CONNECT
N
G
N
G
MAY BE CONDUIT, BUT A SEPARATE
CONDUCTOR IS RECOMMENDED
SHOCK021

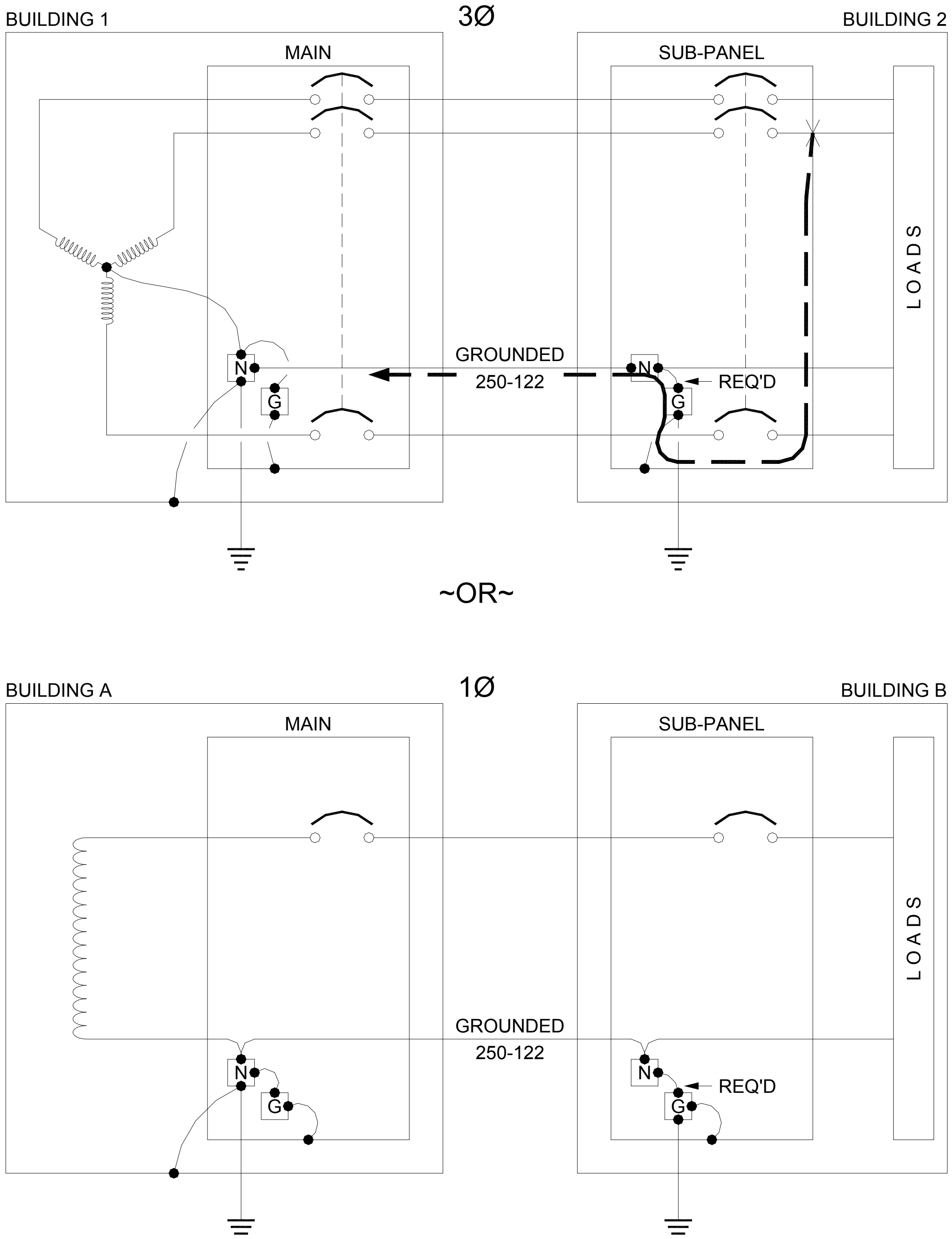
~ FIGURE 22 ~


MULTIPLE BUILDINGS
(N.E.C. VIOLATION)
BUILDING 1
3Ø
BUILDING 2
MAIN
SUB-PANEL
LOADS
N
G
N
ISC
~OR~
BUILDING A
1Ø
BUILDING B
MAIN
SUB-PANEL
LOADS
N
G
N
G

~ FIGURE 23 ~

SHOCK005

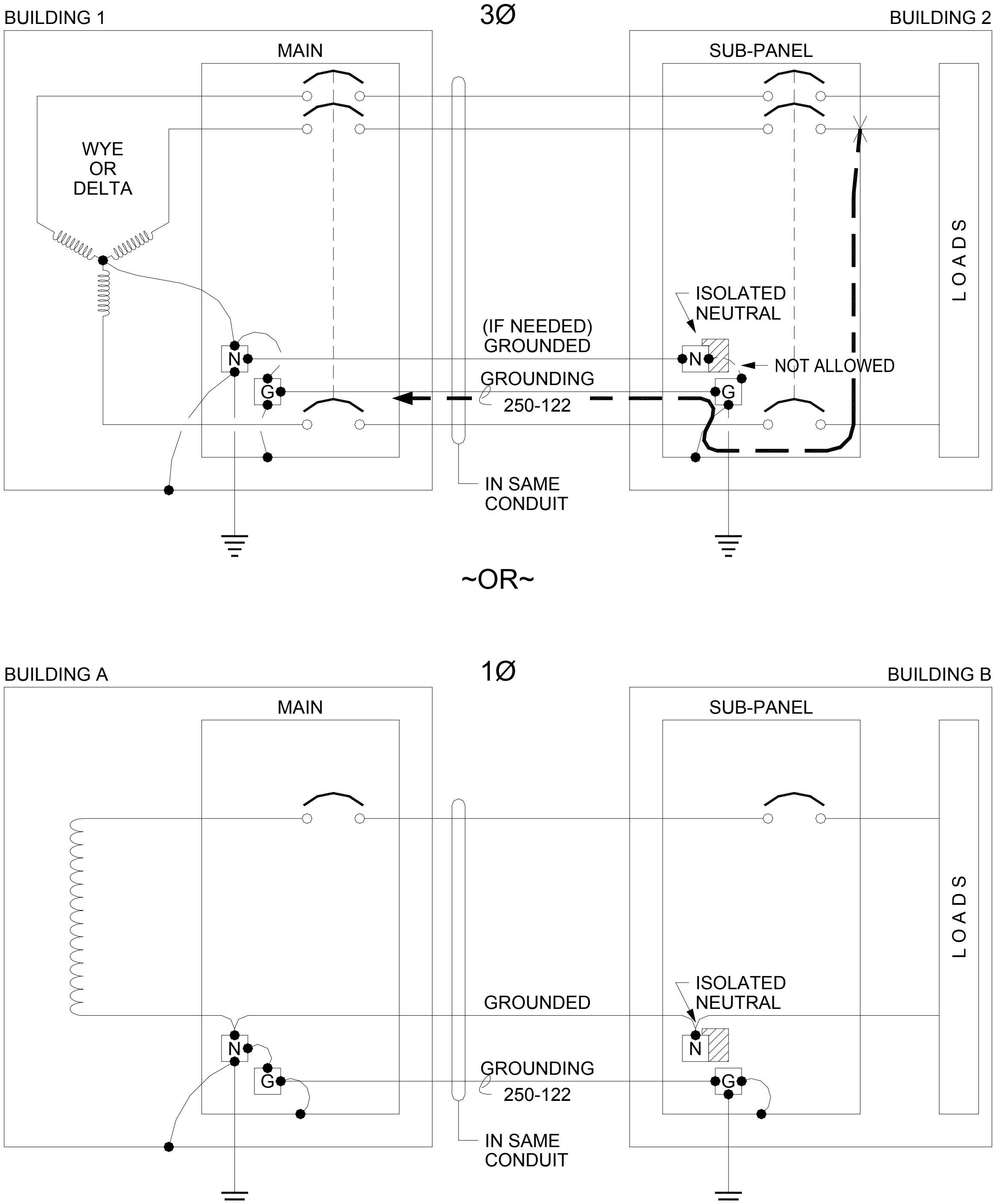
MULTIPLE BUILDINGS



N.E.C. 250-32

~ FIGURE 24 ~

MULTIPLE BUILDINGS

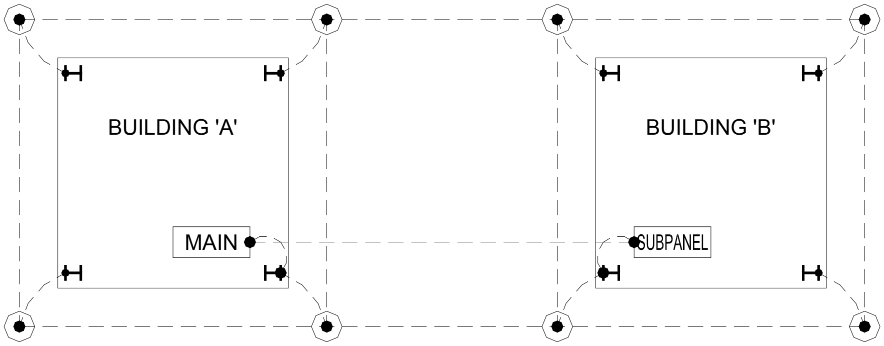


N.E.C. 250-32

~ FIGURE 25 ~

SHOCK027

FACILITY GROUND SYSTEM

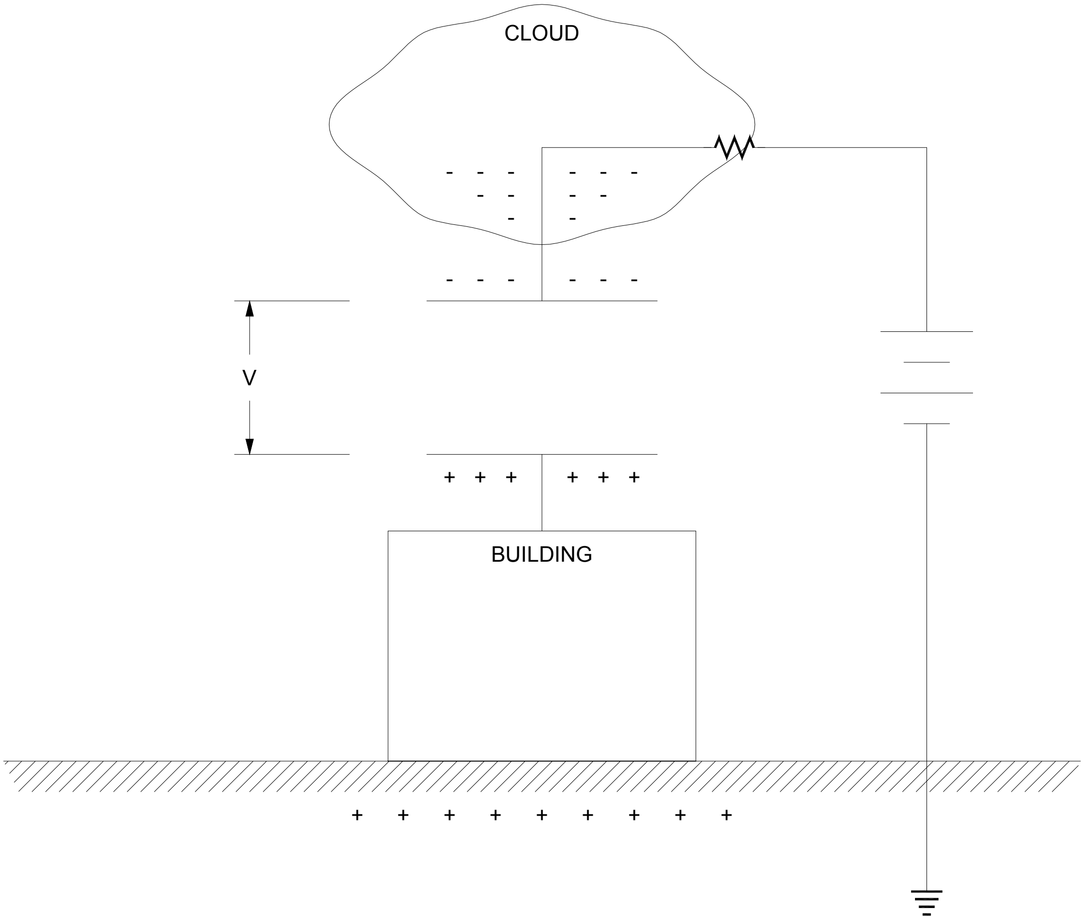


VERY GOOD IN ELIMINATING PROBLEMS
CAUSED BY LIGHTNING, BUT THIS
GROUND GRID WILL NOT ELIMINATE
THE NEED FOR A GROUNDING CONDUCTOR
BEING RUN WITH PHASE CONDUCTORS

N.E.C. 250-32

~ FIGURE 26 ~

SHOCK030



WHEN THE VOLTAGE 'V' BUILDS
TO THE POINT WHERE IT EXCEEDS
THE AIR'S INSULATION VALUE,
YOU HAVE LIGHTNING

~ FIGURE 27 ~

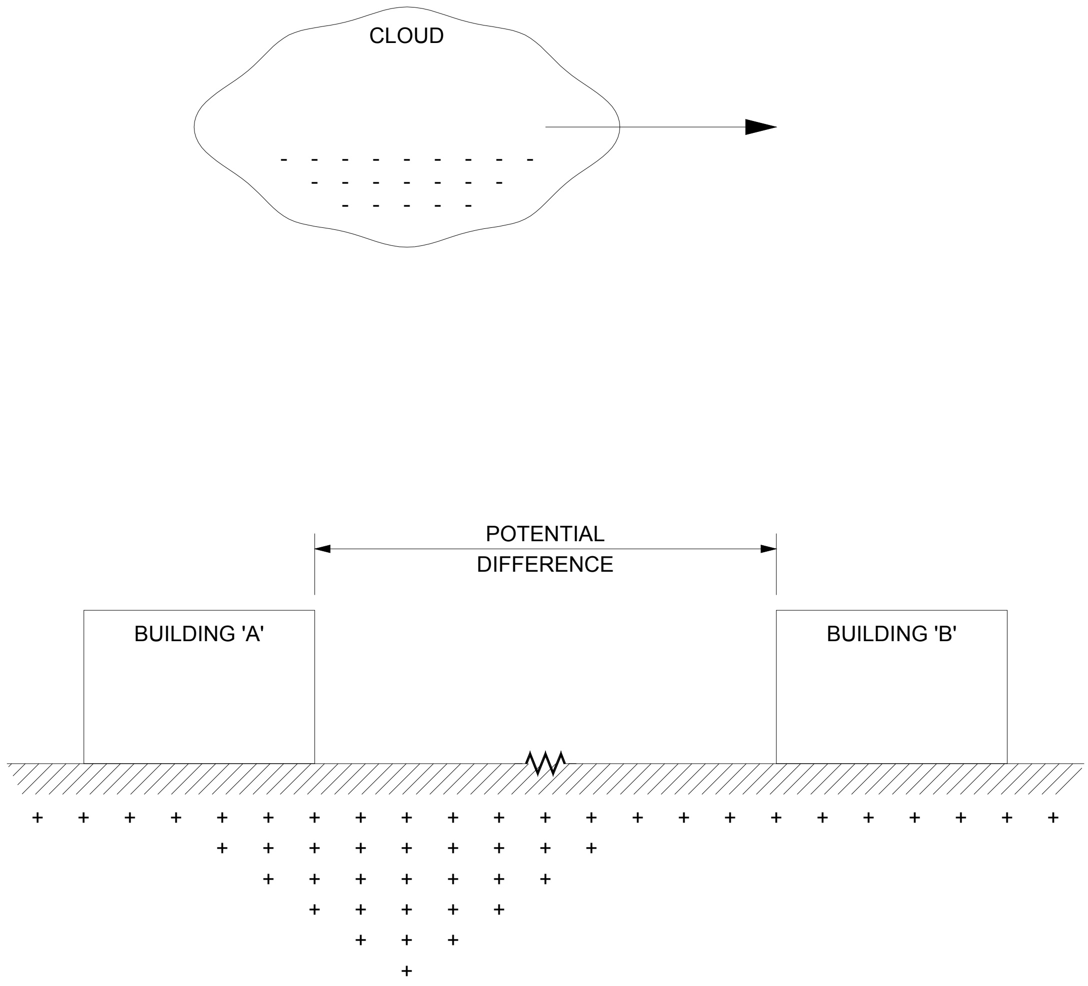
SHOCK028

Static Electricity Control:

This is another subject which requires in-depth study. We will only touch on one point which has begun to show up. For years most concrete floors were strengthened with the addition of a wire mesh in the concrete. Over about the past ten years the construction methods for many floors, especially those required to support relatively light loads, has changed. This wire mesh has been left out as a cost savings. Recently, it has been found that this wire mesh had a second benefit and its elimination is causing problems.

During an investigation of several stores which had a static electricity problem, it was determined that the stores were built without this wire mesh and that the stores were installed in an area where there was a lot of subsurface rock. Basically, the stores were installed on rock. Through the comparison of multiple stores of the same size, design, and age it was determined that the wire mesh was the culprit. Stores which have ten to twenty feet of earth below the floor slab had no problem with static electricity even though the wire mesh had been eliminated. The stores which had the wire mesh and were sitting on the rock had no problem. Only the stores which were sitting on rock and did not have the wire mesh had the problem.

All concrete has some amount of electrical resistance and the floor becomes a ground plane. The wire mesh reduced the concrete's resistance enough to discharge any buildup of charge as a person walked though the store. Figure 30 shows how floors should be designed in areas where the soil conditions are poor.

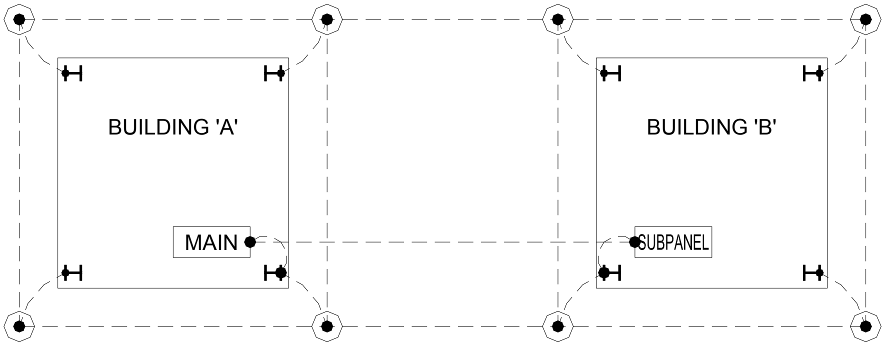


AS A STORM CLOUD MOVES,
THE EARTH'S CHARGE TRAVELS WITH IT

~ FIGURE 28 ~

SHOCK029

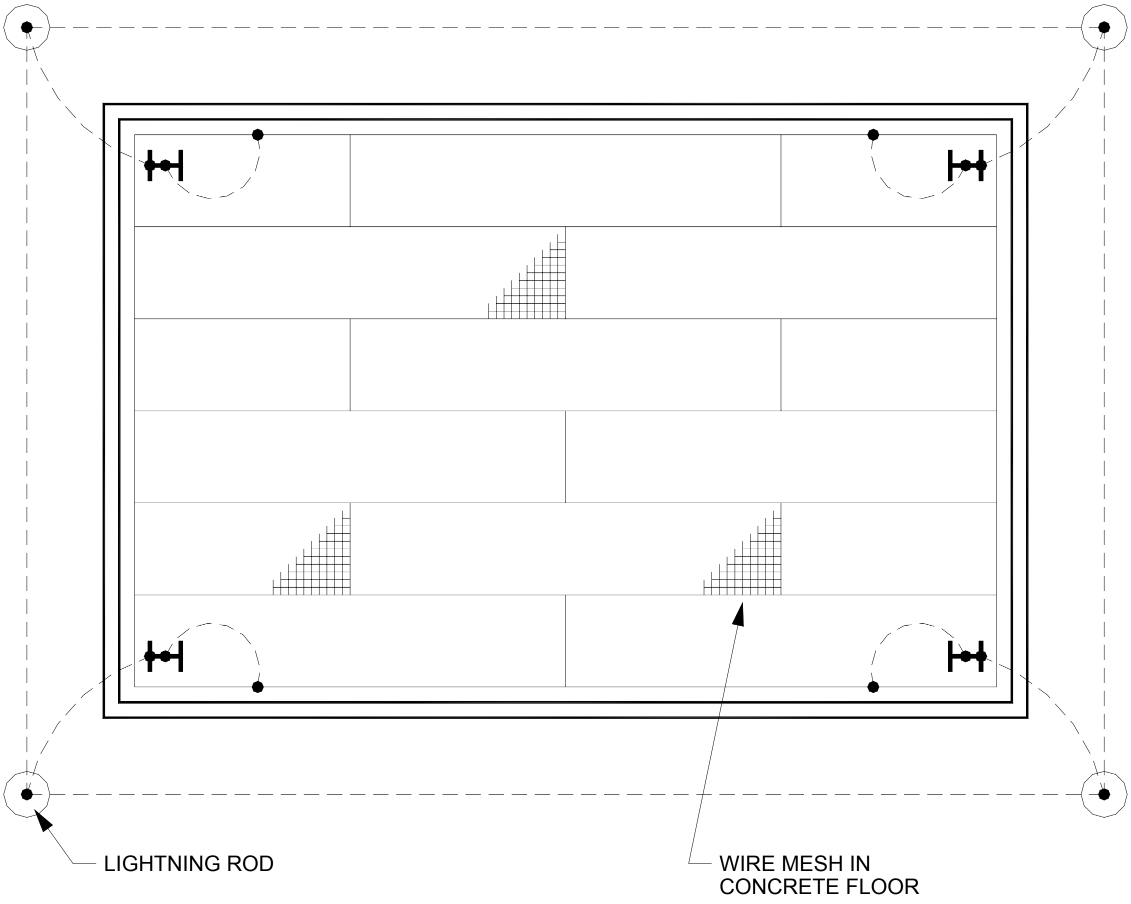
FACILITY GROUND SYSTEM



THE GROUND GRID FORMS AN EQUIPOTENTIAL PLANE WHICH REDUCES EARTH RESISTANCE AND MINIMIZES POTENTIAL DIFFERENCES BETWEEN BUILDINGS

~ FIGURE 29 ~

SHOCK031



STATIC ELECTRICITY CONTROL

~ FIGURE 30 ~

SHOCK032

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Grounding Electrical Distribution Systems for Safety, By Eustace C. Soares, 1966
Lightning Protection Code NFPA 780

Installation Requirements for Lightning Protection Systems UL96A

Biography

John C. Pfeiffer, P.E., president of Pfeiffer Engineering Co., Inc., Louisville, Kentucky has a B.S. of E.E. from Christian Brothers University, Memphis, Tennessee. Mr. Pfeiffer has more than 30 years experience in the design, installation and startup of chemical facilities particularly their electrical systems. Experience covers power systems, lightning protection, surge protection, computer grounding systems, process instrumentation and controls, computer-based control systems and plant network systems. In addition, he has 20 years experience in the investigation of various types of accidents, particularly fires. Through the investigation of accidents, insight has been gained into what leads to accidents.

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