Electrical Failure Analysis

for fire & incident investigations

Lightning Excerpts

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PREFACE

0.1 OVERVIEW

The book is structured for anyone working in the failure analysis industry. The course is particularly designed for individuals that encounter electrical systems in the process of incident investigations. This includes engineers, technicians, investigators, insurance, legal, supervisors, and staff. There is enough technical information that any investigator will benefit from the material, illustrations, and explanations.

The book is not intended to make the user an electrical expert, but to broaden the investigator's insight into electrical systems.

There are over 400 illustarations. The majority are photos of actual incidents we have investigated. Other photos are of events we have created in our research and are used as illustrations and aids. There are numerous diagrams to document the discussion.

The book has purposefully limited the use of equations and math to make it more accessible. That does not limit the technical value and discussion. Only one chapter on Energy Transport is heavily structured with math to illustrate the thermodynamic engineering principles. That material can be bypassed by non-engineers.

At the completion of the book and short course, the participant will understand the components of and know how to look at failures, particularly as related to electrical. This investigation will involve considerations of the Codes and Standards. As members of several Standards organizations, we can assure you that issues addressed in these references are only there because someone had a problem. The discussion will further involve the relationship between investigators, engineers, and legal, as well as the role of public and private sector processes.

In addition to a book structured for electrical failures, there are hands-on components and illustrations. There are numerous plates of electrical failures that we have created in our research. The creation assures the analysis and description is appropriate.

A field exercise will be conducted to see actual equipment and failures. There will be problem solving individually and with a team.

The book has hundreds of color photographs. However, printing cost of color is expensive.

Bring your computer. The entire book, in color, can be downloaded for personal access during discussions.

Enjoy and good learning!

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CHAPTER 1 - FUNDAMENTALS

1.1 INTRODUCTION

Electrical power is the primary form of energy in residences and business. It is commonly used, but its functions are seldom considered. Electrical systems receive very little attention in proportion to their impact; moreover, most operations are critically dependent on electrical energy. Whether for lighting, heating, motors, computers or environmental systems, electricity has become the most used and flexible energy form.

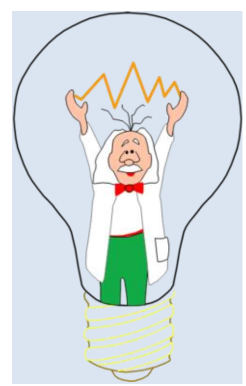
$
universal engineering symbol

The major reasons that study of electrical system is shunned are three fold. The first reason is fear of the perceived hazards associated with electricity. The second obstacle is a lack of understanding of the fundamental theory. The third hurdle is the fact that electrical concepts must be explained by nebulous models. Electricity defies the normal senses. One cannot *see*, *hear*, *taste*, *smell*, or *touch* electricity without significant hazard.

Hear no evil, See no evil, Speak no evil

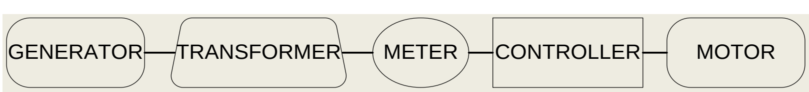
A good grasp and working knowledge of the electrical fundamentals can, nevertheless, be obtained without being a graduate electrical engineer. This book is presented in a form designed to assist future quick reference, as well as to provide a background for understanding electrical phenomena.

Electricity is a convenient form to transfer energy. Seldom is electrical energy generated and used directly. On the contrary, electrical systems convert an available energy source such as gas, coal, hydro, nuclear, wind, or solar to electrical energy. The generated electricity is then conveniently transferred to a load center. The devices at the load center convert the electrical energy back to another useful energy form such as light, heat, or mechanical motion.



Understanding electricity

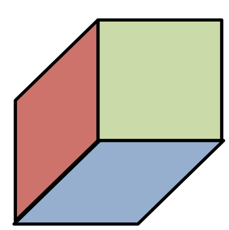
A generic electrical system covers equipment from a generator or power supply through controls to a motor or load.



This book does not specifically address the transmission and distribution of electrically energy. Rather, the concepts covered are applied to the top of the power pole to the bottom of the basement. Since every electrical power circuit has the same form, the concepts discussed are applicable to any situation where electric energy is used. The items of discussion will be basic terminology, application, and failure considerations.

$, t, quality
engineering trade-offs

In addition to technology, the design and installation of any electrical system must consider three major items - safety, environment, and cost. In the design, manufacture, and installation of any item there are trade-offs to achieve a particular dollar, time, or quality value. Failures, then, are a result of poor quality, misuse, or abuse of the product.



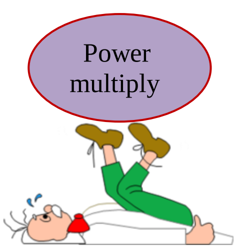
3-D: a triad example

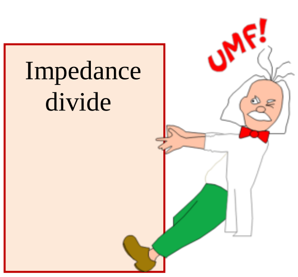
Pressure is like voltage

Flow rate is like current

Parameter	*Symbol*	*Units*	*What*
Voltage	V	Volts	potential
Current	I	Amps	flow rate
Time	t	seconds	duration

3 measures in 1 term





1.2 It's All About 3's

Electrical systems, as all physical systems, operate based on the Trinity or Triad Principle [1] which states:

> *Any item than can be uniquely identified can be further explained by three components.*

The necessary terms for an electrical system can be identified using this grouping of three quantities. If a discussion of a system has either more or fewer items, it is either a combination of unique terms, or an inadequately explained or inadequately defined system.

1.3 Measure

Only three items can be measured in any energy system. All other components are calculated from these. The measured components are *pressure (potential), flow (transfer rate),* and *time.*

It follows, then, that only three items can be measured in an electrical energy system.

Voltage (V) - measured as Volts - is the potential force or pressure in a circuit. It exists whether anything is connected or not. Voltage is measured across, or as the difference between, two points. Voltage is similar to pounds per square inch (psi) on a water line.

Current (I) - measured as Amps - is the rate or quantity of flow through a path. Current can be measured only if a load or fault is connected and operating. The measure for current is an Amp, which is a quantity of electrons per second. Current is similar to gallons per minute on a water line.

Time event (t) - measured in seconds - is the elapsed time between events. The reciprocal of time is the frequency (f), whici is measured in oscillations per second.

The three measurements combine in one term to produce energy *(W)*.

$$W = V\,I\,t$$

Energy is the work or activity performed due to force. It is the common measure between electrical, mechanical, and chemical systems.

1.4 Calculate

From these three measured variables, three things can be calculated. All electrical relationships can be derived from the three measured terms - voltage current, and time. Since the terms are unlike, you cannot add or subtract. The only thing left to do, then, is to multiply and divide.

Power (S) - expressed in Volt-Amps - is the product of voltage and current. Power is energy or work that occurs over some period of time. The asterisk simply notes a time change on the current.

$$S = VI^*$$

Impedance (Z) - expressed in Ohms - is the ratio of voltage to current (Volts per Amp). Impedance is the opposition to current flow. The relationship is called Ohm's Law.

$$Z = V\;/\;I$$

Delay (t_d) - is the difference is the time between voltage and current. It may be expressed in seconds or in angular terms. It is the phase shift between voltage being at a maximum and current being at a maximum. In power systems it is called power factor. It is the differential that arises in the Calculus.

$$t_d = t_V - t_I$$

Parameter	Symbol	Units	What
Impedance	Z	Ohms (Ω)	ratio
Power	S	VoltAmps	product
Delay	td or ∠	seconds	difference

EXAMPLES

Ex 1.4-1
Given: 120 Volts and 10 Amps.
What is the impedance?

$$Z = \frac{V}{I} = \frac{120V}{10A} = 12\Omega$$

Ex 1.4-2
Given: 120 Volts and 10 Amps.
What is the power?
$S = VI^* = 120V \times 10A = 1200VA$

Wire corresponds to pipe

1.5 IMPEDANCE

The opposition to current flow is called impedance. Impedance is a consequence of how electrical conductors are configured. As would be expected, there are three types of opposition.

Resistance (R) is natural opposition of any conductor. Most conductors are wires made of copper or aluminum. Resistance is the friction of a conductor. A resistor *converts electrical energy* into mechanical energy in the form of heat.

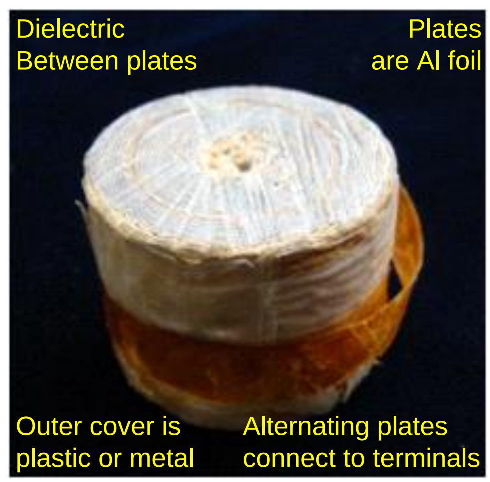
Inductance (L) results from a conductor being bent into a coil. A coil converts electrical energy into a magnet. A coil *stores magnetic energy*. Coils are used to make relays, motors, and transformers.

Capacitance (C) results from two conductors being close to each other. A capacitor *stores electrical energy*. A capacitor can be used to smooth out the electrical energy. Capacitors are used in electronic circuits and to reduce the effect of time delay from a coil. In power circuits, capacitors are often used to assist with motor starting.

For each type of impedance, there is corresponding power consumption. These three combine to create the product Volt-Amp. The most familiar of the three is resistance which creates heat and the resulting power is Watts.

Resistor

Inductor – coil of wire



Capacitor

1.6 RECAP

Take a minute to review all the electrical terms. Remember they are always in groups of three.

There are three things that can be *measured* – voltage (pressure), current (flow rate), and time.

There are three things that can be *calculated* – the ratio called impedance, the product called power, and the time delay.

Finally there are three *types* of impedance or opposition – resistance makes heat, coils make magnets, and capacitors store and smooth electricity.

Impedance	Z	Energy
Resistance	R	mechanical
Inductance	L	magnetic
Capacitance	C	electric

That is all there is

That is all there is. There is nothing else in the fundamentals of electricity.

1.7 REVIEW

Electrical fundamentals always exist in groups of three.

Measured values are

- voltage
- current
- time

Calculated values are

- Impedance (ratio)
- Power (product)
- Shift (time difference)

Impedance components are

- resistance
- inductance
- capacitance

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CHAPTER 2 – PROTECTION

2.1 INTRODUCTION

Protective devices includes items that support and guard electrical systems. From the very first chapter, we found there are three electrical measures – voltage, current, and time. There are three corresponding protections mechanisms. There are myriad implementations of the techniques.

Breaker damage from lightning

2.2 CURRENT

Over current is the most common protection mode. Current creates heat. Heat is proportional to the square of the current (current multiplied by current) and the resistance or opposition to current. This is called I^2R heat.

Fuses are the simplest overcurrent devices. A fuse is simply a piece of wire that melts when heat increases. Expending the wire is referred to as "blowing" the fuse. A fuse is not resettable or reusable. Placing a larger fuse than the rating of the protected device may result in overheating of the other components in the circuit.

Fuse screw-in normal & oversized

Circuit breakers, such as those used in residential and most commercial installations, have an element that creates heat from the current flowing to the load. Once the heat builds up, the mechanical lever will trip. A circuit breaker can be reset after the condition is cleared and the device has cooled.

Note both fuses and circuit breakers are heat sensitive. They can be tripped from incident fire as well as from current. The determination of whether the trip is a cause or result of fire depends on analysis of the condition of other components in the circuit.

In addition, a circuit breaker will trip from a sharp mechanical impact. Therefore, the other circumstances around the scene must be analyzed to determine whether the breaker tripped on overload, incident heat, or impact.

Overload / underload protection is used for motors. Overload / underload control is a sensor that trips when current is out of range. The device may be magnetic or electronic controlled.

Motor overload protection

2.3 VOLTAGE

Over voltage protection is primarily provided by a surge arrestor, which is commonly referred to as a lightning arrestor. These devices may have a space or spark gap, The most common form of these protectors is an electronic device called a metal oxide varistor (MOV). Since an MOV is an electronic device, it will deteriorate to some degree each time it dissipates an overvoltage condition.

Arrestor

During normal conditions, voltage protective devices are passive and do nothing. When voltage spikes, the devices provide a lower impedance path to ground for the excess voltage. Once excessive voltage is removed, the device clears.

GFCI receptacle with test & reset

2.4 GFCI

A ground fault circuit interrupter (GFCI) compares the current on the hot wire with the neutral. If the currents are not equal, then there is leakage current. Leakage current is caused by a failure between the current carrying conductors and ground, such as in submersion of an electric device. When the current difference exceeds 5 milliamps (5/1000 amps), the circuit is opened.

The device has a trip and reset button. The trip button should be tested monthly. Because the devices are in wet locations, the electrical sensing system may deteriorate. When was the last time you tested all your GFCI's?

GFCI are required by the *NEC* to be located in kitchens, bathrooms, garages, and outside. Basically the requirement is any location that is reachable from ground level or from a water pipe.

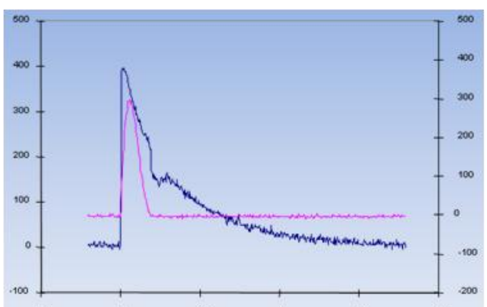
GFCI may be incorporated in a receptacle or a circuit breaker. A GFCI is for personnel protection from shock hazards. It does nothing to protect equipment.

AFCI & GFCI breakers

2.5 AFCI

An arc fault circuit interrupter (AFCI) is a very small, special purpose computer that looks at the shape of the power wave. A normal alternating circuit (AC) is a smooth, continuous signal that cycles 60 times each second (60 Hz sine wave).

An arc has sharp spikes when it starts and stops. Arcs occur anytime a switch is closed and opened, from power system operations, and from lightning. Arcs also occur when a connection is intermittent or erratic, or when the insulation on a wire is inadvertantly breached.



Transient noise L-N

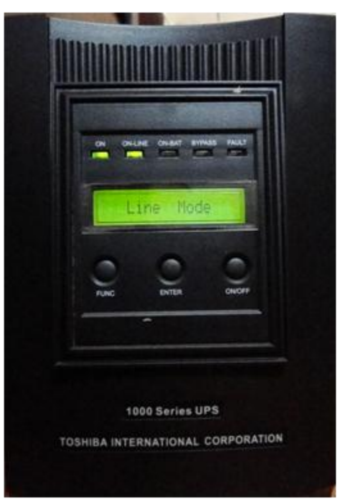
AFCI are required by the *NEC* to be located for all electrical circuits in family rooms, dining room, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closts, hallways, or similar rooms. In essence, arc fault protection is required any place a GFCI is not used.

An AFCI is used to prevent arcing fires from intermittent connections. The interrupter is not heat related.

AFCI are available in circuit breakers. Some manufacturers combine an AFCI and GFCI into the same device.

2.6 Surge Protection Systems

True to form, there are three levels of surge protection – true UPS, battery back-up UPS, MOV systems.



True uninterruptible power supply

True uninterruptible power supplies (UPS) isolate the load completely from the power system. Battery back-up UPS have a battery charger floating on the power system so the battery can provide current during a power outage. Power strips have metal oxide varistors (MOV) that shunt excess energy to ground.

2.7 TRUE UPS

True UPS – 1 kVA

A true uninterruptible power supply (UPS) is referred to as a true on-line double conversion UPS. The unit is a sophisticated power source that operates from alternating current (AC) line power, switches the power to direct current (DC) for charging a battery, then converts the DC back to AC for supplying the load.

They are used as large computer and expensive electronics protection. By converting between AC to DC to AC, the expensive electronic loads are actually isolated from normal power line surges.

These are very sophisticated devices that are generally used in industrial applications and computer server farms. The cost is in excess of $600 for a 1,000 VA unit. The devices are not available in big-box stores.

Nevertheless, these are the ONLY device that provides a reasonable level of protection. They are well worth the investment for valuable data.

These are the units we use for our computers and networks.

2.8 BATTERY BACK-UP UPS

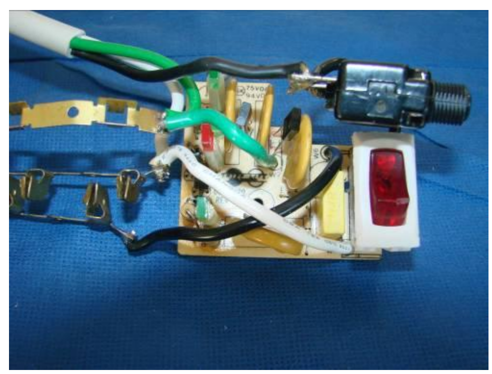
Battery back-up UPS

The battery back-up UPS is simply a surge protection power strip with a battery charger. The battery provides power on an outage. These systems do not protect on low-voltage and high energy transients.

With low-voltage transients we have observed failures on three different UPS units. The failures permitted blowing of capacitors on computer mother boards, failure on video cards, and monitor failures. In addition, one of the back-up UPS had an internal failure.

There are multiple receptacles on the devices. Some receptacles only have surge protection. Others have surge and battery backup.

Risks: These are expensive surge strips whose incremental value may be in keeping power on for a few minutes to allow controlled shut-down.

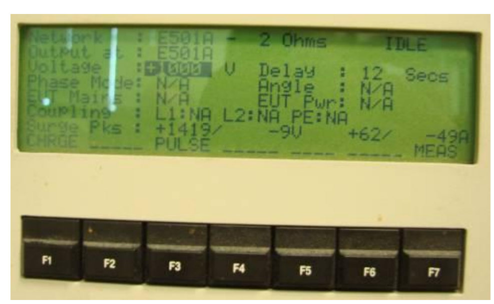


MOVs, circuit breaker, lighted switch

2.9 SURGE SUPPRESSORS

Multi-tap surge suppressors are offered by many vendors and distributors. These are a group of receptacles that are intended to protect items plugged into the receptacles. The devices contain one to three MOV's to shunt overvoltage away from the circuit.

Anything less than three MOV's provides inadequate protection. Most devices use a very low energy MOV that provides little protection.



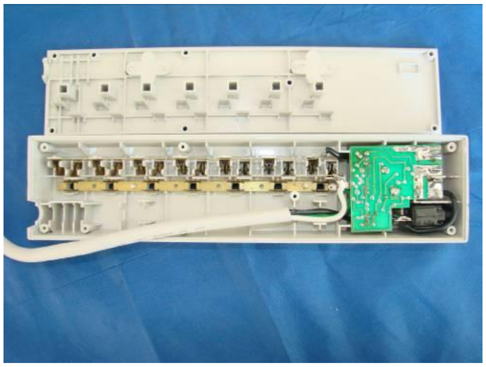
Bad news - 1419 V on 120 V circuit

We have tested numerous of the competitive devices in our lightning laboratory and have found none that provide significant protection. Several of the devices ruptured explosively.

The warranties have so many caveats that they are worth little more than the box they are printed on.

Risks: The failure issues are either it does nothing to protect the electronics or it ruptures and creates a fire. The MOVs themselves can provide an ignition source if they fail catastrophically.

2.10 POWER STRIPS



Power strip

Power strips are similar to the surge suppressors but do not have the MOV surge protection. Both devices may have a circuit breaker for overcurrent protection. Some devices have an on/off switch and an indicator light.

Risks: Power strips are subject to overload, if there is no circuit breaker. They are also subject to mechanical abuse because of where they are used. Identification of the manufacturer is frequently a problem.

2.11 PROTECTED POWER STRIPS

Protected power strip

A protected power strip has a GFCI built in the plug and provides a shielded cord with metal oxide varistors at the receptacles. This combination protects from common failures. The shield provides mechanical protection of the cord and a path for detection of faults. The GFCI shuts off power with problems in the cord or power strip. The MOVs protect for transients on the power line.

This is a very different scheme to protect power strips which commonly have problems.

2.12 CAVEATS - U/L

U/L listing

Note carefully the manufacturer and the ratings of the protection devices. Underwriter Laboratories (U/L) provides standards for testing the units. Other nationally recognized testing laboratories (NRTLs) provide similar testing and listing of electrical systems.

Often the only component that is listed or approved is the power cord. If the only U/L or other NRTL tag is on the cord, leave the device alone. It is unsafe.

Even brands that are sold in big box stores and have traditional names are often questionable quality.

2.13 EXTENSION CORDS

Amp capacity of cords

AWG	25 ft	50 ft	100 ft
18	7	5	2
16	12	7	3.4
14	16	12	5
12	20	16	7

Extension and other power cords are perhaps one of the most common electrical components that contribute to fires.

There are numerous issues that create problems.

1) Length of cord causes voltage drop which results in heat.
2) Size of wire that is too small for the current results in heat.
3) The insulation on most cords will burn.
4) The insulation is subject to mechanical damage that causes failure.
5) A jacket around the insulation provides added material and improved protection.
6) The temperature rating of the insulation must exceed the temperature to which it is exposed during use.

2.14 REVIEW

Protective devices guard electrical systems from failures resulting from the three measured components:

- Voltage
- Current
- Time

Overcurrent protection is most common. Three types of overcurrent protection are used. Fuses and thermal-magnetic breakers can trip due to incident heat.

- Fuses - non resettable
- Thermal-magnetic circuit breakers - resettable
- Electronic-magetic circuit breakers - resettable

Overvoltage protection is provided primarily by surge arrestors. These devices provide a path to ground when voltage exceeds a set value.

GFCI protects against leakage current to ground. They are primarily for personnel protection. *GFCI* protection is required in any wet area.

AFCI protects against arcing faults. The are primarily for protection of faults on feeders. The devices are now required in *all* areas inside a residence not protected by GFCI.

True UPS devices completely isolate the load from the power system. Consequently, they provide the best protection scheme.

Battery back-up UPS devices provide short duration battery backup to electronics during a power outage. They can have some protection from surges.

Surge Suppressors are simply power strips with 1 to 3 MOVs which provide overvoltage protection. Low energy MOVs in these device provide little protection, and can be a source of ignition if they fail.

Power Strips are inexpensively made and are subject to mechanical damage. Often there is no protection for cord or internal damage.

Extension Cords are a common failure item. They have several issues.

- Length increases voltage drop which results in heat
- Undersized conductors result in heat
- Insulation is combustible in presence of heat source.
- Easily damaged insulation results in electrical failure and fire.
- Low temeperature rating of insulation in presence of high temperature source results in failure.

Chapter 3 – Grounding

3.1 Introduction

An electrical ground is a connection to earth. *Ground* in electrical parlance is the common basis or reference for all electrical measurements, circuits, and safety. There are three functions of grounding systems based on the electrical measurements of voltage, current, and time.

Equi-potential (V) keeps the voltage the same between two points.

Fault current (I) has a path back to the source.

Transients (t) are snubbed by the massive inertia of the earth.

Grounding is a very complex topic that is critical to electrical safety. The *National Electrical Code (NEC)* has over 28 pages devoted to the requirements plus numerous other Articles that reference the topic. The *National Electrical Safety Code (NESC)* has specific requirements for grounding. The Institute of Electrical and Electronics Engineers (IEEE) has multiple standards that are specific to grounding installations.

The authors have published over 25 technical papers and have received numerous awards and recognition for their research on grounding and lightning.

3.2 Investigator Perspective

The significance of grounding is not readily understood by most engineers and investigators, but it is a major element of every electrical system.

It is well recognized that the "hot" wire in an electrical system is dangerous and can cause shock or a fire. Those incidents can only happen if there is a neutral or ground return path for the current from the "hot" wire. As we found in Chapter 1, an electrical system involves a complete "circle" or circuit from the source through the wires to the load and then returning back to the source.

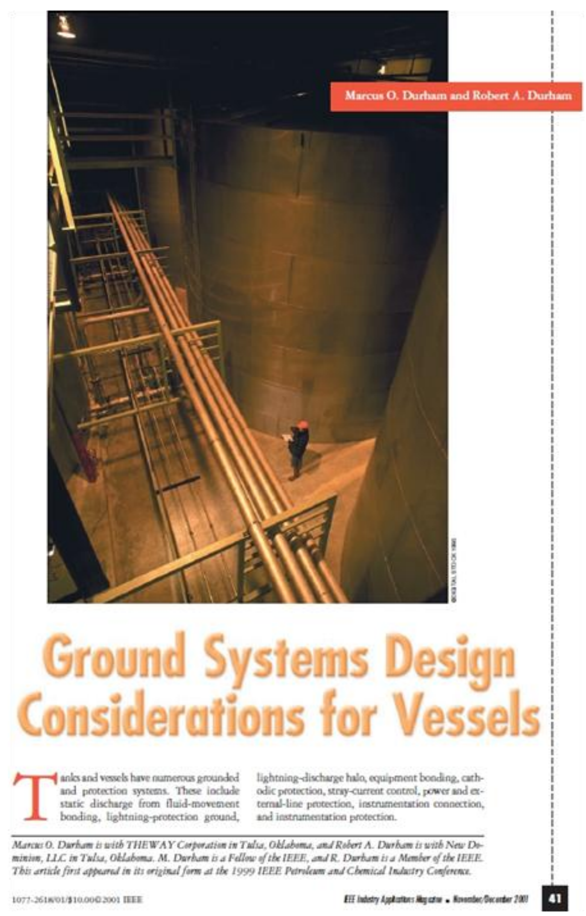
A ground, including neutral, path is the return half of every conventional electrical circuit.

Any electrical activity on a neutral or ground conductor is a clear indication of faulting involving the ground system.

Improper grounding is a common problem. Electrical ignition that is undetermined is likely related to a grounding issue. Grounding issues are a *Code*, and therefore, a legal violation.

In our combined experience of over 65 years in failure analysis investigation and in looking at thousands of incidents, we have found that the ground system is seldom properly investigated.

A complete and thorough examination of an incident has not been conducted until the grounding system is eliminated or the ground measurements have been made.


Marcus O. Durham and Robert A. Durham

Ground Systems Design Considerations for Vessels

Tanks and vessels have numerous grounded and protection systems. These include static discharge from fluid-movement bonding, lightning-protection ground, lightning-discharge halo, equipment bonding, cathodic protection, stray-current control, power and external-line protection, instrumentation connection, and instrumentation protection.

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IEEE Industry Applications Magazine ■ November/December 2001 41

One of many grounding articles by authors

3.3 3-IN-1

The three elements that are critical to electrical safety including fire mitigation are *insulation*, *connections*, and *ground system*.

The proper interconnection of ground system elements, including the grounding electrode, is critical to manage voltage and current in the prevention and mitigation of fires.

Notwithstanding the immense literature on the topic, the fundamentals of grounding are relatively straightforward and naturally consist of three components.

3.4 GROUNDING SYSTEM

The three components of a grounding system are *grounding electrode*, *grounding electrode conductor*, and *bonding*.

Grounding electrode is the contact point with earth. The electrode may be existing metal in contact with earth, metal in concrete, or made electrodes. The grounding electrode may consist of a grid, loop, or rings.

According to *NEC* requirements, if a made electrode has a contact resistance to earth of greater than 25 Ohms, an additional made electrode must be installed. The *NESC* is more specific. The ground must be less than 25 Ohms.

The *IEEE Green Book* on grounding is more specific. “This should not be interpreted to mean that 25 ohm is a satisfactory resistance value for a grounding system.” The Standard gives a specific recommendation. “Resistances in the 1 ohm to 5 ohm range are generally found suitable for industrial plant substation and buildings and lare commercial installations.” Although the Green Book is not specific to residential installations, there is no difference in the earth needs, so its recommendations are still appropriate.

Unfortunately, very few installers, inspectors, or investigators measure ground contact resistance, due to lack of equipment, lack of knowledge, or both. As a result, inadequate grounding is a common problem.

Grounding electrode conductor is the wire that connects the grounding electrode to the rest of the system. The wire must be large enough to handle available fault current. The NEC specifies the size of the conductor.

Bonding connects metal surfaces that may become energized to the grounding system. Bonding is required between all grounding electrodes.

The NEC fine print note (FPN) advises to bond all metal even that not specifically noted in other sections.

> FPN: Bonding all piping and metal air ducts within the premises will provide additional safety.

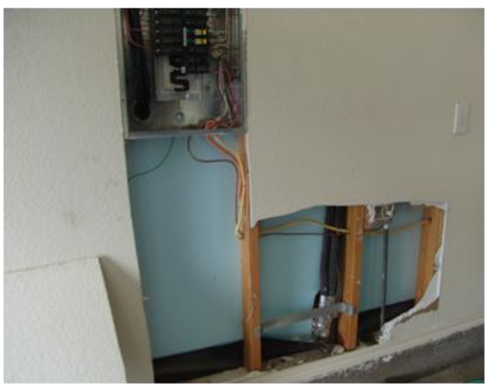
An *energized ground* has current from another circuit. The cause is poor connections and poor ground. The “tell” is melted insulation on the ground wire, or on the jacket of multiconductor cable, even though the energized conductor may not be melted.

Melted insulation on a normally unenergized conductor is an interesting “tell” that the ground system has been energized.

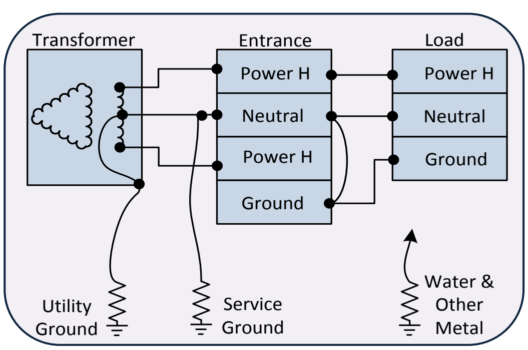
The proper interconnection of ground system elements, including the grounding electrode, is critical to manage voltage and current in the prevention and mitigation of fires.

Set in stone

Made electrode



Electrode in concrete



Grounding electrode, bonding, neutral

Energized ground

3.5 NEUTRAL

Neutral is a current carrying conductor. It is identified by white insulation or markings. It is connected to the ground at one point and one point only. If connected at multiple points, the ground would carry part of the neutral current and the ground would be energized.

A neutral can be operated in three ways, two of which create problems.

Proper neutral is grounded at one point only, has good low-impedance connections, and carries only the current of the associated circuit.

Floating neutral has a poor connection to the source that results in heat and current taking an alternate path. Shock and fire can result.

Energized neutral has current from another circuit. The cause is poor connections and poor ground. The “tell” is melted insulation on the neutral or ground wire but the normally energized conductor may not be melted. This is particularly observed on devices and fixtures connected to another ground path, such as a water line. Shock and fire will result.

An energized neutral may create saddle burns on top of wooden structural members such as joists and plates.

3.6 STRAY

Stray currents are the result of improper grounding and bonding. Stray currents result from uncontrolled flow of electrical energy. The current takes an alternate path through the earth. The current can reenter a metal path at some point on its journey back to the source.

Research has been conducted to evaluate the amount of current that flows in the earth for a power system that has multiple ground points on the neutral. This is typical of most overhead power lines. The research found that 60% of the neutral return current actually travelled thorugh the earth as stray current.

In effect any system that has a neutral with two or more ground points will have the current flow partially through the wires and partially through the earth.

Control: Stray current is caused by a neutral that is grounded at multiple points. Stray current can result from a fault of a hot wire to ground. Commonly, stray current is caused by a difference in potential of ground connections.

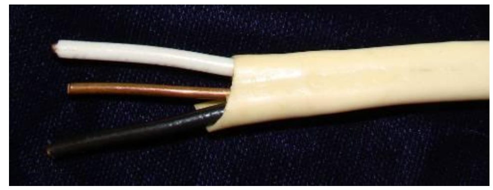
Risks: Stray current will energize unintended metal and will cause a potential difference between the soil and metal. The result is shock to living creatures and risk of fire.

3.7 STRAY 120/240V

Interestingly, every 120/240 Volt single-phase system is also constructed as a two-point ground on the neutral. Therefore, it is reasonably expected that up to half of the neutral current will flow in the earth or ground path on its sojourn back to the transformer source.

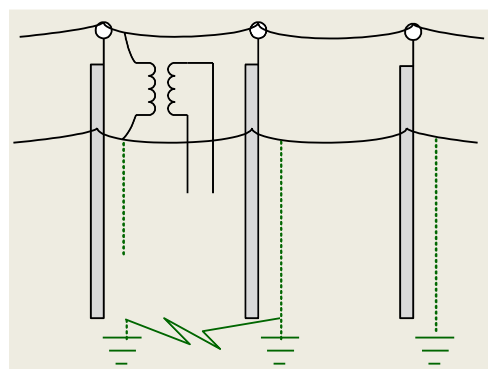
If the impedances are not very low or the grounds are not bonded, stray current will flow through the earth and any other conductive material. The stray current can create a shock or fire hazard.

Energized ground from lightning

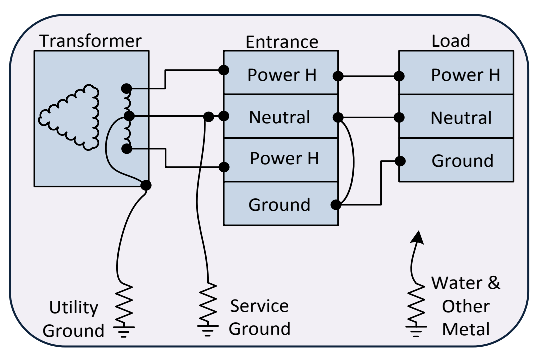


Neutral is white, common wire

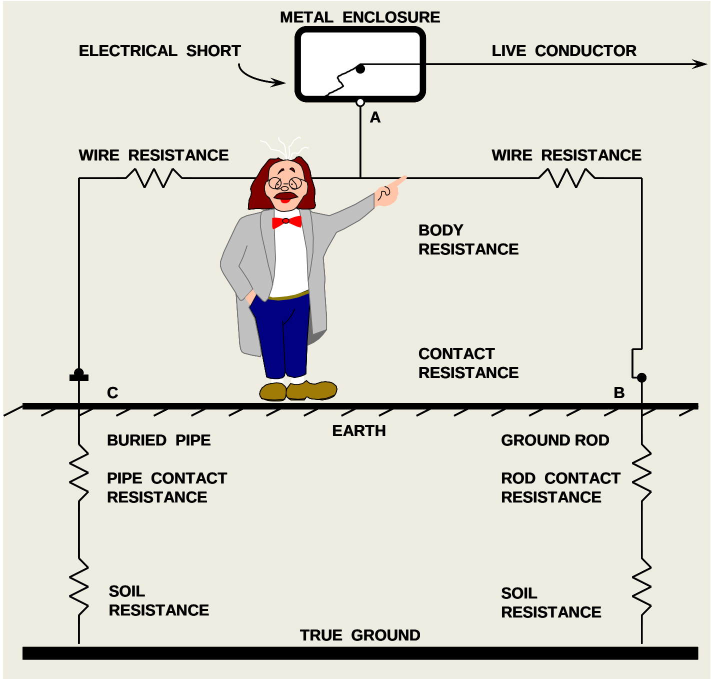
Energized neutral on top of joists



Stray current from overhead power line



Stray current from multi-point neutral



Ground differences

There is current flowing in the earth. If the ground electrode resistance at the service entrance is not low, as required by the Code, then the ground current has a greater tendency to stray and take alternate paths.

3.8 GROUND DIFFERENCES

Contrary to common opinion, the earth is not a monolithic ground. Three things impact the impedance of a ground connection – *electrolyte, moisture,* and *metal*. As a matter of interest these are the same three items that cause corrosion.

Different soil, moisture, and metal create a different impedance or opposition to current. Different impedances result in a difference of voltage and a current path. Current takes the path of least impedance.

Look at the illustration. Notice the individual can be shocked or a fire can result near the location of his pointing. The ground at "B" and the ground at "C" are not equal, even though they are both in the soil.There is different wire resistance, contact resistance, and soil resistance. Therefore, current can and will flow in the ground wire and the earth.

Ground resistance varies

3.9 GROUNDING ELECTRODE

An electrical grounding system should use a single point as a reference for all measurements. This is called the grounding electrode.

In an attempt to create minimum potential difference in the ground system, a grounding electrode system is mandated by NEC 250.50. "All grounding electrodes as described in 250.52(A)(1) through (A)(6) that are present at each building or structure served shall be bonded together to form the grounding electrode system."

NEC Article 250.52 lists seven alternatives for the grounding electrode.

1) Metal underground water pipe
2) Metal frame of the building or structure
3) Concrete encased electrode, including rebar
4) Ground ring
5) Rod and pipe electrodes
6) Plate electrodes
7) Other metal underground systems or structures.

3.10 GROUND VALUES

Grounding considerations are comprehensively addressed in the *NEC* and *NESC*. An understanding of these issues assists in determining responsibility for incidents.

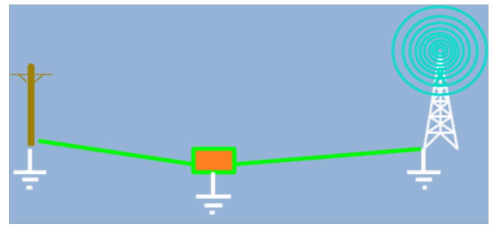
Both the *NEC* and the *NESC* reference that resistance greater than 25 Ohms is not acceptable for a made electrode. Additional grounding must be performed in order to reduce the value.

IEEE 142, Grounding of Industrial and Commercial Power Systems, is much clearer in describing the resistance must be lower. The following quote is from paragraph 4.1.3 Recommended Acceptable values.

The 25 ohm value noted in the NEC applies to the maximum resistance for a single electrode consisting of a rod, pip, or plate . If a higher resistance is obtained for a single electrode, a second electrode of any of the types specified in the NEC is required. This should not be interpreted to mean that 25 ohm is a satisfactory resistance value for a grounding system.

Electrolyte, moisture & metal

NEC has additional requirements of lower resistance for classified areas. The result of this discussion is the Codes allow some flexibility for different conditions. However, in no circumstance is a ground greater than 25 Ohms acceptable.



All ground must be bonded

A good ground resistance reference for electronic circuits can be obtained from the standards for intrinsically safe shunt diode barriers. In these systems, ground resistance from the furthest barrier cannot exceed 1 Ohm. This requirement is incorporated into the NEC by reference to ANSI RP 12.06.01.

For safety, consider Ohm's law that we looked at in the first chapter. Impedance is the ratio of voltage to current. For a normal 120 V circuit with a 20 A breaker, a total circuit resistance of less than 6 Ohms is required to trip. In other words, if the hot wire were to touch the earth, the total path resistance would have to be less than 6 Ohms.

$$Z = \frac{V}{I} = \frac{120V}{20A} = 6\Omega$$

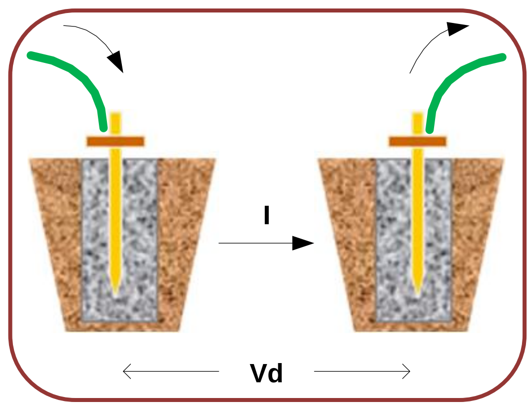
The low ground resistance allows objectionable energy, including harmonics, to be dissipated safely into the earth.

3.11 ILLUSTRATION – CIRCULATING CURRENT

Ground by definition is connection to earth.

Bonding is connection between two metals that may be electrically energized.

Consider two ground rods driven in the earth. There will be a potential difference (V_D) between them, because of the difference in ground resistance. Differences are caused by the electrolyte, moisture, and metals. When there is a voltage difference, current (I) will flow.

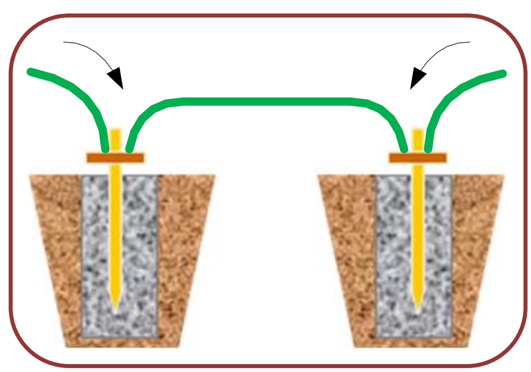


Grounds unbonded – circulating current

A bond is necessary between the two grounds and all other metal surfaces.

The purpose of bonding ground systems together is three-fold.

1. To assure that all the systems are operating at the same reference (V). This is crucial to control voltages seen in the structure.
2. To prevent circulating currents (I) from developing in the ground systems. Circulating currents cause overheating of ground and neutral conductors.
3. To allow building and service protection (t) systems to operate effectively and as designed.



Grounds bonded – no current

The fact that the ground system is not bonded together properly creates three problems associated with the voltage, current, and protection time.

1. It allows voltages (V) in the structure to "float" and exceed equipment ratings.
2. It allows circulating currents (I) to overheat the existing ground conductor.

3. It prevents the structure and utility protection systems (t) from operating.

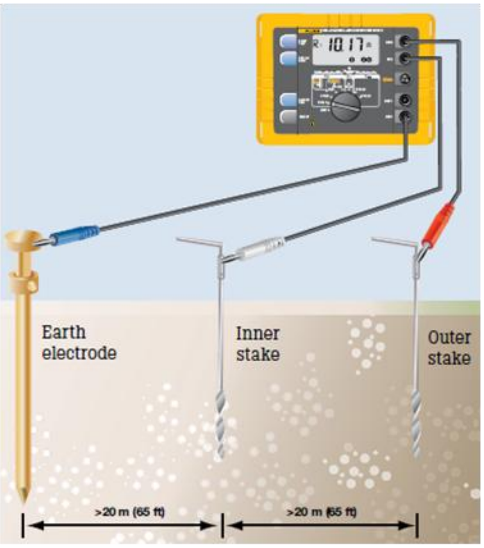
3.12 HOW MUCH IS TOO MUCH?

$$S = VI^*$$
$$I = \frac{S}{V} = \frac{12}{120} = \frac{1}{10}\ Amp$$

From research on low energy systems, we have been able to ignite cellulose with a "high-resistance" connection that generated power from as low as 11 to 20 Watts.

On a 120 V system, 12 Watts is created with a current of only 1/10 Amp. A poor connection, damage to insulation, or stray current can easily generate that level of current.

A very small quantity of current flow in an improper path can create fire or personal injury.



Voltage fall method – gnd resistance*

3.13 MEASUREMENT

Since ground values are so important, there must be a method to measure the resistance. Standard voltmeters, current meters, and ohmmeters will not work for this task. Few engineers, electrical contractors, or utilities have made the substantial investment in equipment, technology, and time to make the measurements.

Years ago the only technique was the voltage drop (fall of potential) method. This instrument can be used to determine the resistivity of the soil. It can also be used to detemine the resistance of a ground rod.

The voltage drop off requires additional ground rods be driven in the earth. The spacing between the measurement stakes and the length of the stakes are critical to prevent interference. Soil resistance measurements are often corrupted by existing ground currents and harmonics.

Furthermore, measurement results are often distorted and corrupted by underground metal, water, and other conducting paths. Therefore, multiple measurements are required. A second set of driven stakes should always be turned at 90 degrees from the original measurement for a comparison. By changing the depth and distance several times, a contour or profile can be developed that can determine a suitable ground resistance system.

Gnd resistance - AEMC

Because of the difficulty and the inconsistancy of the voltage drop results, alternative methods are preferred. Over twenty years ago, the clamp-on ground resistance instrument was developed. Now there are multiple manufacturers of these instruments including such well known quality instruments as AEMC, Amprobe, and Fluke. The price ranges around $1200 to $2000.

The clamp-on ground-resistance instrument greatly simplifies the process of measuring ground resistance, non-intrusive leakage current, and continuity, without breaking the circuit. In addition adding other components such as stakes and rods is eliminated. Furthermore, the hazard of disconnecting parallel ground rods is eliminated. Measurements can be conducted where other methods are not possible, such as inside a building. The technique allows measurement of individual connections.

The clamp is placed around the ground rod. The instrument induces a known voltage by one-half of the clamp. This signal will be reflected by the boundary between the ground system and the surrounding earth. The other half of the meter measures the size of the reflected signal. By comparing the reflected signal to the original signal, a calculation of ground contact impedance can be made. Then the instrument displays the impedance.

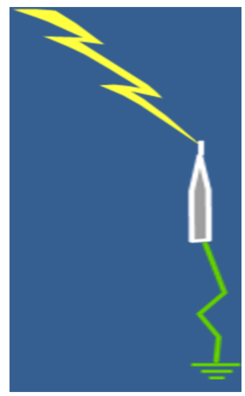
The clamp-on resistance metere is is well-tested, accepted, and very mature technology. Not having the capability to determine the ground circuit contact resistance is no longer a professional option.

Gnd resistance – Fluke*

3.14 GROUNDING & LIGHTNING

Lightning is the discharge of electro-magnetic energy between a cloud and earth. Ben Franklin demonstrated lightning can be controlled in 1760. Three items are necessary for lightning management - *air terminal, conductor,* and *grounding system.*

The grounding system for lightning is separate from the grounding system from electrical power. Nevertheless, the lightning ground must be bonded to all other grounds.



Terminal, conductor, ground

Grounding is included in the *Codes* for protection of persons and property. One of the things that grounding provides is a path for transients and lightning.

Lightning like wind and rain is an act of God. Protection can be provided if the system is properly installed. If there is damage due to lightning, there is most likely a problem with the installation. A further discussion of lightning and its effects is contained in Chapter 10.

3.15 SUM IT UP

Improper grounding is a frequent problem.

Electrical ignition that is undetermined is likely a grounding issue.

Grounding issues are a code, and therefore legal, violation.

3.16 REVIEW

Ground is the common reference for all electrical systems. A proper ground has three functions.

- Maintain equal *voltage* between points in the system.
- Provide path for fault *current.*
- *Transients* are snubbed by ear.th inertia

The proper interconnection of ground system elements, including the grounding electrode, is critical to manage voltage and current in the prevention and mitigation of fires.

A grounding system has three components

- *Grounding electrode*
- *Grounding electrode conductor*
- *Bonding*

Neutral is the common name for the white or *grounded* conductor. It must be connected to the ground system at one point and one point only. The neutral carries the unbalanced load current. A neutral can be operated in three ways

- *Proper neutral*
- *Floating neutral*
- *Energized neutral*

Stray Currents are inadvertant current flows through the earth. They are caused by multi-point grounded neutral wires. Stray current can energize metallic surfaces creating shock risk and risk of fire.

3.17 BIBLIOGRAPHY - ILLUSTRATIONS

Select photos courtesy of Fluke.

1. http://support.fluke.com/find-sales/Download/Asset/2633834_6115_ENG_A_W.PDF

2. http://us.fluke.com/fluke/usen/Earth-Ground/Fluke-1630.htm?PID=56021

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CHAPTER 4 – CODES & LAW

4.1 INTRODUCTION

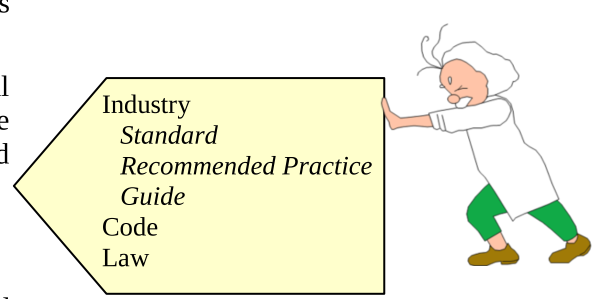
Industry standards are consensus practices for conduct within a particular field, such as residential electric, utilities, or HVAC. The standards are developed by interested professionals through organizations involved in an activity. Many standards are subsequently adopted by the American National Standards Institute (ANSI) for more general application. The ANSI standards are coordinated with the International Electrotechnical Commission (IEC) as international standards.

There are three levels of standards. The difference is in the language and requirements for implementation. *Standards* must be followed. *Recommended Practices* should be followed. *Guides* may be followed.

Codes are industry standards that have been adopted by various *government jurisdictions.*

Law consists of regulations, administrative code, and legislation that carry the power of the political jurisdiction charged with enforcing the activity.

Within the fire investigation field, the National Fire Protection Association (NFPA) is one of the leading organizations which develop standards. Others include, but are not limited to Institute of Electrical and Electronics Engineers (IEEE), American Society of Mechanical Engineers (ASME), American Petroleum Institute (API), Underwriters Laboratories, and International Code Council.



The engineering authors are voting members of the NFPA electrical section and are members of the IEEE standards association. The engineering authors have chaired numerous standards within IEEE and API.

4.2 NATIONAL ELECTRICAL CODE

The *National Electrical Code* is the most well-known, used, and referenced electrical standard. It is a consensus document developed by the NFPA electrical section as NFPA 70. The *NEC* is the accepted minimum standard for electrical installations in structures.

Article 90.1(A) gives the purpose.

> The purpose of this Code is the practical safeguarding of persons and property from hazards arising from the use of electricity.

Article 90.1(B) gives the adequacy.

> This Code contains provisions that are considered necessary for safety. Compliance therewith and proper maintenance results in an installation that is essentially free from hazard but not necessarily efficient, convenient, or adequate for good service or future expansion of electrical use.

Article 90.2(A) gives the areas covered as most any type wiring.

NEC – electrical standard

NEC

Mandatory application
&
Use by insurance inspectors

> This Code covers the installation of electrical conductors, equipment, and raceways; signaling and communications conductors, equipment, and raceways; and optical fiber cables and raceways for the following: (1) Public and private premises, including buildings, structures, mobile homes, recreational vehicles, and floating buildings...

Article 90.4 gives enforcement to government and standards for insurance inspectors.

> This Code is intended to be suitable for mandatory application by governmental bodies that exercise legal jurisdiction over electrical for use by insurance inspectors.

4.3 JURISDICTION

The state of Oklahoma and most other states have adopted the *NEC* as the standard for electrical installation. The Oklahoma Electrical Licensing Act gives the authority to the Construction Industry Board, which is under the Department of Health.

> "Electrical construction work" means installation, fabrication or assembly of equipment or systems included in "premises wiring" as defined in the 2008 edition of the National Electrical Code, which is hereby adopted and incorporated by reference.

In addition, the state Fire Marshal's office has adopted this code along with others. The State Fire Marshal agency is charged with the responsibility of enforcing the codes and standards relative to fire safety adopted by the State Fire Marshal Commission under the "Fire Marshal Act".

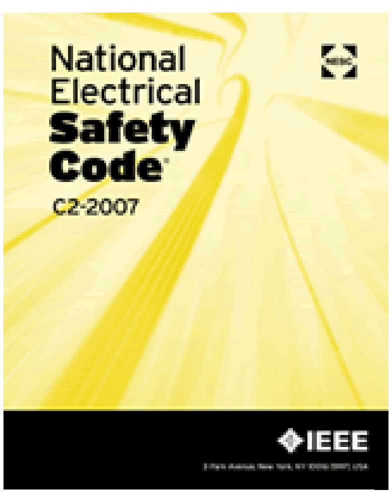
Code enforcement

> The following national codes and standards are incorporated by reference:
>
> (12) NFPA #70 The National Electric Code and its annex's, 2008 Edition.

The matter of jurisdiction and inspection is a question for any installation. The *NEC* is the minimum standard for electrical installations.

The State can inspect an installation under the Department of Health Construction Industries or under the authority of the Fire Marshal. For public facilities, the jurisdiction is clear. For private residences there is some challenge because of the castle doctrine. Finally, an insurance company can demand compliance as a condition of the contract.

4.4 NATIONAL ELECTRICAL SAFETY CODE



NESC – utility type standard

The *National Electrical Safety Code (NESC)* is the recognized authority for electrical utility installations, whether by a utility or individual. The *NESC* is the minimum standard for safe installation, operation, and maintenance of utility systems. It was developed by the IEEE as IEEE / ANSI C2.

Article 010 gives the purpose.

> The purpose of these rules is the practical safeguarding of persons during the installation, operation, or maintenance of electric supply and communication lines and associated equipment. These rules

> contain the basic provisions that are considered necessary for the safety of employees and the public under the specified conditions.

Codes are not just suggestions, It's the law.

Article 011 gives the areas covered.

> These rules cover supply and communication lines, equipment, and associate work practices employed by a public or private electric supply, communications, railway, or similar utility in the exercise of its function as a utility. They cover similar systems under the control for qualified persons, such as those associated with an industrial complex or utility interactive system.

4.5 STATE LAW

The state of Oklahoma and most other states have adopted the *NESC* as the standard for electrical utility installations. The Oklahoma Corporation Commission is responsible for enforcement of those utilities under their jurisdiction.

> The Commission hereby adopts the minimum requirements of the 2002 Edition of the National Electrical Safety Code (NESC) adopted by the ANSI (ANSI-C2) as its rules and regulations governing safety of the installation and maintenance of electric utility systems.

Even for groups not under OCC rate rules, the law establishes that the minimum standard for safe utility construction, operation, and maintenance is the *NESC*.

MINIMUM STANDARD
Practical safeguarding of persons & property

4.6 IMPORTANCE

Codes are defined for the practical safeguarding. Any installation that does not meet the *Code* is not safe. Personal or property damage is the result.

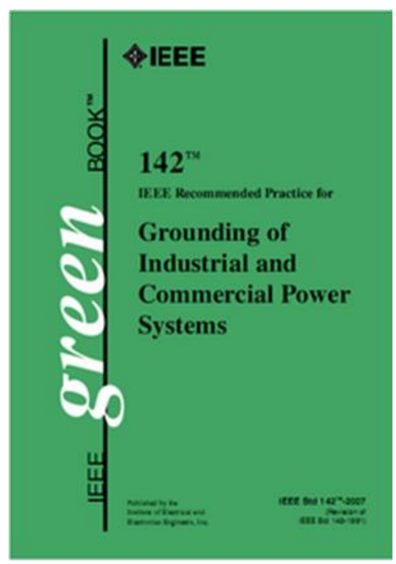
An installation that does not meet *Code* requirements has three basis of fault. One is the violation of accepted industry standard, two is violation of insurance processes, and three is violation of state law.

It is incumbent that the investigator knows and understands the *Codes* and their interpretation to effectively evaluate an electrical failure. Many non-compliant installations and equipment are overlooked because of lack of familiarity with the industry standards and state law.

The reason that the Code is mandatory is actually quite simple. Each item in the Code is there because someone had a problem in that area.

4.7 IEEE 142

The *IEEE Green Book* is the recognized standard for grounding of electrical installations. It was originally developed for industrial and commercial power systems. The *NEC* Article 250 on grounding systems is the same for all structures. The electrical relation to earth is the same for all installations. Therefore, the *Green Book* appropriately applies to all structures and installations including residential systems also.



IEEE 142 Standard

NFPA 780 Standard

4.8 NFPA 780

The *Standard for Installation of Lightning Protection Systems* is the recognized standard for lightning protection. It is published by the National Fire Protection Association as *NFPA 780*. The Standard is reverenced in the *NEC.*

This is not a new or novel topic, regardless of common understanding. The first NFPA standard on the topic was *Specifications for Protection of Buildings Against Lightning* published by NFPA in 1904. The fundamental procedures were developed by Dr. Benjamin Franklin in the 1760's.

NFPA 780 is one of the many standards published by NFPA to address various safety issues. Since it is a standard, its practices are not optional. A complete lightning protection system is not required for most installations, but lightning risk assessment must be considered as noted in the introduction.

> The lightning risk assessment is provided to assist the building owner, safety professional, or architect/engineer in determining the risk of damage or injury due to lightning…Once the level of risk has been determined, the development of appropriiate lightning protection measures can begin.

There are several items that increase the risk of damage.

1. Large structures are higher risk
2. Multistory structures have elevated risk.
3. Isolated structures have increased exposure.
4. Structures on hill tops have higher vulnerability.
5. More flammable construction methods increase probability.
6. High value objects increase the risk potential.

There are standard practices outlined in the document that are required to mitigate lightning effects.

There are a few key items that must be followed for any installation.

1. There must be an adequate ground system for the strucutre.
2. Each electrical system must be grounded.
3. All electrical systems muct be bonded together.
4. All metal that can become energized must be bonded together.
5. The wire size must be adequate for the current exposure.
6. The wires must be installed with bends having a radius greater than 8".

You will note that these are essentially the same requirements as the other *Codes* that address grounding.

NFPA 921 Guide

4.9 NFPA 921

Guide for Fire & Explosion Investigations was developed by the NFPA as NFPA 921. It is a *guide* for investigations. As such it is a suggested practice.

Article 1.2 gives the purpose.

> The purpose of this document is to establish *guidelines* and *recommendations* for the safe and systematic investigation or analysis of fire and explosion incidents.

Article 1.3.3 gives the limitations.

> Not every portion of this document may be applicable to every fire or explosion incident.

As a guide, its use is not enforceable. Since it is a recognized industry document, deviations could result in questioning about the investigators practice. As a result, deviations from this guide should be well reasoned and supportable.

Licensed Professional Engineer

4.10 PROFESSIONAL RESPONSIBILITY

A *licensed professional engineer* and a *licensed electrical contractor*, under State law, are obligated to operate under the Code. Although these individuals are not attorneys, it is necessary to know the legal requirements of the professions.

An installation that does not comply with defined state law is classified as *negligence per se* by attorneys.

Therefore, an understanding of the *Code* is necessary when conducting a failure analysis that may have resulted in an incident.

4.11 REVIEW

There are three levels of *industry standards.*

- Standards – must be followed
- Recommended Practices – should be followed
- Guides – may be followed

Codes are industry standards adopted by government institutions

Law consists of regulations, administrative code, and legislation.

NEC is the most used electrical standard. The purpose is the practical safeguarding of persons and property. The Code covers electrical installations on the user side of the electric meter.

NESC is the code for utility type installations. The purpose is the practical safeguarding of persons and propery. The Code covers electrical installations on the utility side of the meter.

IEEE Green Book is the standard for grounding installations.

NFPA 780 is the standard for lightning installations.

Wire Use	Amps	AWG
Low-voltage lighting and lamp cords	10	18
Extension cords	13	16
Light fixtures, lamps, lighting runs	15	14
Receptacles, 110-volt air conditioners, sump pumps, kitchen appliances	20	12
Electric clothes dryers, 220-volt window air conditioners, built-in ovens, electric water heaters	30	10
Cook tops	45	8
Electric furnaces, large electric heaters	60	6
Electric furnaces, large electric water heaters, sub panels	80	4
Service panels, sub panels	100	2
Service entrance	150	1/0
Service entrance	200	2/0

Chapter 5 – Electric and Communication Utilities

5.1 Introduction

Utilities are defined as any supply and signal that is external to the structure. Electrical related utilities are power, telephone, cable, satellite, television, and radio. There are three common features – they bring an electric signal into the structure, they require a ground connection, and they are covered by standards and codes.

An overview of the latter two items was covered in previous chapters. This chapter will look at the specifics.

Ground connection utility meter pole

Ground inadequate

Utility end pole is problem

Telephone entrance no ground

5.2 Electric utility

The electric utility provides 120/240 volt, single-phase power to most buildings and structures. The power is typically two hot wires and a common that is grounded. The power is derived from a transformer which converts higher voltage, greater than 4160 Volts, to relatively lower voltage. The transformer is simply two coils of wire with the number of turns equal to the voltage ratio.

Multiple customer services may be supplied from a single transformer. Larger loads will have a dedicated transformer.

The utility installation, operation, and maintenance is controlled by the *National Electrical Safety Code (NESC)*. Oklahoma and many other jurisdictions have adopted the *NESC* as the minimum standard for overhead and buried electric service.

Control: The utility has fuses on the high voltage side of the transformer. These are not sized to protect the load but only to protect the line that supplies the transformer.

NESC has extensive requirements for grounding for protection. Problems are discussed as risks.

Risks: There are substantial problems with ground paths, nuisance currents, and multi-point grounds. The utility connects the common or neutral conductor to earth at numerous locations, sometimes as often as every pole. A multi-point ground allows part of the current to flow through the neutral wire and part of the current to flow through the earth. Studies have shown that as much as 60% of neutral current flows through the earth. That means that at some location, the utility current is flowing through metal paths that were not designed to handle the current. Shock and fire is the consequence.

Another issue is transients or surges that are on the power system because of inadequate protection and operations practices. In some instances, excessive current is delivered to a facility causing failure of electrical components or appliances. The result is fire.

Service entrances

Ungrounded coax discharge to electric

Ungrounded dish with lightning damage

Coax with lightning blowout

Antenna coax shield connection to ground

It should be noted that the utility operates the primary or high voltage side as a multi-point ground. However, the secondary or low-voltage side is specifically identified as a separately derived source at the transformer. Therefore, it is not a multi-point ground. If it is grounded at more than one location, the high voltage ground currents will flow into the low voltage system. The consequence will be structure damage in the form of fire and corrosion and biological impact by stray currents. That is very bad.

5.3 COMMUNICATIONS

NEC Article 800 defines communications systems.

Communications circuit include voice, audio, video, data, interactive services, telegraph, outside, etc. from the communications utility to the customer's communication equipment up to and including terminal equipment such as a telephone, fax machine, or answering machine. These are basically analog systems.

The wiring may be telephone wire, Cat 6 cable, or coax.

Circuits and equipment must be installed in a neat and workmanlike manner so that the wiring will not be damaged in normal use. Wiring and penetrations are made so that the possible spread of fire or products of combustion will not be substantially increased. Wires must have defined separation from other wires and roofs.

Control: A primary protector is required on each circuit that is not grounded or interruped with a block and where potentially exposed to power lines or lightning. That includes every circuit.

The metallic sheath must be interrupted or grounded where it enters the building.

The grounding conductor shall be insulated and listed. The conductor shall not be smaller than 14 AWG. The primary protector grounding conductor shall not exceed 20 feet in length. Where separate electrodes are used, a bonding jumper not smaller than 6 AWG shall be connected between the communications grounding electrode and power grounding electrode.

On a mobile home, the distance to a grounding electrode is extended to 30 feet. The ground must be bonded to the metal frame with 12 AWG or larger.

Risks: Coax is designed to carry electromagnetic signals that are in the same frequency range as lightning. Communications lines are a common entrance for transients, including lightning, if not properly installed and grounded. Transients can damage the equipment connected and cause fire.

Voltage up to 85 Volts can exist when a phone rings. Normally the lines are very low voltage and current.

5.4 RADIO & TELEVISION

NEC Article 810 defines radio and television antenna systems.

Antenna systems include radio and television receiving as well as amateur radio transmitting and receiving equipment. The system includes satellite dishes and the antenna site of community television systems.

The structure shall be able to withstand ice and wind loading conditions and be located *well away* from overhead power conductors.

Control: Each conductor of a lead in shall be provided with a listed antenna discharge unit that is not located near combustible material. The mast must be grounded.

The discharge unit shall be grounded. The ground conductor shall be 12 AWG copper or larger. The conductor does not have to be insulated. The bonding jumper to the power grounding electrode system shall be 6 AWG copper or larger.

Risks: Aluminum cannot be used for direct contact with earth. Grounding is crucial to carry transients away from the wiring to the earth.

CATV coax grounded

5.5 CATV

NEC Article 820 defines community antenna television (CATV) or cable systems.

The article covers coaxial cable distribution or radio frequency signals typically employed in community antenna television (CATV) systems. Power up to 60 volts may be applied on the system, which is adequate for shock and fire.

Coax with bead started fire

Circuits and equipment must be installed in a neat and workmanlike manner so that the cable will not be damaged in normal use. Wiring and penetrations are made so that the possible spread of fire or products of combustion will not be substantially increased. Wires must have defined separation from other wires and roofs.

Control: The metallic sheath shall be grounded where it enters the building.

The grounding conductor shall be insulated and listed. The conductor shall not be smaller than 14 AWG or larger than 6 AWG. The conductor shall not exceed 20 feet in length. Where separate electrodes are used, a bonding jumper not smaller than 6 AWG shall be connected between the communications grounding electrode and power grounding electrode.

Wireless internet

Mobile home distance to a grounding electrode is extended to 30 feet. The ground must be bonded to the metal frame with 12 AWG or larger.

Risks: Cable lines are common entrance for transients, including lightning, if not properly installed and grounded. Transients can damage the equipment connected and cause fire.

5.6 NETWORK POWERED BROADBAND

NEC Article 830 defines network-powered broadband communications systems.

Broadband communications includes any combination of voice, audio, video, data, and interactive services through a network interface unit (NIU). These are basically high speed digital computer networks.

Mobile home service permits 30' to ground

Circuits and equipment must be installed in a neat and workmanlike manner so that the cable will not be damaged in normal use. Wiring and penetrations are made so that the possible spread of fire or products of combustion will not be substantially increased. Wires must have defined separation from other wires and roofs.

Control: A primary protector is required on each circuit that is not grounded or interrupted with a block, and where potentially exposed to power lines or lightning. The primary protection can be an integral part of the NIU.

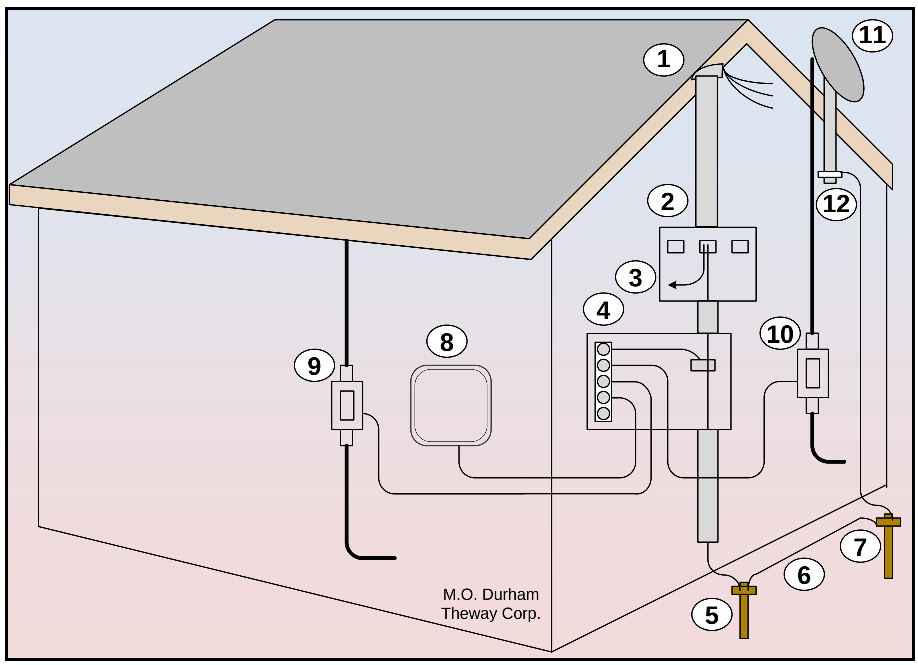
The grounding conductor shall be insulated and listed. The conductor shall not be smaller than 14 AWG or larger than 6 AWG. The conductor shall not exceed 20 feet in length. Where separate electrodes are used, a bonding jumper not smaller than 6 AWG shall be connected between the communications grounding electrode and power grounding electrode.

Mobile home distance to a grounding electrode is within 30 feet and in sight of the entrance. The ground must be bonded to the metal frame with 12 AWG or larger.

5.7 INTERSYSTEM BONDING

The drawing illustrates the inconnection of the bonding and grounding for the various electrical systems entering a structure.

All bends should be greater than 8 inch radius to keep inductance down for high frequency transients. The maximum length of a ground conductor should be 20 feet to keep high frequency impedance to acceptable levels.



Intersystem bonding & grounding

#	Device	NEC
1	Feeder with utility ground	NESC
2	Meter-connect utility gnd to gnding electrode conductor	250
3	Service panel - neutral connect to ground	250 - II
4	Intersystem bonding point for all grounds	250.94
5	Grounding electrode conductor >#6	250.66
6	Grounding electrode – bond all	250 - III
7	Grounding electrode within 20 ft of antenna	810
8	Telecommunications with discharge	800
	Network interface with discharge	830
9	CATV discharge / block unit	820
10	Antenna discharge unit	810
11	Antenna coax	810
12	Antenna ground	810

5.8 REVIEW

Utilities are any supply and signal that is external to the structure.

Electric utility provides electric power to the structure.

- Utility installation, operation, maintenance is covered by *NESC.*
- Utility fuses do not protect the structure or equipment.
- Multi-point grounds are a major problem and source of stray currents.
- The structure ground is from a derived source and is not multi-point.
- Transients or surges on power lines transfer to the strucutre.

Communication circuits are voice, audio, video, data, etc. These systems are governed by *NEC* Artcles 800 ff.

- These are basically analog systems.
- A primary protector is required on each circuit.
- The metallic sheath must be interrupted or grounded at the entrance.
- The ground connection must be < 20 ft away.

Radio and Television antennas are governed by *NEC* Article 810.

- Antennas must be located well away from overhead power conductors.
- Antennas need a discharge unit.
- The mast must be grounded.

CATV sytems are governed by *NEC* Article 820.

- The metallic sheath of coax must be grounded at at the entrance.
- The ground must be within 20 ft (30 ft for mobile homes).

Network Powerd Broadband systems are governed by *NEC* Article 830.

- Basically this is digital, high-spead computer networks.
- A primary protector is required on each circuit.
- The ground connection must be <20 feet from the entrance.

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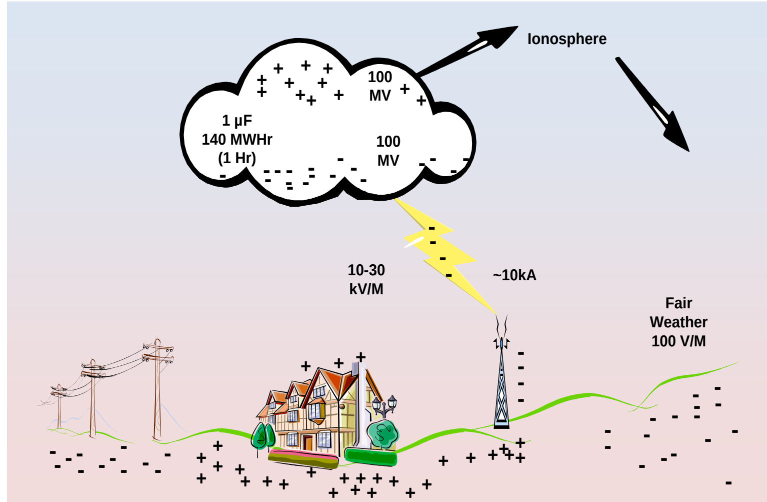
Chapter 6 – Lightning

6.1 Introduction

Lightning is at once fascinating, dangerous, and little understood by most. Lightning is considered an act of God by many.

Think about other weather conditions such as rain and temperature. These are equally an act of God. However, we have learned to control them with buildings and other structures. Similarly, lightning can be controlled and directed by following industry practices and standards.

The origin of lightning, like other weather, is an act of God. However, damage due to lightning is an act of negligence or omission in most incidences we have investigated. The authors have conducted research and written extensively about lightning and grounding. These papers form the basis and background for the observations included.



Lightning circuit

6.2 Differential potential

There is a voltage or potential between a cloud and the earth. The voltage is spread over the distance separating the two. The result is an electric field or voltage gradient.

Regardless of the presence of a thunderstorm, there is always a gradient in the air. These are all examples of a vertical electric field.

Similarly, as a cloud moves over the surface of the earth, a horizontal potential develops between areas under the cloud charge and those outside the cloud. Furthermore, the earth resistance and the electrical ground are not uniform, which causes a horizontal potential.

Any potential difference, whether vertical or horizontal, can create a discharge resulting in injury or damage.

Discharge on edge of metal vent

Lightning discharge on aluminum vent

6.3 Lightning transients

Before addressing the failure analysis, the characteristics of lightning and transients should be identified. There are three possible vehicles for lightning influence. These are (1) a *direct strike*, (2)an *indirect strike* or induced potential, and (3)an *earth charge*.

For the first mechanism, a *direct strike*, lightning is simply the discharge of electromagnetic energy developed above the earth. It discharges through a conductive path to earth. The discharge path is often metal. However, trees and posts in earth also make a good path. Concrete is also a possible path because of its low resistivity compared to most soils.

The actual discharge is a direct strike. A direct strike carries the full energy and results in the most damage. This is what most people think of when they discuss a lightning strike.

Lightning discharge on CSST

Arcing from indirect strike

The second mechanism, an *indirect strike*, will also result from a discharge. A potential is built up between the cloud and earth. Any conductive surface within this field will develop a proportional potential. When the cloud discharges, a charge remains on the metal and must be dissipated. This remaining energy will find all possible paths to earth.

The charge typically builds on a metal surface with a large area that rises above the earth. This may be a metal chimney, flue pipe, antenna, transmission line, or similar conductor. The charge travels along the metal to a point of discharge. The energy then can discharge to a surface that has a lower impedance path to earth. Since the charge build-up and the resulting potential difference is quite large, it can easily “jump” across normal electrical insulation as well as a substantial air gap.

Arcing of lightning on brass gas fitting

For the third mechanism, *earth charge*, the earth will be energized by lightning in the area of impact. The charge creates a higher potential than both the surrounding earth and conductors in contact with the earth. The energy will dissipate to form a uniform field. The result of this dissipation is current flow from the area of impact. All conductive paths in the area will develop current flow.

Adjacent conductors will not develop a large potential difference. Remote conductors, however, can have a substantial difference in potential as a result of this earth charge.

6.4 STROKES

A lightning strike is not a single event. The strike begins with a down stroke toward the earth. An upward leader meets the stroke. A return stroke then completes the process. A detailed analysis is discussed in the authors’ technical papers.

Discharge to bolts on air conditioner

As air is ionized from the initial strike, the impedance of the air is reduced. This may result in multiple strokes in a very short span of time. These may discharge to the same location or a nearby area. This would be recognized as multiple strokes.

A single strike will create a dispersed field near the area of discharge. The energy is not discharged at a single point; it will be distributed to numerous spots. If the metal surface that carries the charge to earth is lightweight enough, the dispersed discharge will look like numerous pits on the metal surface.

St. Elmo’s fire is visual plasma created by a corona discharge about a grounded object during a thunderstorm. The phenomenon clearly shows the dispersed effect of the electromagnetic field. We have observed arrays which distribute lightning energy create an effect of St. Elmo’s.

Discharge between CSST and cable

Ball lightning is another dispersed electromagnetic field that is visible. Ball lightning is generally a spherical shape which develops and often travels along a conductor to a discharge point. It is a long duration phenomenon and may last for seconds.

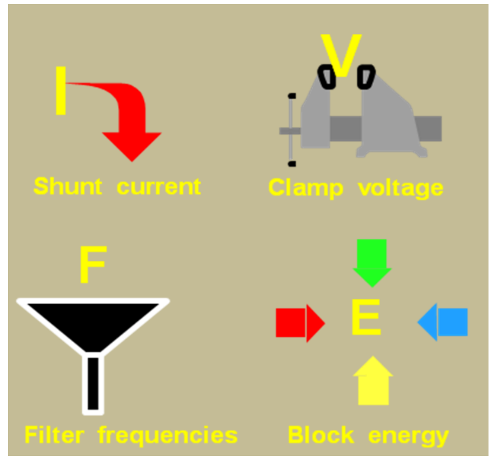
6.5 CONTROL

Lightning is simply the discharge of an electromagnetic (EM) field. Since lightning is electromagnetic energy, it can be managed as any other circuit.

Three measurements completely describe EM energy. Voltage is the potential or pressure. Current is the flow rate. Frequency is the inverse of the time for the signal. By controlling all three measures, lightning can be managed.

Voltage is clamped at a threshold level that precludes damage. Current is diverted to earth. Energy of a particular frequency is filtered from the conductor.

Energy that is developed in a cloud is attempting to return to earth or ground potential as lightning. Hence, an excellent ground network is the critical element of a lightning management system.



Transient control

6.6 GROUND

An electrical grounding system uses a single point as a reference for all measurements. This is called the grounding electrode.

In an attempt to create minimum potential difference in the ground system, all grounding electrodes that are present at each building or structure served must be bonded together to form the grounding electrode system.

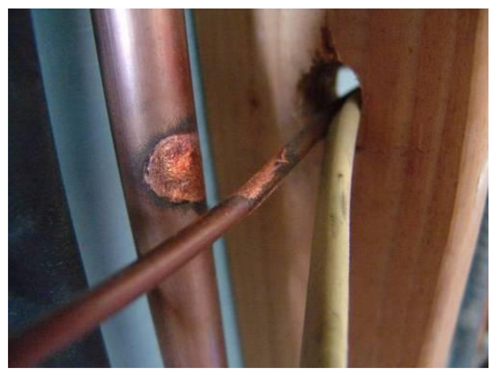

Potential difference panel to ground

6.7 BOND

A bond is a connection between metal surfaces that may be energized.Assuming there is an adequate ground, bonding is crucial. Three factors impact the effectiveness of the grounding and bonding conductor.

- First, conductor diameter should be AWG 4 or larger, to minimize resistance.
- Next, the distance from the bond to the ground should be less than 20 feet, to minimize impedance.
- Finally, the route must be as direct as possible with only sweeping bends, to minimize inductance.

Other than the size, these factors correlate to *NEC* Article 820 requirements for communications circuits.


Potential difference ground to AC tubing

6.8 ERRORS & OMISSIONS

The following are five preventable incidents that were investigated in a three-month period. This is by no means a complete list of our lightning investigations, but is representative of the types of errors that are related to lightning damage. The lightning event was verified by witnesses or lightning reporting services.

6.8.1 CLEAR AIR AND END POLES

Must the lightning occur at the point of discharge? No, the charge can build up in one region and travel along a conductive path and discharge in another location. Further, the charge can be distributed over a long area such as a power line.

Clear-day lightning may build up along an overhead power line. If there is not an alternate path, the discharge is typically at an end pole on the line.


End pole on power line

The end pole sees a reflection of the incoming wave. As a result the voltage transient at the end of the line is twice as large as at other points.

Energized neutral melted insulation

6.8.2 POOR GROUND ELECTRODE

What is the effect of a high resistance ground rod? Any fault current will take an alternate path to earth and will damage items in the path. A ground rod at a service meter pole had virtually no contact with earth. The resistance was 800 Ω, which is approaching no connection.

A transient fault occurred and took two identifiable paths. One path was another overhead triplex cable. The uninsulated grounded neutral carried excessive energy. This caused the insulation on the other two phase conductors to melt in the shape of the neutral. The insulation on the opposite side was unaffected.

Unbonded rebar arc through concrete

6.8.3 REBAR

What is the effect of not bonding concrete encased metal and rebar to the electrical ground system? The potential difference will damage the concrete and create enough discharge energy to ignite combustibles. The ground on the system met the letter of the Code but was not good. The resistance was 6.5 Ω, but sharp bends increased the inductance.

A lightning strike entered the structure at the peak above the second floor on the northwest side. The first contact with metal was a bundle of 21 non-metallic (NM) cables that were routed to the circuit breaker panel.

Rather than take the torturous path of the grounding electrode conductor with sharp bends, an alternate path was identified by arcing. The circuit breaker panel cover was removed during construction. The panel arced to a metal grate leaning against the panel. The grate arced to the panel cover setting on a concrete floor. The energy arced through the concrete creating spralling.

Flexible pipe arc to wiring

6.8.4 GAS PIPE

Should gas lines be grounded or bonded? The Code is clear that they as well as other metal piping should be, but some jurisdictions prohibit the connection, since they improperly interpret bonding as grounding. In many installations we have found that the connection simply was not made.

The electrical ground resistance was excellent with 0.7 Ohms. The flue to an HVAC unit is a large metal surface area that protrudes above a structure. It is a ready entrance for lightning energy, whether direct or indirect. A strike will penetrate the cap with nail size holes. Arcing is noted along the pipe joints.

The lightning energizes any metal connected to the unit. This includes gas line, copper air-conditioning lines, and electrical conductors. Seldom does rigid steel gas pipe have a failure. However, flexible metal lines will be penetrated if crossing another metal conductor including insulated electrical wires.

Satellite dish ungrounded

6.8.5 SATELLITE DISH & CABLE

Will coax cable carry enough energy to cause a fire? Must satellite dish and coax cable be grounded and bonded? Coaxial cable is designed to carry high frequency electromagnetic energy in the form of television signals. Lightning is a high frequency signal with substantially more energy. So, lightning will preferentially travel along a coax.

Lightning struck the post of an ungrounded dish mounted to a roof. A hole was blown in the steel post. The cable splitter was destroyed at the terminations. The cable jacket was split but otherwise appeared intact. The foam filler, shield, and copper had become plasma and vaporized.

Bolts severed on ungrounded dish

Vent entrance for lightning

6.9 GROUNDING & LIGHTNING

The origin of lightning, like other weather, is an act of God. However, damage due to lightning is an act of negligence or omission in most incidences we have investigated.

Grounding and lightning control is included in the *Codes* for protection of persons and property. Protection can be provided if the system is properly installed. If there is damage due to lightning, there is most likely a problem with the installation.

NFPA 780 Standard states in the introduction:

> The lightning risk assessment is provided to assist the building owner, safety professional, or architect/engineer in determining the risk of damage or injury due to lightning…Once the level of risk has been determined, the development of appropriate lightning protection measures can begin.

Clearly a lightning risk assessment should be made. Then the decision is what type lightning protection is required. If an assessment is not made and an appropriate system installed, the identified parties are negligent or worse. How many assessments are actually conducted?

A common perception is that lightning caused incidents have no recourse. That has been proven as incorrect in numerous incidents. The failure to provide and install a proper system is the basis for most incident recovery.

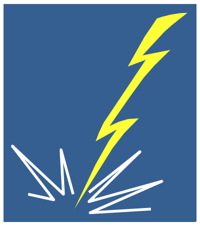
You cannot sue God, but you can show negligence by people for improper and inadequate systems.

6.10 LIGHTNING REPORT

Lightning activity is recorded by a number of entities. One of the organizations is Vaisala. These reports can be used to identify the proximity of a strike and other properties of the event.

The probability of a strike depends on a confidence ellipse that is calculated from their detection antennas.

The illustration is one page of the report and is shown based on the proximity of a strike. Recall that lightning damage can result from a direct strike, indirect strike, and ground current. Therefore, the strike does not have to be at ground zero for it to affect a structure.



Lightning incidents

STRIKEnet®

STRIKEnet Report 276872

Report Title: STF / Ramos
Total Lightning Strokes Detected: 1149
Lightning Strokes Detected within 10 mi/16 km radius: 822
Lightning Strokes Detected beyond 10 mi/16 km whose confidence ellipse overlaps the radius: 327
Search Radius: 10 mi/16 km
Time Span: Jun 16, 2008 05:00:00 PM US/Central to Jun 17, 2008 04:59:00 PM US/Central

Lightning Stroke Table (Note: Closest 50 events shown. Events ordered by distance.)

Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Jun 17, 2008	08:39:38 AM	139.8	0.1/0.2	35.3951	-97.4209
Jun 17, 2008	07:43:55 AM	-8.0	0.3/0.5	35.3898	-97.4188
Jun 17, 2008	07:43:55 AM	-53.5	0.6/1.0	35.3934	-97.4294
Jun 17, 2008	07:43:55 AM	-23.8	0.6/1.0	35.3907	-97.4285
Jun 17, 2008	07:53:06 AM	-47.6	0.6/1.0	35.3859	-97.4220
Jun 17, 2008	07:25:09 AM	-14.5	0.7/1.2	35.3847	-97.4233
Jun 17, 2008	07:43:55 AM	-27.6	0.8/1.2	35.3936	-97.4318
Jun 17, 2008	07:25:09 AM	-21.8	0.8/1.2	35.3847	-97.4250
Jun 17, 2008	07:28:04 AM	-34.8	1.1/1.7	35.3883	-97.4012
Jun 17, 2008	07:26:18 AM	-9.5	1.1/1.8	35.3907	-97.4374
Jun 17, 2008	07:26:18 AM	-12.5	1.2/1.9	35.3924	-97.4393
Jun 17, 2008	07:42:02 AM	-31.0	1.2/2.0	35.4080	-97.4328
Jun 17, 2008	07:42:01 AM	-10.4	1.3/2.2	35.3955	-97.4423
Jun 17, 2008	07:08:02 AM	-11.9	1.4/2.3	35.3942	-97.3932
Jun 17, 2008	07:42:01 AM	-17.7	1.4/2.3	35.3936	-97.4436
Jun 17, 2008	07:42:01 AM	-45.8	1.4/2.3	35.3946	-97.4441
Jun 17, 2008	07:45:13 AM	-22.1	1.5/2.4	35.4074	-97.4397
Jun 17, 2008	07:42:01 AM	-34.1	1.5/2.4	35.3953	-97.4452
Jun 17, 2008	07:25:09 AM	-41.1	1.6/2.7	35.3711	-97.4243
Jun 17, 2008	07:45:13 AM	-35.9	1.7/2.7	35.4149	-97.4340
Jun 17, 2008	07:42:01 AM	-23.6	1.7/2.7	35.3984	-97.4477
Jun 17, 2008	07:28:39 AM	-7.1	1.7/2.8	35.3716	-97.4071
Jun 17, 2008	07:45:14 AM	-27.5	1.7/2.8	35.3873	-97.4476
Jun 17, 2008	07:45:14 AM	-28.7	1.7/2.8	35.3873	-97.4481
Jun 17, 2008	07:45:13 AM	-29.9	1.8/2.9	35.3883	-97.4493
Jun 17, 2008	07:45:14 AM	-69.8	1.8/2.9	35.3857	-97.4486
Jun 17, 2008	07:28:04 AM	-32.1	1.8/3.0	35.3781	-97.3929
Jun 17, 2008	07:25:10 AM	-6.8	1.9/3.1	35.3751	-97.4423
Jun 17, 2008	07:30:55 AM	-4.9	1.9/3.1	35.3756	-97.3934
Jun 17, 2008	07:27:00 AM	-24.5	2.0/3.2	35.4057	-97.3863
Jun 17, 2008	07:25:30 AM	-5.5	2.1/3.4	35.3848	-97.3827
Jun 17, 2008	07:25:30 AM	-21.3	2.1/3.4	35.3851	-97.3825
Jun 17, 2008	07:25:29 AM	-27.0	2.1/3.4	35.3853	-97.3823
Jun 17, 2008	07:45:13 AM	-22.6	2.1/3.4	35.3738	-97.3902
Jun 17, 2008	07:25:29 AM	-6.6	2.2/3.5	35.3848	-97.3813
Jun 17, 2008	07:25:30 AM	-15.2	2.2/3.6	35.3842	-97.3809
Jun 17, 2008	07:16:41 AM	-6.9	2.2/3.6	35.4139	-97.4502

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Chairman, Production Subcommittee, IEEE/IAS/PCIC
Voting Member-Electrical, Nat'l Fire Protection Assoc
CESE Professional Engineering Instructor, U of Tulsa

He is a nationally recognized author; having received several awards for the over 46 papers and articles he has co-authored. He has published three books and five eBooks used in university level classes.

Dr. Durham's extensive client list includes the development of a broad spectrum of forensic, electrical and facilities projects for many companies. He specializes in power systems, utility competition, controls, and technology integration. His technical emphasis has been on all aspects of the power industry from electric generating stations, to EHV transmission systems, to large-scale distribution systems and power applications for industrial locations to audit of market participation in competitive utility markets.

Dr. Durham received a B.S. in electrical engineering from the University of Tulsa, and M.E. in Technology Management from the University of Tulsa. Dr. Durham earned a PhD in Engineering Management from Kennedy Western University.

Rosemary Durham, CFEI, CVFI

Rosemary Durham is the Chief Administrative Officer and Past-President of Theway Corp. in Tulsa, OK. Professional recognition includes the following.

Certified Fire & Explosion Investigator, NAFI
Certified Vehicle Fire Investigator, NAFI
Licensed FCC Amateur Radio Tech
Member, Int'l Assoc of Arson Investigators-OK

She has co-authored two technical papers. She has co-authored three books on leadership, two books on theology, and two eBooks for university level classes. She is acclaimed in the *National Registry of Who's Who*.

She is a photographer, who has analyzed the photography record for over 1000 fires and failures. She has been active in traveling to over 15 countries on business and development. She has extensive training from The Crowning Touch Institute. Her credentials are Certified Advanced Color Analyst: Introduction, Intermediate, and Advanced Color analysis and Image analysis.

Rosemary received the AB from Ayers Business College. She has additional studies at Imperial Valley College, Tulsa Community College, Oral Roberts University, Southwest Biblical Seminary and Trinity Southwest University.

JASON A. COFFIN, CFEI, CVFI

Jason Coffin is a Technical Consultant for Theway Corp. in Tulsa, OK. His specialty is information systems and failures. He is a Construction Manager who develops upscale properties. He is also a natural resources developer and operator who owns interest in numerous properties. Professional recognition includes the following.

Certified Fire & Explosion Investigator, NAFI
Certified Vehicle Fire Investigator, NAFI
Certified Lead Renovator, EPA
Member, Int'l Assoc of Arson Investigators-OK & AR

He has actively worked hundreds of fires and failures.

Mr. Coffin received the BS in Information Systems from Rogers State University in Claremore and the MS in Information Systems from The University of Tulsa, Oklahoma.

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6.11 ELECTRICAL SHOCK SURVEY

Please complete an additional survey, if you have been shocked more than one time.

1. Have you ever been shocked? Yes ___ No___
2. What voltage? 9V___ 12V___24V___48V___120V__200V__400V__Higher V__
3. Was the voltage ac___ dc___ rf___ frequency ___
4. What was the cause? intentional___ accidental contact___ failure of what component____________
5. What was the machine / device / equipment ____
6. What insulation or material was between you and the electrical circuit? none___ material_________
7. Part of anatomy contacting the energized point____
8. Part of the anatomy contacting the metal or ground or common ______________________________
9. Could you still control your muscle movement? Yes___ No___
10. How did you "get off" the energized circuit? fall___ someone assisted___ removed self_____
    brushing contact___ explain other ____
11. Discuss any sensations you recall
    a. Taste ____
    b. Smell____
    c. Hearing____
    d. Sight____
    e. Touch / feeling ____
    f. Mental / thoughts____
    ____
12. Describe any known permanent injuries as result ____
13. Describe any additional details of your experience with electrical shock? ______________________
    ____
    ____
14. Approximate age at time of incident _______
15. Profession / major ___________________________ City _________________________ State____
16. Optional: name_______________________ email _____________

Return to:

Dr. Marcus O. Durham, PhD, PE
THEWAY Corp
PO Box 33124
Tulsa, OK 74153

mod@thewaycorp.com
www.ThewayCorp.com

6.12 *EVALUATION FORM - ELECTRICAL FAILURE ANALYSIS - LIGHTNING*

It has been a pleasure to have you participate in this program. To assist in conducting future Continuing Education programs, we would like you to evaluate the contents of this short course. Please take a minute to complete this evaluation form.

Name ______________________________ Title ______________________________

Organization ____ FAX ____________

E-mail ____

What is your overall evaluation of this program?

( ) Excellent ( ) Good ( ) Satisfactory ( ) Unsatisfactory

What did you most like about the program? ____________________________________

What areas were best covered? ____

What areas would you like to discuss more or in more detail? 1. ___________________________

2. ____

3. ____

For people in your position, what information could be reduced? ___________________________

What were your expectations for the class at the beginning? _____________________________

____

Did the class meet your expectations? ____

For our use in possible promotional materials for future programs, we would like to have your comments on this short course:____

____

____

What are other classes that you would like to see offered? ______________________________

What is your job description?

( )Adjuster ( )SIU ( )Subro ( )O&C ( )Attorney ( )Staff ( )Engineer ( )Other__________

Are you licensed? ( )PI ( )Attorney ( )Engineer ( )Electrician ( )Public ( )Other __________

Are you certified? ( )CFI ( )CFEI ( )CVFI ( )Insurance ( )Others ____________________

To which professional association(s) do you belong? _________________________________

How did you first hear of this short course?

( )brochure ( )received at association meeting ( )mail ( )email ( )word of mouth

( )other - please explain ____

Who in your company should be contacted about future programs (Please give name, title, and contact info)

____

NOTE: PLEASE COMPLETE AND RETURN TO THE PROGRAM COORDINATOR OR INSTRUCTOR. THANK YOU!

FINIS

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