

What You Don't Know About Grounding Can Hurt You

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Abstract - What the telephone guy, engineer, installer, electrician, dairy farmer, veterinarian and homeowner don't know about grounding can and often will get 'em in the end. Yes, that end. This presentation will focus on the many - if seemingly unrelated - commonalities between telecom facilities and central offices, data centers, dairy farms and residential homes or businesses and how effective grounding and bonding techniques and properly designed and applied electrical protection can make the difference between annoyance and tragedy during common electrical perturbations. Examples of failures will be shown as will practical examples of how relatively cheap improvements would have changed the outcome for the better.

I. Why do nearby lightning strokes present such a threat?

Lightning energy dissipates across the surface. Therefore, when lightning strikes the earth it energizes a large area of soil often called a "Ground Potential Rise (GPR). Until the voltage is dissipated, this area of raised potential therefore has a much higher voltage potential than the surrounding soil. From the site of the lightning strike to a place that is totally unaffected by the GPR could be as much as kilometer or more. This area that is unaffected is called "Remote earth" for it is remote to the area of the GPR. Depending on the soil characteristics, mineral content, hydration etc, the soil has a measurable value of electrical resistance. Because of soil resistance, the soil therefore gives the electrical appearance of a network of series parallel resistances between the point of the lightning strike and Remote Earth as shown in Figure 3.

Picking the hypothetical values of a half million Volts and a kilometer area of GPR with respect to Remote earth, the series voltage drop across each meter of earth could be 500 Volts.

This is the reason that farm animals often succumb to lightning strikes, the so called "Step potential" or the voltage drop across the span of their legs is great enough to cause death (Fig 1). Indeed, in a lightning related accident in South Jersey in 2007 a man standing in his front yard was injured when lightning struck nearby. The legs of his denim jeans burst off him in flame and tatters and his legs suffered serious skin and deep tissue burns yet the man's upper body had no injury. Step potential is the likely cause of this frightening

injury. Additionally, long runs of poorly grounded fence wire also contribute to the loss of livestock (Fig 2).

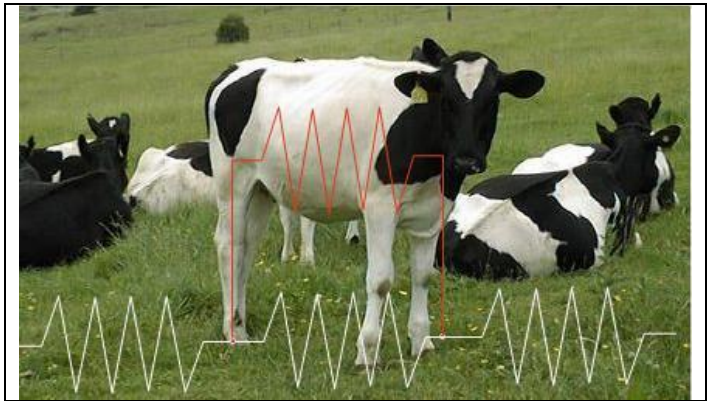


Figure 1 Step potential in livestock.

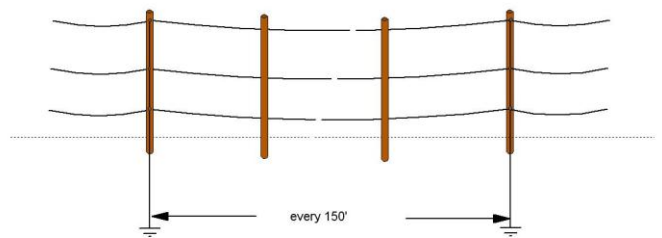


Figure 2 Long runs of fence wire can expose livestock to huge electrical potentials during nearby lightning strikes. Has these wooden fence posts been metal ones or had bonding wires or galvanized steel fence posts connected each lateral wire together and to a solid connection to earth ground every 150 feet the difference in potential in any section of fence would have been far less lethal.

Considering the impact of a Ground Potential Rise on a building some 40 meters square as shown in Figure 4, the difference in potential could be some 20 KV. Obviously such voltages could cause significant injury or equipment damage unless very detailed means are employed to minimize the voltage stresses across equipment buildings and the systems within them.

Interestingly, even Amish farms that have no electricity on them are experiencing problems from return current and electrical faults. Figure 3 shows why. Fault current may flow through soil from one farm through another to reach a ground source.

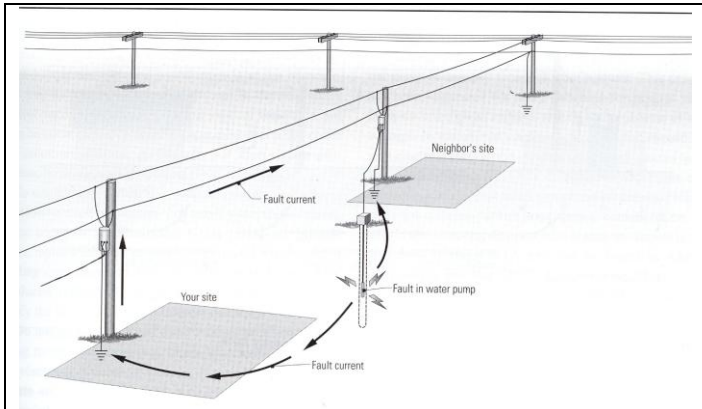


Figure 3 A ground fault on one farm can place stray current into the soil of a neighboring one.

What have these farm issues to do with modern telecommunications facilities and data centers? The fact is that bonding and grounding are critical to all of them. Figure 4 shows the fault relationship between cattle and electronics to unwanted current. In digital electronics, a 5 Volt pulse is interpreted as a logic 1. Because of wiring losses, anything above typically 3 volts is considered a logical 1 and anything less, a logical 0. Accordingly, ground faults greater than 3 volts cause problems. Cattle are electrically sensitive critters with a fairly low internal impedance of about 500 Ohms.

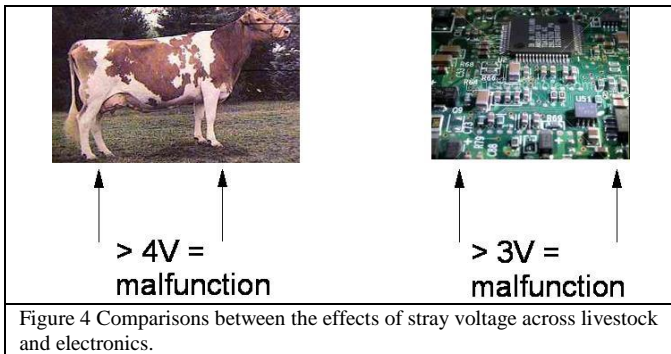


Figure 4 Comparisons between the effects of stray voltage across livestock and electronics.

For the central office, a data center or a milking barn, simply bonding each building column to a buried electrode

counterpoise ring dramatically reduces the potential for damage (Figure 5).

Another approach is to provide a grounded steel mesh concrete reinforcement element. In addition to strengthening the concrete floor slab, the grounded mesh reduces the overall resistance of that area essentially providing a shunt path for the unwanted current. Often, swimming pools are protected the same way with a well grounded conductive mesh embedded in the pool's concrete.

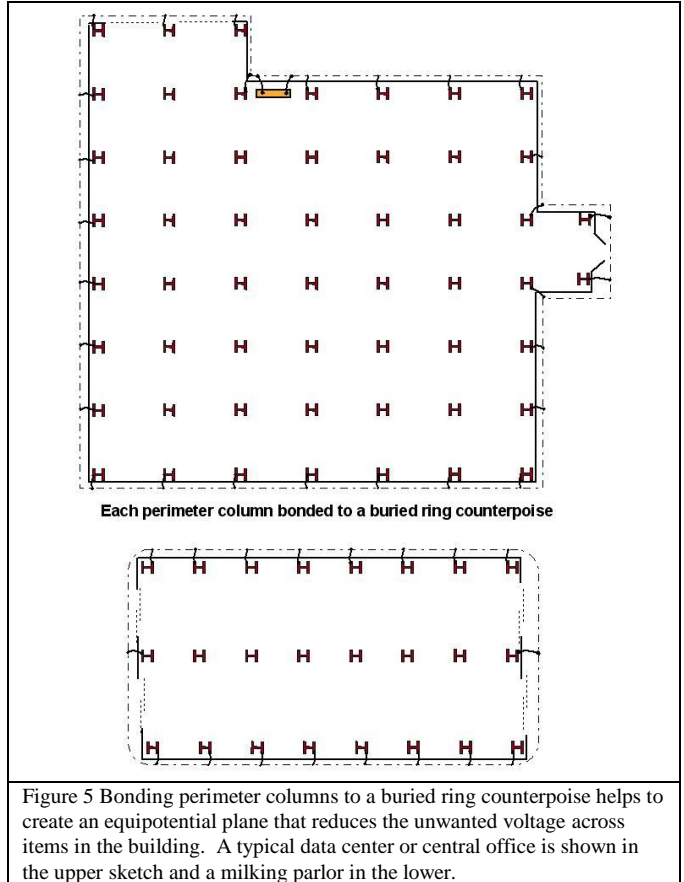


Figure 5 Bonding perimeter columns to a buried ring counterpoise helps to create an equipotential plane that reduces the unwanted voltage across items in the building. A typical data center or central office is shown in the upper sketch and a milking parlor in the lower.

Engineers responsible for central offices in lightning prone areas would do well to consider providing air terminal protection (lightning rods) to protect the investment in building and systems. Properly designed and installed air terminals offer lightning currents a safe alternative path to ground and thus avoid damage. In this author's experience simple Franklin type rods, either blunt or pointed provide excellent protection when properly connected to down conductors and the earth. Franklin rods describe a type not a brand of air terminals. Franklin rods are simple lightning rods and were first designed by Benjamin Franklin, hence the name.

Some say that lightning rods will attract lightning to a building but this is a myth and not substantiated by fact. Lab experimentation has shown that even wooden dowels are as likely to be struck as are copper or aluminum Franklin rods^[4] and so it's not a matter of attracting lightning but giving it a safe alternative path to ground thus shunting unwanted current around a structure to protect the structure and its occupants. The likeliness of being struck depends mostly on height and isolation.

OK so I'm out playing golf and a thunderstorm rolls in what do I do? Your objective is to seek shelter quickly. First, if you have golf cart use it and get to shelter! Do not isolate yourself by riding down the middle of the fairway! Instead, ride maybe 40 or 50 feet from the tree line and don't hide under the trees either because the threat of a side flash looms large. Keep your hands close together on the steering wheel or use only one hand. While driving, remember the words, "Our Father who art in Heaven", and hustle to shelter.

If you're caught outdoors and can get into a metal bodied vehicle – do it. The skin effect from the vehicle offers a lot of protection. If you're standing outdoors and no shelter is available and lightning is close or you feel your hair standing up, assume the "lightning Crouch." This position is to crouch low, keep your feet as close together as you can balance and cover your ears with your hands. You want to make your body "look" like a basketball standing on one foot.

II. *Protect your building*

Lightning rod systems are well understood however the design and installation of these systems goes a long way towards establishing a level of protection. While any electrician knows how to cobble together the hardware for a lightning rod system, very basic issues such as the way a wire is routed or how it is bent makes big differences in how well the system will perform. This author has seen some very poor lightning protection work over the course of his career.

In the US, there are three affiliate organizations that should be considered when adding lightning protection to a central office or other network structure. The United Lightning Protection Association (ULPA) and the Lightning Protection Institute (LPI) both are well established organizations that set strict guidelines for the quality of a design or installation by member companies. It is important that a US engineer specifying lightning protection for his or her project also specify that a contractor in good standing with either of these two organizations be used. Further, it is prudent to specify that the job should come with a "UL Master Label." This means that the contractor will commission a local representative from Underwriter's Labs

(UL) to inspect and certify the installation. There are similar trade affiliations in Europe that should be considered.

III. *Bonding and Grounding is not Voodoo*

Bonding and grounding precepts are a result of well established science. However, it's somewhat different set of scientific rules than the ones governing dc or low frequency as electrical systems. Most people in telephony are intimately familiar with Ohm's Law and its various applications in dc systems and line frequency ac systems. When ac is involved, the term "resistance" gets replaced by the term impedance to express how current flow is opposed by circuit conditions.

Circuit impedance is composed of a number of factors including the frequency of the ac current being conveyed. Lightning and electrical surges or line transients both have very fast rise times from zero Volts to the thousands, tens of thousands or even millions of Volts. As the frequency of the ac increases so does the reactance and impedance of common electrical components including wire and cable. Even a few extra feet of wire can raise the impedance of a wire by thousands of Ohms of impedance and degrade the performance of a surge arrester or a ground lead. Sharp bends also dramatically increase the impedance of wire. So, protection from high frequency anomalies such as lightning and line transients is the science of keeping lead lengths short and making sweeping bends instead of sharp ones.

"Touch potential" is a term used to describe some conductive item such as a panel or motor frame that becomes energized and someone who might touch that item is in danger of completing an electrical path to some grounded part and become shocked, burned or even killed. When such items are bonded together, they are at the same electrical potential and therefore no touch potential can exist. The familiar 3-wire cords on electrical tools etc are an example of preventing Touch Potentials because the 3rd wire provides a safety ground connection to the chassis. If there is an internal fault the 3rd wire will protect the user because the housing is at ground potential and if the electrical fault is significant the feeder circuit breaker will operate.

Grounding provides a safety path capable of clearing a fuse or circuit breaker in the event that an internal fault would energize a chassis, frame or cabinet (Fig 6). While this seems very fundamental, it is common to visit a telephone network remote terminal, microwave hut or cell site and find that the dc battery plant is not referenced to ground. Usually such visits are prompted by lightning damage to systems and engineers or technicians performing such work should be alert to verify that in fact the battery is in fact connected to an earth referenced ground source.

Some equipment vendors have placed greater emphasis on grounding their products because it improves performance and reduces the likelihood of damage. In addition to Framework Ground leads there sometimes is yet another bonding connection that some call a “NEBS Ground.” Cisco Systems [12]CRS-1 Router is being widely deployed in Telecommunications applications and this unit includes a “NEBS Ground” extra terminal.

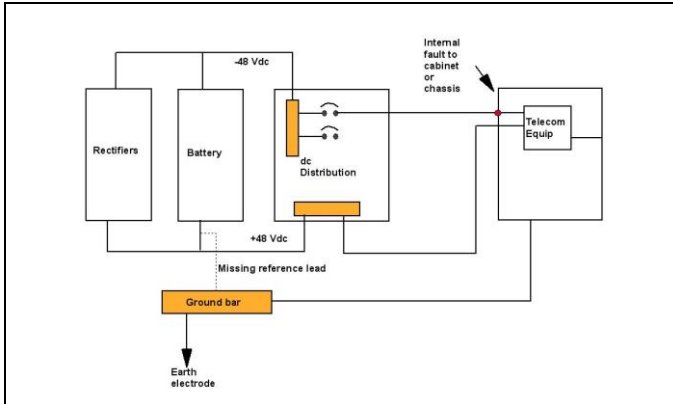


Figure 6 when the battery plant is not referenced to ground there is no fuse or circuit breaker clearing path to prevent Touch Potentials and the equipment cabinets may become an electrical hazard.

Of what use is an expensive ground system if someone steals it? Global demand for electrical wiring has produced a huge increase in the commodity cost of raw copper. With that increase is a corresponding rise in copper thefts. The theft of copper ground bars, ground rods, exterior cabling etc. is reaching epidemic proportions at cell and microwave sites.

Most telcos use copper bars and copper ground rods as a standard practice because copper is a highly weather resistant good conductor of electricity. As a practical matter though, if the copper gets stolen, why keep replacing it with more copper? The fact is that most of the bonds and grounds for wireline telephone network outside plant cabling, tower legs, and electric utility ground rods rely on galvanized steel. Galvanized steel is highly weather and corrosion resistant and a good conductor of electricity. Further, galvanized steel is cheap and unattractive to thieves. There is no reason why hot dip galvanized steel cannot be used for exterior ground bars and ground rods.

Galvanizing is a process for preventing corrosion (rust) on steel by applying a layer of zinc over the steel. Zinc is very resistant to corrosion in damp or wet environments. There are two methods for galvanizing, plated and hot dipped. Plated zinc is known to cause problems and therefore what should be specified is “Hot dipped” galvanizing per A.S.T.M. Specification A 153/A 153M-05. [14] Also important is the issue of dissimilar metals

when making outdoor connections. When metals are dissimilar and in contact with each other there is a likelihood that the metals will interact with moisture and corrode. Essentially the water acts as an electrolyte in a chemical “battery” and the current flow corrodes the less noble metal. To prevent this corrosion condition from happening it is crucial that a thin coating of a good anti-oxidation grease be applied between the lug and the ground bar or ground rod.

One problem that occasionally arises in power grid substations or other places where fence lines are influenced by power lines is bonding and grounding the fence, especially at gates (Figure 7). Induced power can result in some very nasty shocks when someone opens or closes a gate. In such situations, the gate “looks” like a switch. Another induction issue comes into play when cellular radio base stations are mounted on electrical power pylons or towers. Technicians must be very careful about bonding their ladders or bucket trucks to the tower or radio cabinets to avoid shocks (Figure 8).

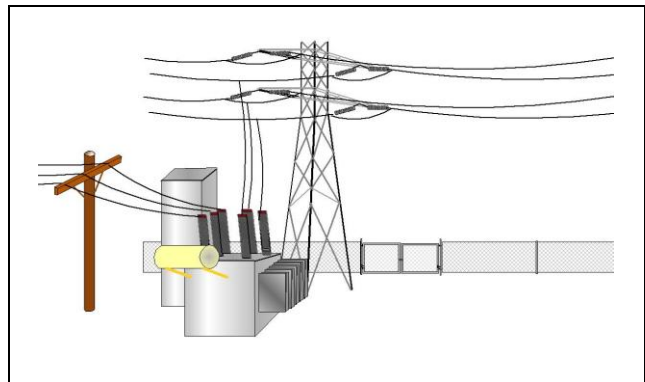


Figure 7 Bonding and grounding fences is critical when they are exposed to high tension lines.

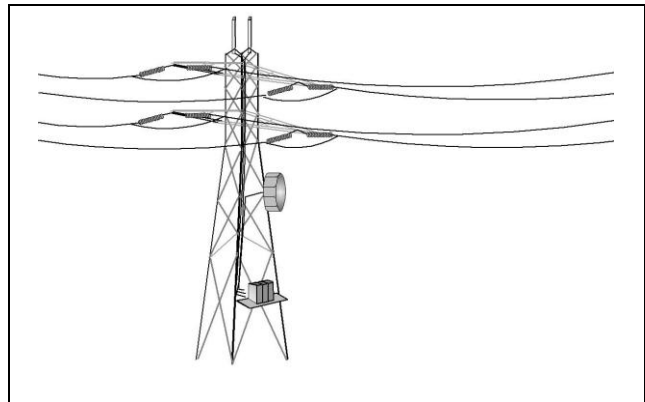


Figure 8 When radio equipment shares a utility grid tower bonding is critical to avoid injury.

Add-on screened porches or “lanais” can become a problem if they aren’t bonded to the building’s electrical system. Sometimes during installation a screw easily can pierce house wiring thus energizing the framework (Figures 9 & 10).



Figure 9 Add on screened porches with metallic frames need bonding to prevent shocks from electrical faults that occur when screws fastening aluminum track to the wall pierce wiring inside the wall and energize the framework.

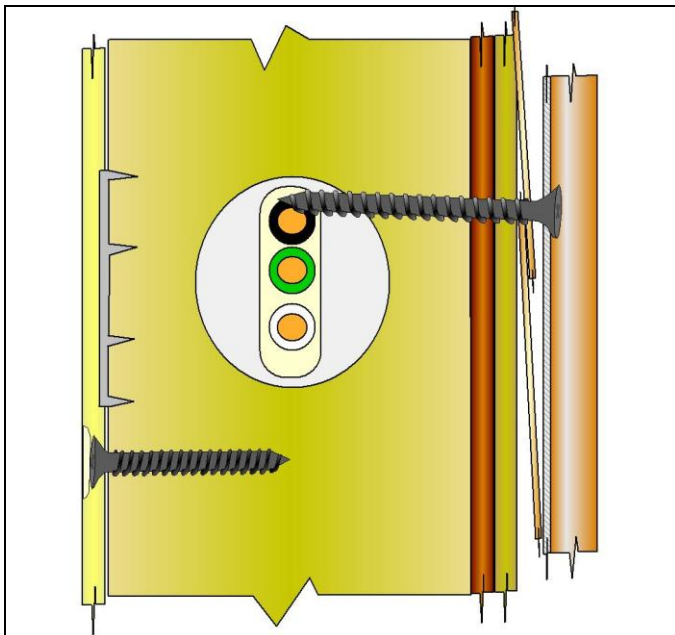


Figure 10 Add on porches with metallic frames need bonding to prevent shocks from electrical faults that occur when screws fastening aluminum track to the wall pierce Romex wiring inside the wall and energize the framework.

Just because a home was built with a well grounded service entrance doesn’t mean it stayed that way. Figure 13 shows a home (mine) where a previous owner added a lawn sprinkler system made of plastic pipe. The plastic tee interrupted the Ground path and it needed to be repaired by adding a jumper around the tee. Figure 14 shows a basement where the electrician used steel staples to support an aluminum ground wire and he drove those staples into mortar joints in the masonry wall. In the damp environment of masonry, a dissimilar metals corrosion cycle corroded the wire beneath the staples to where the sections of aluminum wire fell to the floor, opening the ground connection. Why is the loss of electrical ground to a home such a big deal? The loss of ground to a home service becomes a significant issue when a home is the

only electrical service drop on a transformer as might be the case in rural areas. Other properties such as farms, cell sites, microwave repeaters and any facility that is the only service drop on a transformer has an interesting risk. If the ground on the customer’s service equipment and the ground at the utility transformer both go open, the transformer no longer has a circuit path for the Primary. (Figures 11, 12) Without this path to ground, primary voltage (typically about 7KV) will be introduced into the home or business causing very dangerous conditions for electrocution and/or fire. Virtually every appliance, light or outlet could be energized to Primary potential with respect to ground (plumbing, heat ducts etc).

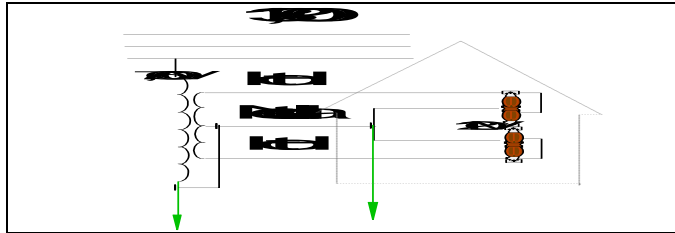


Figure 11 A simplified view of home receptacles with respect to the utility transformer

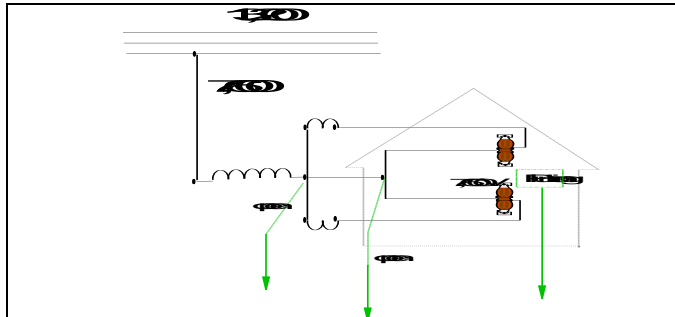


Figure 12 What the transformer “looks like” if the ground path fails. Primary voltage is introduced to the feeder and branch circuit wiring.



Figure 13 A lawn sprinkler addition made of PVC pipe interrupted the water pipe ground path with a plastic tee that needed to be jumped around.

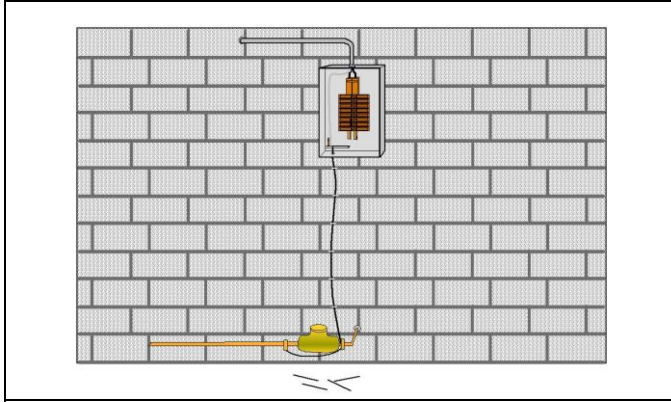


Figure 14. A poorly installed aluminum ground wire failed due to corrosion at support staples driven into the masonry.

Bonding water heater pipes as well as the gas line to Ground prevents lightning currents from instantaneously boiling the water into high pressure steam that could cause an explosion. Also obsolete, thin brass flex lines to gas ranges, dryers and the like should be replaced because lightning strikes to or near the building can result in flashover arcing that produces pin holes in the tubing and therefore, gas leaks in the home.



Figure 15 Water heaters need bonding for safety

Is the TVSS actually operating? This writer has seen numerous instances where the circuit breaker feeding a TVSS was left open and one case where the electrician failed to run the wiring between the circuit breaker and the TVSS.

Also, there are many, many cases where the wiring between a TVSS and the panel they are protecting is so long that the high impedance of such wiring causes a drastic increase in the unwanted voltages that are “let through” or get by the TVSS device. Leads should be short and straight and without sharp turns.



Figure 16 Long wiring loop between TVSS and electrical cubicles causes an excessively high let through voltage.



Fig 17 Cheap consumer grade devices with TVSSs not conforming to UL-1449 may initiate collateral fires when their MOVs burn up due to electrical fault such as an open Neutral lead or end of life.

It is critically important that those selecting TVSS devices insist on units that pass UL-1449. There are any number of cheap devices on the market that lack the "fail-safe" operation of surge suppression components contained in these devices under abnormal service conditions or "end-of-life" degradation modes specific to metal-oxide varistors. This is particularly problematic in Category A devices especially when TVSSs are incorporated in multi-outlet terminal strips common to office personal computers and similar installations.

When MOV devices are subjected to long-duration overvoltage such as might occur if a Neutral lead goes open the MOVs burn catastrophically. The provisions of UL-1449 demand that such devices fail safe. In the past 18 months, this author has investigated two incidents where cheap surge suppressor strips initiated collateral fires from burning MOVs in the strips (Figure 17). Other issues come into play when TVSS devices are housed in plastic boxes. The catastrophic failure of a MOV device could burn through the plastic and initiate collateral fires (Figure 18).

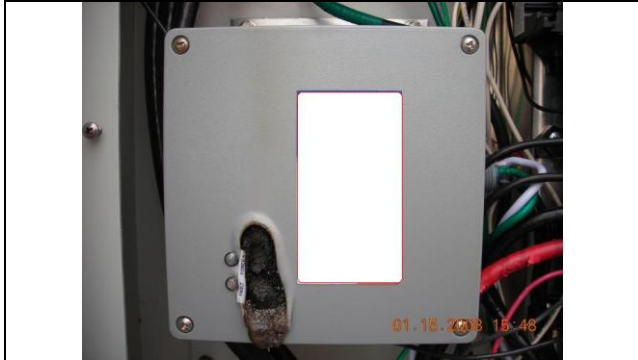


Figure 18 Burning plastic houses provide a risk of collateral jobs. (Logo blocked)

Central offices, data centers, hospitals and other facilities often employ Isolated type “Orange” receptacles and the fact is that these devices are only rarely installed correctly in the field. In most cases, the fact that they are installed wrong simply means that the Isolated Ground feature the receptacle was intended to provide isn’t realized. Reportedly, there have been cases where the Isolated Ground bus of distribution panel has no ground source. In such cases, a Ground Fault in any piece of equipment plugged into a receptacle fed by that panel, expends that energy onto the chassis of everything else plugged into that system. So, in the case of a hospital where there are both Isolated receptacles and common ones in the same space, a ground fault down the hall could cause a severe shock to a patient connected to a piece of equipment fed from an orange receptacle while in a bed plugged into a common receptacle.

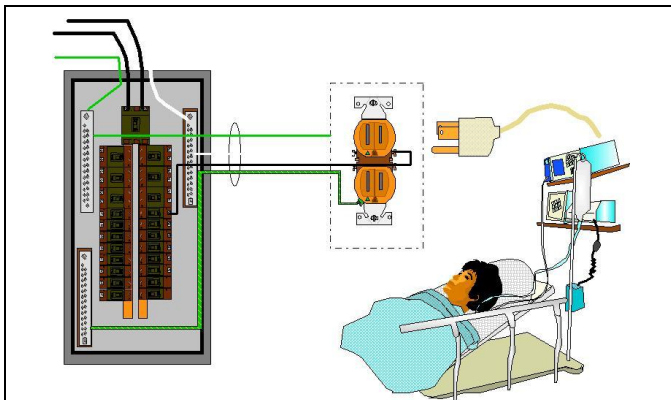


Figure 19 Isolated outlets in hospitals or nursing homes need special attention to correct detail.

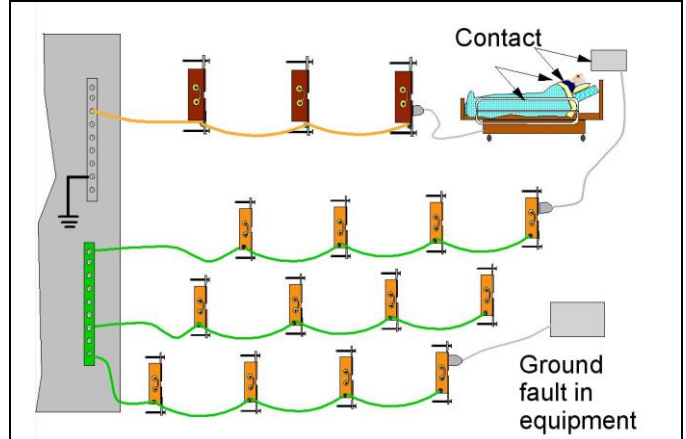


Figure 20 She died from “Complications” If the isolated bus in a hospital system loses ground, then someone in contact with anything plugged into a common receptacle such as a hospital bed frame, and anything plugged into an isolated receptacle, are vulnerable to a touch potential shock if there is a ground fault in anything plugged into any orange receptacle.

Public Service Access Points (PSAP) are radio dispatch centers for Police, Fire, Emergency Medical Technicians (EMT) and other emergency services. These dispatchers use numerous of radio systems for the various departments they serve and also they interface with the ground planes of the telecommunications network, the power grid and with building steel. The same is true of telephone operators and similar workers.

Unless the systems and sub systems are effectively bonded together, there is the potential for lightning or electrical fault pulses that impinge on one system to capacitive couple through the dispatcher’s body (Figure 22) to complete a ground path to building steel or to some other system. This is a process that some call “Fortress grounding” and usually it involves creating a bonding point at attendant console positions that provide a common connection point for all subsystems that enter the attendant’s workstation area. Further, if any of those systems are radio systems, as is shown in Figure 21, lightning energy to antennas more often than not are present on both conductors in a coaxial cable making suppression advisable.

Conclusions

Bonding, Grounding and Electrical Protection are just another skill set to be learned by people having responsibility for telecommunications and data center systems as well as farms, hospitals, police departments and virtually any structure with power wired to it. Sometimes, the rules and formulae are somewhat different from those of electrical systems based on dc and low frequency ac but they still are valid science. Attention paid to proper Bonding, Grounding and Electrical Protection reaps rewards in system reliability and an improved bottom line. Conversely, poorly grounded equipment will get you in the end.

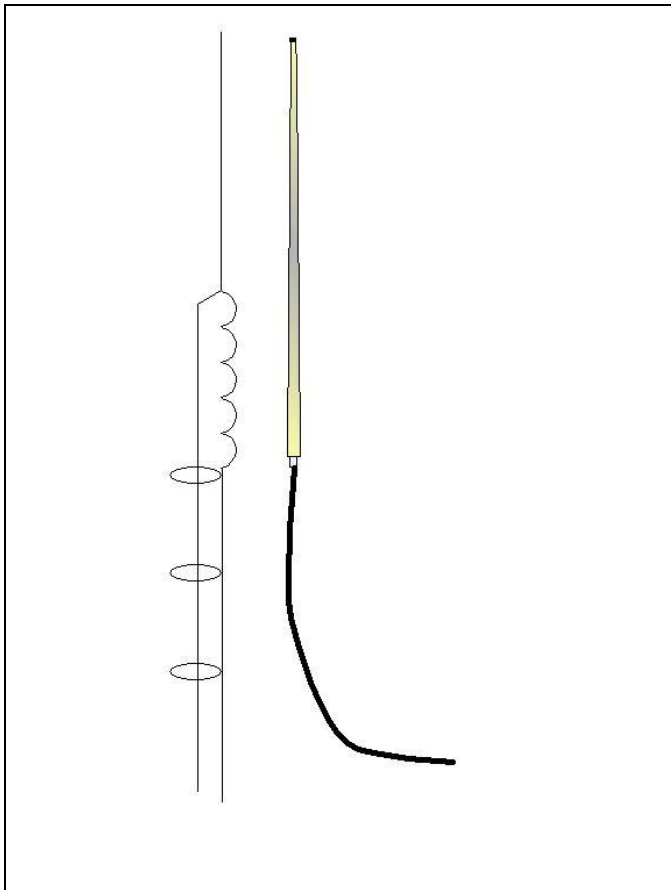


Figure 21 Because many antenna designs are shunt fed coils, lightning energy is present on both leads of the coax making the use of a reliable lightning arrester advisable.

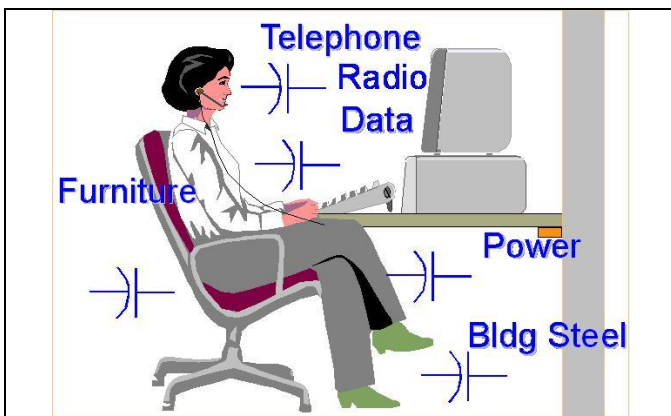


Figure 22 Attendant consoles such as those found at PSAP centers etc need effective bonding and grounding of all systems to avoid electrical shocks that conduct across the person's body.

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