THE FLAT EARTH SOCIETY
PERCEPTION OF GROUNDING

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Abstract – In pre-Greek history, the common scientific hypothesis was that the earth was flat. Columbus' trip to the New World would expectedly have permanently changed that. Nevertheless, the hypothesis has become accepted scientific "fact" in the majority of electrical practitioners including engineers. This rather obtuse observation is based on a simple premise: the ground is the reference of all electrical measurement and is therefore assumed to be equipotential.

Numerous references including our papers have advocated an equipotential grounding solution, but these do not assume the earth is uniform [1,2,3,4]. The references include the *National Electrical Code* [5], *NFPA 780* [6], and *IEEE 80* [7]. The *NEC* requires less than 25 Ohm ground connection. By definition, 25 Ohms will yield a significant voltage difference for any circuit.

Unbalanced and circulating current are carried through the earth path. If there is current flow, there cannot be a zero voltage difference. If there is not zero voltage difference, there is not an equal potential.

The paper addresses obtaining an equipotential ground plane in the presence of an unequal potential earth. The resolution of this issue and controlling current flow in the earth is critical to the safety of life forms, prevention of fires, and mitigation of lightning risks.

Actual photos illustrate problems with unbalanced and inadequate ground paths that have resulted in fires we have investigated. Diagrams illustrate the life form safety issues.

INTRODUCTION

In early history, the earth was considered flat. It was not until Columbus's fateful journeys that the "scientifically" known perception was completely debunked. To this day there exists a Flat Earth Society.

Accepted science is often flat wrong or limited, just as the original flat-earthers. As the ancient philosophers have repeated "Just because you do not know does not mean it is not true." We do not know what we do not know.

It is obvious that the earth has terrain. It is equally obvious that the surface varies from water to wetlands to desert. It would be ignorant to assume that these varied conditions would have the same soil. If the soil is different, then the soil properties including resistivity vary.

When a voltage is impressed on the soil, whether by fault or by design, then there is current flow through multiple paths of resistance. These stray currents are not well defined. The results can wreak havoc.

UNPARALLEL PATHS

The origin of electricity on a site is the service entrance panel [4]. Several ground paths exist at this point. These include the grounding electrode (rod), the transformer ground, bonding to the structure and bonding to metal piping. To displace the "flat earth" presumption, several questions must be asked.

Figure 1: Service entrance ground

Why are all these different ground paths bonded together? It is to create a single-point reference to ground. Do all the paths have the same resistance to earth? No, obviously there is different resistance, therefore a difference in potentials.

What is the resulting equivalent resistance of all these routes? Many assume that the paths are in parallel, so the equivalent resistance is less than the smallest.

$$\frac{1}{R_{EQ}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_N}$$

In reality, that calculation is not appropriate because of the differences in earth resistance paths as shown in Figure 2.

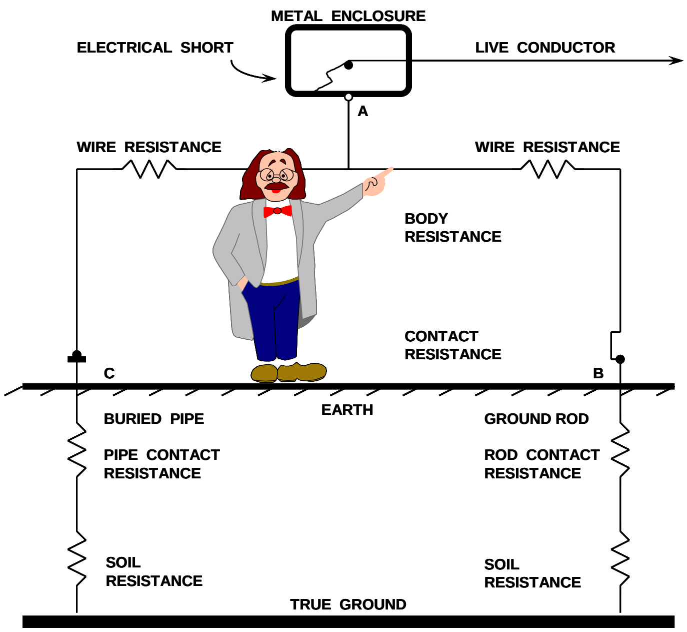

Figure 2: Different earth resistance paths

The contact resistance is the value that is measured on the surface of the earth. There is a potential difference between points B, C, and the feet of the man. The result is current flow between the points. This is not an equipotential or "flat earth". The concept of a zero voltage difference may occur, but it is not on the surface of the earth.

Rather than a parallel circuit for the various ground paths, a more accurate model is resistors joined by current sources as shown in Figure 3. The resistor values are those measured by a ground resistance instrument.

WHAT DOES GROUND MEAN?

In an electrical sense what does ground mean? It is called earth, reference, zero volts, equipotential, and other terms. These are all valid in some context but do not adequately address the issue. First it is necessary to identify the region of the earth.

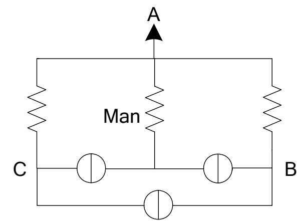

Figure 3: Model of earth resistance paths

Global. At some location somewhere in the core of the earth, there is a point or place that is a reference. However, this location is not known and changes with conditions.

Regional. In the vast majority of locations there is not a single reference point. There are multiple ground locations in different soils, operating at different voltage levels, with different current paths.

Local. In a limited system, a local reference can be established by a single-point ground. All grounded and grounding systems are tied to this location or system. This may be a chassis for a piece of equipment or an established location by design choice [4,8,9].

EARTH RESISTANCE

Earth resistivity changes with the material, residual moisture, and contact resistance. The earth material ranges from muck to loam, clay, sand, and rock. These progressively have greater resistance. The moisture level ranges from wet to dry.

With these different conditions would you expect a different resistance? Obviously. If there is a difference in resistance, then there is a difference in potential. If there is a difference in potential, then there is current flow. If there is current flow, then the entire idea of an equipotential earth is shattered.

Soil resistivity is a property of materials that is volume based. Because of the ratio of area to length, the units are generally expressed in Ohm-centimeters (Ω-cm).

$$\rho = R\frac{A}{l}$$

For effective earth contact, concrete is the preferred permanent medium [2,10]. Regardless of the surrounding soil, it has a resistivity about 3000 Ω-cm, which is approximately equivalent to good loam.

The contact resistance depends primarily on the soil conditions, electrode length, and electrode cross sectional area. The contact resistance of one ground rod is given by Dwight's formula where the dimensions are in cm [11,12].

$$R = \frac{\rho}{2\pi L}[\ln(\frac{4L}{A}) - 1]$$

where

p=soil resistivity in Ohm-cm
L=rod length
A=rod diameter

If the length is feet and the diameter is inches, the relationship changes [1].

$$R = \frac{\rho}{192L}[\ln(\frac{48L}{A}) - 1]$$

A single deep well casing or one long deep rod is not as effective as an array of radials for dissipating surge energy. The deep well may have a lower resistance, but its circuit reactance is greater resulting in a greater total impedance [1].

Ground rods cannot be placed too close together [12]. Each ground rod impacts the circuit impedance. When placed adjacent, the effectiveness is reduced by interference which causes the net shunt impedance to not decrease in proportion to the number of rods. Separate ground rod electrodes by greater than 2.2 times the length of the rod.

INTENTIONAL UN-EQUIPOTENTIAL

The *National Electrical Code* (*NEC, Code)* devotes 27 pages to grounding including neutral and bonding [5]. Trying to accommodate all soil conditions, *NEC* Article 250.56 allows a ground resistance of up to 25 Ohms. Above that resistance, an additional ground electrode is required.

This high ground resistance is inadequate for communications, data, fire, and safety purposes. According to the *IEEE Green Book*, Section 4, “There is no implication that 25 ohm, per se, is a satisfactory level for a grounding system [12].”

NEC Article 250.60 FPN No.2 states “Bonding together of all separate grounding elements will limit potential differences between them and between their associated wiring systems.”

In another attempt to create minimum potential difference in the ground system, a grounding electrode system is now required 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.”

These grounding electrodes include metal underground water pipe, metal frame of the building or structure, and concrete encased electrodes which includes rebar. An exception is for existing buildings “where the steel reinforcing bars or rods are not accessible for use without disturbing the concrete.”[5]

NEC Article 250.68 declares “The connection of a grounding electrode conductor or bonding jumper to a grounding electrode shall be accessible.” The interpretation of the local inspectors is the connection must be made in a wall opening protected by a two-gang cover [13].

The neutral is called the grounded conductor. It carries the unbalance current. It is purposely bonded to earth at only one point. If the neutral is grounded at more than one point, then part of the load current is transferred through the grounding system to the earth.

The electrode and bonding requirements are a clear effort to create an equipotential system in recognition that the earth is *not* equipotential.

The combinations of current flows through the earth are called stray currents in some contexts. Even very small current in the earth is hazardous to life forms.

Simply connecting a wire to a clamp does not assure an adequate bond. *NEC* Article 250.60(C) specifies type connections that are necessary for adequate bonding and grounding. Exothermic connections or irreversible compression are preferred. Any other type should use a meter to measure the adequacy of the connection.

Clearly, the only way to assure the quality of a ground system is to measure the contact resistance. By definition, this requires some type instrument, not simply assuming that the ground is adequate.

HAZARDS

NEC Article 90.1(A) declares “The purpose of the *Code* is the practical safeguarding of persons and property from hazards arising from the use of electricity.” Inadequate grounding and the lack of an equipotential earth can cause problems in at least three ways – alternate path fires, living systems safety, and lightning damage.

All these can be mitigated. Each area is complex enough that separate sections will address the challenges.

Seldom do systems have problems when only one component is improper. Failures and catastrophes are the result of multiple conditions. There are clues before failures, if the clues are properly interpreted.

NOT PARALLEL

Current taking an unintentional path can result in fire. Consider events that occurred near the end of construction on a new building.

1. Early in the day, a cord on a water circulation pump in the water heater closet melted and caused a small fire.

Figure 4: Ground conductor melted insulation

2. In the afternoon, a tradesman was shocked at a water faucet across the wall from the burned cord.

3. Late in the night, the structure caught fire from electrical wiring and was destroyed.

Figure 5: Destruction from inadequate ground

What was found on the scene inspection? The burned cord insulation on the ground conductor was destroyed, but the hot and neutral insulation was undamaged. This is a major clue. Obviously there was excessive current in the ground path that was not because of the circuit current, but was from different circuits.

A calibrated ground resistance meter was used for measurements [14].

1. The grounding electrode had 29 Ohms resistance. The National Electrical Code requires additional action if the value is over 25 Ohms [5].

2. The transformer was behind the building on the corner of the property. The transformer ground read 1 Ohm at the transformer.

3. The adjacent building is connected to the same transformer as the incident. The grounding electrode conductor on the adjacent structure read 1.3 Ohms. That reading is consistent with the transformer.

4. The neutral in the circuit breaker panel read 8.5 Ohms. It was connected to the grounding wire.

5. Unfortunately, the ground resistance of the water pipe could not be measured. Based on the events, would you suspect it was lower than the ground rod resistance?

The presumption would be that there are multiple parallel paths to ground and the resulting resistance would be less than the smallest resistance in the system. That is clearly not the case as illustrated in Figures 2 and 3.

The cord was the least impedance path for the fault and unbalance current that was in the building. This caused the first fire. When the cord was removed, the water line was a preferred path. The higher impedance ground did not provide an adequate path to trip the faulted breaker, so a fire ensued.

NO EFFECTIVE GROUND

The results of having no effective ground are equally dramatic. A commercial facility had been in use for over twenty years. A fire resulted in destruction of the facility. The initial fire report identified the origin of the fire above a vent and the source as electrical, but did not identify the failure mechanism.

After eliminating all other potential causes, an inspection of the origin area yielded a dramatically damaged ground wire on a power circuit illustrated in Figure 6 [15]. Although there was external heating, the damage indicates the ground was energized at the time it failed. It was not at zero potential. The hot and neutral had little damage. Like the previous case, the ground wire was providing a fault path for unbalance current of different circuits.

Figure 6: Ground wire

Fault current from other circuits through a ground wire will not trip the breaker unless the ground resistance is less than that required to provide current greater than the breaker rating.

$$R \text{ (of ground)} < \frac{V \text{ (voltage of supply)}}{I \text{ (current rating of breaker)}}$$

When the building ground resistance was tested, the value was 900 Ohms. In effect, there was no ground. Without an adequate ground, the fault current took the least impedance path. However, the wire size was inadequate for the amount of current. The resulting overheating was adequate to ignite the accumulation of materials in the vicinity of the wire.

Figure 7: Ground resistance measurement

LIVING SYSTEMS

Inadequate grounding systems affect living species in a variety of ways. The body is an electro-chemical system consisting of numerous circuits. Responses of the body to stimuli can be measured with tools such as an electroencephalogram (EEG) for brain patterns, an electrocardiogram (EKG) for heart patterns, an electromyogram (EMG) for muscular effects, and a galvanometer for skin resistance.

At low levels external current interferes with and overrides the current signals within the body. At higher levels, the external current is providing heating effects.

Step-potential is the voltage that exists between the feet as a person walks. Touch potential is the voltage that a person would sense if he touches an energized object. The Institute of Electrical and Electronic Engineers (IEEE) established standards for mitigating these effects by appropriate grounding [7]. OSHA requires protection from risks of step and touch potentials [16]. These documents exist because the professional community realizes there is current in the earth.

Ground fault circuit interrupters (GFCI) are designed to trip when ground fault current exceeds 5 milliamps. Clearly, current is flowing in the earth.

For many years, it has been recognized that very small levels of current can dramatically impact the human condition. Short term exposure to current as low as 10 milliamperes can cause muscles to contract and the body cannot let-go of an electrically charged item [17].

Table 1 – Body of 150 lb man sensitivity to current

Current 60 Hz	**Physiological Phenomenon**	**Feeling or Lethal Incidence**
< 1 ma	none	imperceptible
1 ma	perception threshold	
1 - 3 ma		mild sensation
3 - 10 ma		painful sensation
10 ma	paralysis threshold of arms	cannot release hand grip, may progress to higher current
30 ma	respiratory paralysis	stoppage of breathing frequently fatal
75 ma	fibrillation threshold, 0.5%	heart action not coordinated probably fatal
250 ma	fibrillation threshold, 99.5% > 5 second exposure	
4 A	heart paralysis threshold no fibrillation	heart stops for duration may restart on interruption usually not fatal from heart dysfunction
> 5 A	tissue burning	not fatal unless vital organs burned

Effects of long term exposure to small electrical currents are not as well established. However, realizing that exposure to current levels in the range of the low level body control signals are not uncommon, it would be expected that these low levels will disturb the normal body information handling. Any disturbance in the life form body controls will have some impact on the body functions.

It is not acceptable to experiment with humans. Because of the number of living creatures that can be observed and compared, livestock have provided the most information to date. Reports of reduced milk production and birth rate have been attributed to low level ground currents.

Multiple grounds that are not adequately bonded will have a voltage difference between them. They are not at equipotential. Therefore a current will flow. Any living creature that is on the soil is an alternate path for current flow. A small stray current will impact the body controls and can have very deleterious effects that are short of burning or death.

ATMOSPHERE

Lightning and clouds impact structures by a strike or by induced energy. It is well known that lightning and thunderstorms cause a voltage field between clouds and the earth [1]. Benjamin Franklin recognized this phenomenon in the mid 1700's [18]. A difference in potential exists a few feet apart depending on the cloud, material, earth, and metals.

A strike is not required to have potential. The magnetic field from a cloud can cause current flow in the earth. The electric field under a cloud can result in a charge on metal. The potential must be discharged from the metals. If not controlled, damage occurs to the metal.

If two metals are in proximity, not only will there be a potential due to the cloud electric field, but a difference will exist between the two pieces of metal. The difference can cause a side-flash or discharge from one to the other. The likely result is a hole in one of the metals and a resulting fire if surrounding materials are ignitable. Side-flash damage occurs with metal fireplace vents or metal flues that are adjacent to other metal or electrical wiring.

The construction of a metal surface impacts its ability to dissipate the energy. Thin materials, not uniform surface paths, disruption in continuity, and sharp changes of direction increase the probability of damage.

Structures can be protected from the potential build-up by three techniques including bonding, shielding, or arrestors. Regardless of the technique, an effective equipotential ground system is imperative.

1. Metal that is not intended to carry electrical power is grounded or bonded together in a ground plane system. The metal is bonded to earth to drain off potential differences [5].

2. Shielding is used to divert external charge before it enters a structure or conductor. A shield above a facility is simply raising a ground plane to an elevated position [6]. Shielding may be as complex as a Faraday shield consisting of a fine mesh or as simple as a Franklin lightning rod. Reasonable designs are now in popular publications [19].

3. Energized power lines have lightning arrestors to drain off potential above a certain level. Arrestors permit a voltage to exist on a line, but drain off excess

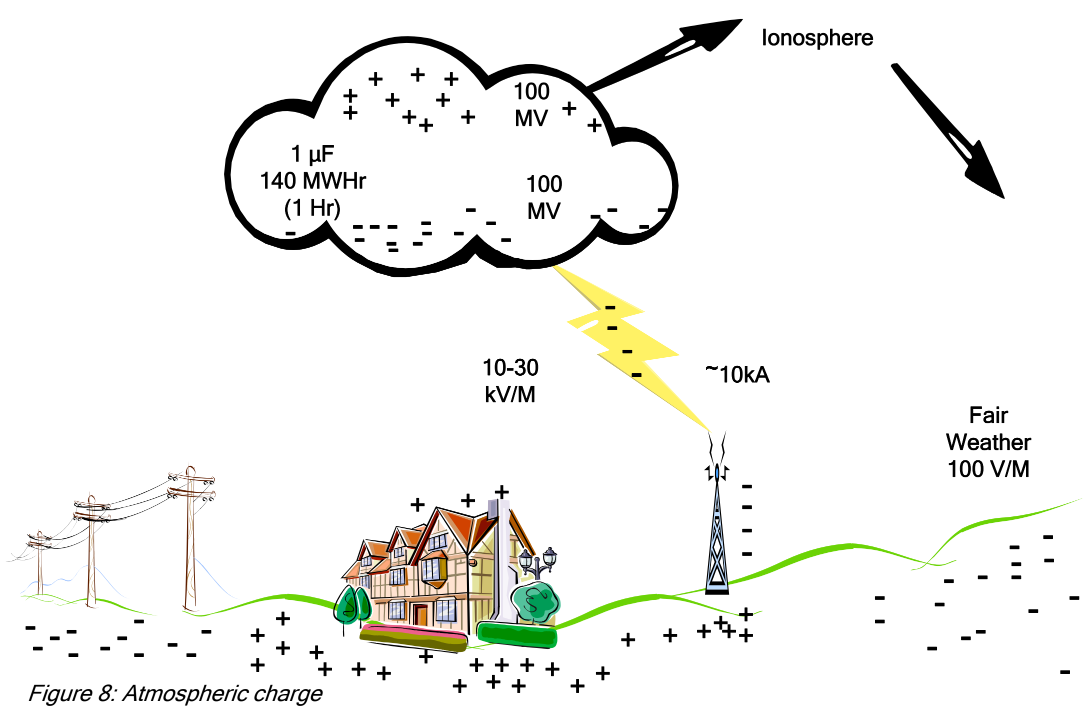

Figure 8: Atmospheric charge

charge [20].

Lightning is a high voltage (V), high current (I), high frequency (f) signal. Therefore, the reactance (X) is greater than the resistance (R). Any voltage difference causes a high current flow. High current results in very high heating because power (P) is the square of the current times resistance.

$$V\uparrow,\ I\uparrow,\ f\uparrow$$

$$X > R$$

$$P = I^2 R$$

It is crucial to get the ground resistance and reactance down. Therefore a grid is the only chance. To reduce the inductive reactance, minimize bends. Keep all bends in a greater than eight inch radius sweep. High frequency lightning will not travel around a sharp corner.

Realizing the difference in potential over an area, industrial facilities use a ground grid with rings and radials [1,21]. By reducing the distance between grounded objects, the potential can be equalized. This was the very reason that the *NEC* added structural steel and rebar to the grounding electrode system.

A LITTLE HISTORY

An increase in lightning related incidences has been observed in certain types of construction. Not so many years ago, metal water pipe was common. When in contact with the ground, this is considered the best of all grounding electrodes.

In addition, the metal line effectively bonded most of the metal in a structure. Any metal vent pipes or related protrusions above the structure were in effect bonded via the metal lines.

Fireplace stacks were originally brick, stone, or masonry. These were not metal. Some structures would be somewhat conductive when wet, but in general were mostly insulators.

Now the proliferation of metal fireplace stacks act as an attraction to lightning. These are large area structures and easily become charged when a cloud passes over. The potential exists even if the metal is not exposed to a direct strike. As a result, the metal vent must be bonded to a grounding electrode system.

NFPA 780 addresses the thickness of steel that is acceptable to withstand a lightning strike [6]. If that thickness is not used for vents and other metal exposed to lightning, then the metal must be bonded.

FIX THE PROBLEM

From these analyses, it is clear that the earth is not equipotential. Therefore, it is necessary to create an equipotential plane. The following list is a minimum starting point for safety and fire protection [22].

1. The ground resistance must be less than 25 Ohms according to the *National Electrical Code* [5].

2. The ground resistance should be less than that considering the *IEEE Green Book* on Grounding [12].

3. The ground resistance should be less than 6 Ohms in order to trip a 20 Amp breaker with a direct fault to earth [3].

4. If adequately low resistance cannot be achieved use a triad ground system. The system consists of three ground rods encased in individual concrete filled holes spaced 20 feet apart. All the rods are interconnected [4].

5. Bond the structural steel and bond the rebar as part of the grounding electrode system according to the *NEC* [5].

6. Bond all metal in the structure. This includes the chimney and metal vents. Bond all pipes including gas lines [5].

7. Connect all grounds together according to the *National Electrical Code* and the *National Electrical Safety Code* [5,23].

8. Create a shield for high elevation locations where lightning is a potential problem. Keep all lightning electrode bends with a greater than 8” radius since lightning will not travel along a sharp turn [6].

There are at least eleven grounding systems possible in a structure. Hence, the proper interconnection is typically a very involved process. [4].

CONCLUSIONS

Grounding is critical to safety and fire protection. The earth is not uniform. Therefore, there is a difference in resistance. The result is a voltage difference. The earth is not an equal potential medium. Difference in potential causes a current to flow.

Current flow in the earth creates step potential and touch potential. These can cause low level current in a living system that overrides the organism’s control signals. Higher levels cause burns and death.

Current flow in the ground of an inadequately protected circuit results in overheating and ignition of fires.

Atmospheric clouds create a potential in metal which is under the cloud whether lightning strikes the metal or not. The potential difference between the metal and other conductive surfaces or ground creates a side-flash resulting in a high energy discharge.

Adequate bonding and grounding are the basis of the protection system for all these conditions. An equipotential ground plane must be created. This includes bonding to all metal and ground systems within the area of protection.

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VITAE

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