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Ground Versus Earth, There Is a Difference

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ABSTRACT: Investigations of injuries and fires caused by electrical circuits and equipment can result in incorrect conclusions when grounding systems are neglected. The term ground is loosely used in electrical jargon as any zero reference point for voltage measurement. Power systems are usually grounded to the earth. Other electrical systems are sometimes grounded to the same earth through a low impedance circuit. Residential grounding systems are described and a simple method is proposed for the investigator's use in evaluating the grounding system for potential shock or equipment damage hazards.

KEYWORDS: engineering, grounding, electrocution, ground resistance, electric shock, electric appliance, ventricular fibrillation

The terms ground and earth are used interchangeably in electrical engineering with Americans preferring ground and the English earth. The author would like to make a distinction that would, for practical purposes, clarify proper grounding procedures. To put the distinction in simple terms, ground could be considered a floor. As long as one is on the floor they cannot fall. If they climb above the floor their potential for injury is a function of their height above the floor. If we consider an electric system as a multistory building with each circuit being a story with its own floor, a person will not be seriously injured as long as they remain on a floor. Should they encounter an open shaftway, however, their potential for injury will depend on which story they were on. In my simple analogy each floor is the ground of a particular circuit in the system, and earth is the lowest floor. In residential electric systems (Figs. 1 and 2) the earth would be the point where all grounds are connected together or bonded to form the grounding electrode system as defined and required by the National Electric Code (NEC) 250-81 [*1*].

Figure 1 shows a typical residential service pole containing, from top to bottom, a 7160-V primary, the power neutral, 110/220-V secondary, cable for cable television, and telephone wires. Figure 2 is a schematic drawing on the same service pole showing possible grounding paths if the NEC bonding requirements were not followed. Note that each circuit has its own ground and is connected to other circuit grounds at the residence only through the soil resistance.

Grounding objectives frequently cause conflicts between protection of life, protection of property, and continuity of service. This is especially true in power plant and industrial applications. When this conflict occurs, other design features, such as barricades and ground fault interrupters, are added to protect life. In residential, institutional, and commercial applications, however, grounding for personal safety is mandatory.

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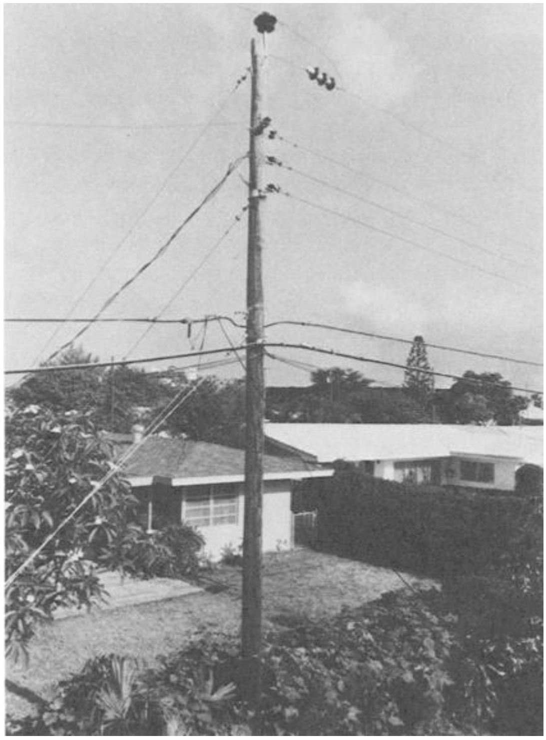

FIG. 1—*Typical electric service pole.*

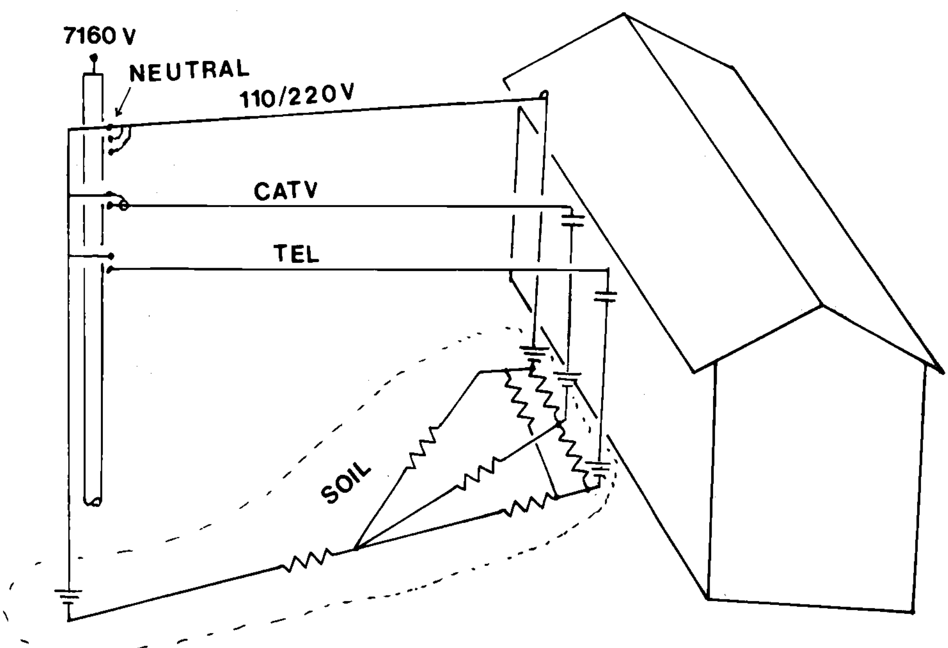

FIG. 2—*Schematic drawing of electrical services to a residence.*

Table 1 shows the spectrum of consequences of electric shock [2]. This table omits the important difference between a mild sensation felt while sitting on a chair and that same sensation felt unexpectedly while working on a ladder. The first may evoke laughter from onlookers whereas the second could result in crippling injuries or death. The more serious consequences that are not dependent on the victims' location involve respiratory paralysis or ventricular fibrillation which can result in death unless quick rescue operations are effected.

Studies have shown [2-4] that physiological effects (onset of fibrillation) are time dependent and take the form $I^2t = K$, where I is the current flowing through the body in amperes, t is the time in seconds, and K is a constant. The value of K has not been rigorously established but extropolation from animal studies indicated that values between 0.013 and 0.027 give reasonable results. Figure 3 shows this relationship with the upper curve drawn using $K = 0.013$.

The author was a party to the investigation of the cause of a serious electric shock received by a housewife during a lightning storm. The investigation revealed that the telephone system at the residence was grounded only through a rod driven into the ground and no connection was provided to the water pipe or the power system ground. In addition, the installer had wrapped excess wire around the top of the rod which added inductive impedance to the ground circuit. Figure 2 also represents this condition. More recently, the author found a cable television ground installation made with a 0.9-m (3-ft) driven ground rod which again was not bonded to the power system ground. The author measured the resistance between this ground rod and the power system ground (water pipe) and found it to be 45 Ω, even with damp soil. Figure 4 shows the top of this ground rod. Both of these cases indicated ignorance of the NEC requirements.

Shock hazards exist in any electrical installation unless adequate insulation is provided between conductors and potential victims or a ground path is provided to divert any stray currents away from the victim's body. The NEC requires grounding and bonding of grounds because it is impossible to assure insulation is adequate in every situation.

Much of the author's experience has been in the start-up and testing of electric power plants where it is customary to use functional tests to verify protection systems. A functional test applies a known perturbation to the system and then closely monitors the system's performance to observe the actions of the protective devices and circuits. If performance matches design predictions the system is considered acceptable. Application of the functional test philosophy to grounding systems in forensic science applications seemed a logical step. Search of the lit-

TABLE 1—*Current range and effect on a 68-kg (150-lb) man* [2].

60-hz Current	Physiological Phenomenon	Feeling or Lethal Incidence
<1 mA	none	imperceptable
1 mA	none	perception threshold
1-3 mA	...	mild sensation
3-10 mA	...	painful sensation
10 mA	paralysis threshold of arms	cannot release hand grip; if no grip, victim may be thrown clear
30 mA	respiratory paralysis	stoppage of breathing (frequently fatal)
75 mA	ventricular fibrillation threshold (0.5%)	heart action discoordinated (probably fatal)
250 mA	ventricular fibrillation threshold (99.5%) (≥5 s exposure)	heart action discoordinated (probably fatal)
4 A	heart paralysis (no fibrillation)	heart stops for duration of current passage for short shocks, may restart on interruption of current (usually not fatal from heart dysfunction)
≥5 A	tissue burning	not fatal unless vital organs are burned (similar to nonelectrical burn consequences)

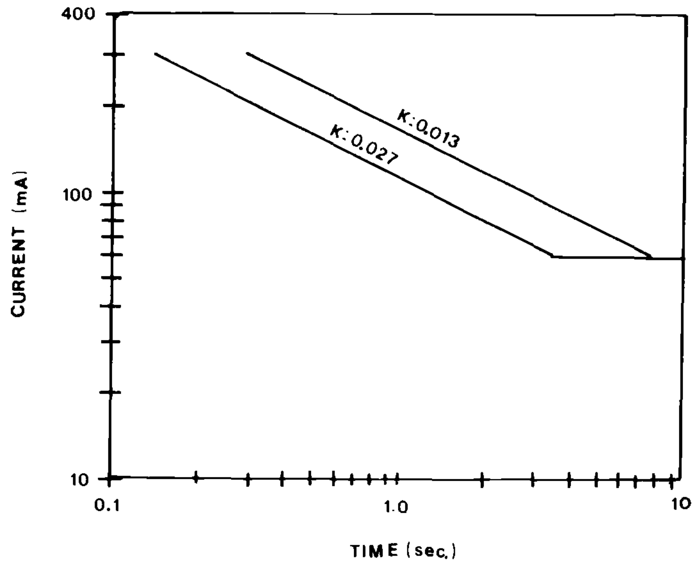

FIG. 3—*Ventricular fibrillation threshold for a 68-kg (150-lb) adult.*

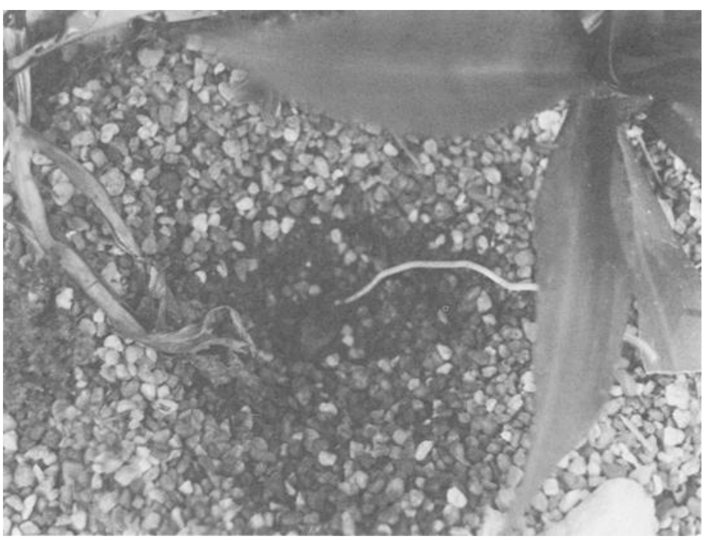

FIG. 4—*Cable television service ground investigated by author.*

erature failed to disclose a simple functional test of a grounding system. Soil resistivity tests such as "triangulation," "ratio," and "fall of potential" appeared in most handbooks but these tests do not test the grounding system as a whole nor do they simulate fault conditions.

What then would be the acceptable criterion for a functional grounding system test? Reverting to basics, the criterion that appears most logical would answer yes or no to the critical question "Could a voltage exist under fault conditions that would be hazardous to an individual who was in contact or close proximity to the equipment or conductors in question?."

When the criterion stated above is evaluated, the determining factor is voltage across a potential victim's body. Voltages experienced under fault conditions can vary widely. However, the voltage at which a hazard can be expected to exist can be estimated using the $I^2t = K$ relationship and a measured value of ground resistance. With the uncertainties in the value of K, it follows that a precise value of ground resistance is not necessary. The critical question can be answered using order of magnitude values. The answer will show as a definite yes or no or the answer will fall within the uncertainties.

When uncertainties are encountered involving safety of life a conservative approach is essential. If the answer is uncertain, a hazard must be presumed to exist until the uncertainty is resolved.

The author proposes that the ground resistance be measured using as large a value of current as practical to simulate actual conditions and evaluate the circuit's current carrying capacity. In residential installations this would be in the order of 15 to 30 A. Ground resistance determined with this current should be representative of the resistance during faults as this current is close to the circuit breaker or fuse trip point.

Figure 5 shows a proposed circuit for testing ground resistance. In this circuit R_T is a current limiting resistor which is also used to measure the current. E_T is the measured voltage drop across R_T. R_E is the unknown ground resistance and E_E the voltage drop across the unknown ground. Applying Ohms law it can be shown that

$$R_E = R_T \frac{E_E}{E_T}$$

The simplicity of this relationship reduces the importance of instrument error, especially if R_T is selected so the both voltages E_E and E_T are measured on the same voltmeter scale. Sensitivity studies show that the order of magnitude of R_E is sufficient to evaluate the ground against the criterion.

If we assume that a power secondary (110 V) falls onto a communication service wire and R_E was determined to be 45 Ω and a victim with a 1500-Ω body resistance was in contact with com-

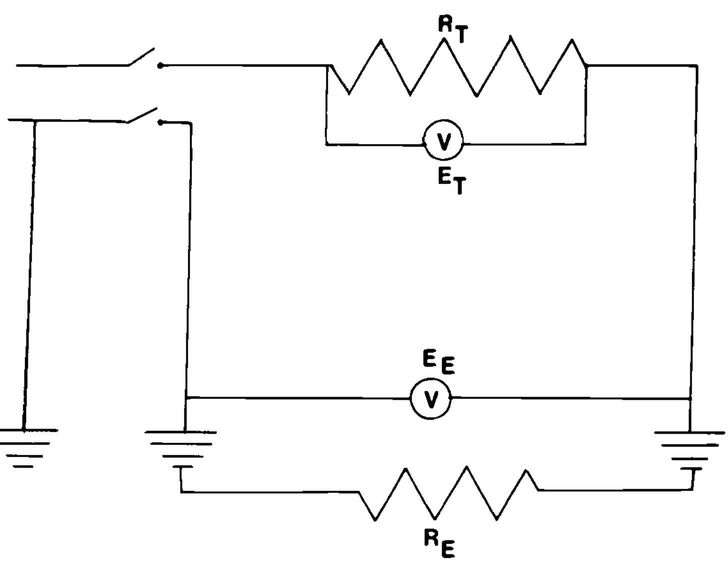

FIG. 5—*Schematic drawing of proposed ground resistance test apparatus.*

munication equipment, calculations show a current of about 3 A flowing through the grounding circuit and 80 mA through the victim. From Fig. 3, the time to fibrillation would be 1.3 s. The power system fuse would not react to this small current and fusion of the communication wire is the only available protection. If the shielded communication wire was equivalent to a No. 16 AWG copper wire, a current of about 320 A would be required to fuse the wire in 1 s [5]. In this example, there is no question that the answer to the critical question is yes there is a hazard without any uncertainty.

There are four alternatives that would always give a no answer to the critical question. They are: (1) lower the secondary voltage to a safe value, (2) raise the victim's voltage to that of the secondary, (3) limit the victim's exposure time to a safe value, or (4) limit the fault current to a benign value. Of these, 1, 3, and 4 are not practical as they would adversely affect the quality of electrical service. The only practical alternative then is 2. The NEC selected 2 when it required that all grounds be bonded and that the common ground be an 2.4-m (8-ft) driven ground rod bonded to a water main whenever possible. Further evaluation of our acceptance criterion shows that any resistance between grounds creates a hazardous condition.

Reference to the acceptability of a 25-Ω ground resistance is made in several publications, including the NEC and the IEEE Green Book [6]. This 25-Ω value is frequently taken out of context by defense experts and used as the justification for separately driven grounds. Such justification is false and misleading because:

1. The 25-Ω value does not apply between grounds that are required to be bonded by the National Electric Code.
2. Using the calculational method explained above, 80 mA would still pass through the victim with a fault current of only 5 A.

So far the author has addressed this paper to personnel safety. There is also the situation where there is no human victim. Should the power primary (7160 V) fall on the communication service it would cause a fault current of about 150 A to flow through the communication system generating considerable heat. Fusion would ultimately occur and fire damage is almost sure to follow with resulting economic losses. If the fusion does not cause a fire, the high voltage on the communication equipment would stress its components severely and accelerate failure.

Many building codes limit their scope such that communication circuits do not require permits or inspection by defining electrical systems as those furnishing power and light. Cable television and telecommunications companies are then at liberty to make their own rules.

This leaves the national Electric Code requirements for bonding grounds in limbo as far as enforcement is concerned. It becomes the forensic engineer's responsibility to establish what is considered good industry practice. Communications and cable television carriers have ignored the NEC using the argument "We have done it this way for many years and haven't had any trouble." Their expert witnesses have used that same argument in court with mixed results. The statement may be correct but for a forensic engineer to refute successfully the argument, he should not only know the code requirements but also the record of discussions within the Code Committee that led up to the requirements. These records are available from the National Fire Protection Association and are given wide distribution prior to Code revision.

Conclusion

It is the author's opinion that investigators frequently overlook improper grounding as a probable cause of electrocutions and fires. Television sets and other appliances can be damaged or weakened by surge voltages caused by improper grounding but failure does not occur immediately. When failure occurs and causes damage or injury, plaintiff's expert will erroneously attribute causation to the equipment. On the other hand the defense expert likewise misses the root cause with the result that justice is not served nor is future injury or damage prevented.

It is essential that the grounding electrode system be thoroughly tested in any investigation of injury or damage caused by failure of electrical systems or equipment.

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