# ELECTROSTATIC EFFECTS NEAR EHV POWER LINES - DESCRIPTION AND MITIGATION

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## 1. GENERAL

**1.01** Telephone personnel and aerial hardware in the vicinity of extra high voltage (EHV) power transmission lines may become electrically energized by electrostatic coupling to the EHV power line. This section describes the electrostatic induction phenomena, the zone affected by an EHV line and the procedures recommended in order for the craft persons to operate safely and comfortably in this environment.

**1.02** Whenever this section is reissued, the reason(s) for reissue will be listed in this paragraph.

## 2. ELECTROSTATIC PHENOMENA

**2.01** EHV power transmission lines maintain a phase-to-phase voltage of over 300 kV (approximately 173 kV phase-to-ground). The region near an EHV power line is a unique work environment due to the intense and extensive electric field produced by the line. An ungrounded object (telephone cable, craft person) suspended in the electric field surrounding an EHV power line assumes a potential with respect to the earth. The electrical potential is primarily a function of the power line voltage and geometry and the position of the object with respect to the power line and ground. Large potentials can be induced at considerable distances from the power line.

**2.02** The current which can be drawn by connecting the suspended object to ground is dependent upon the induced free-space voltage, the capacitance of the object to ground, and the capacitance of the object to the power lines. Although the induced voltage can be quite high, the capacitance of most objects, such as 100m length of TELCO cable or a craft person at working height, is quite small. The currents which result are typically less than a milliampere.

**2.03** Currents of less than one milliampere are below the levels that may cause direct electrical injury by fibrillation, suffocation, or inability to release. However, the small arc formed when such a high-voltage, low-current source is contacted by the human body can be painful or startling.

**2.04** This type of electrical discharge is in some ways analogous to the transient static discharge produced by shuffling across a carpet; however, an important difference is that electrostatic coupling can produce a continuous 60-Hz discharge. This continuous current flow can be significantly more startling to an individual than a single static discharge. Receiving such a shock could startle an individual into an involuntary reaction that could cause an accidental injury. To avoid such secondary accidents, surprise shock should be eliminated.



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**2.05** In addition to surprise shock, continuous arcs may be formed between energized and grounded apparatus. These arcs have resulted in damage to the insulation of F-drop wire.

**2.06** The use of rubber gloves will enable craft personnel to work safely on electrostatically energized conductors and to touch grounded hardware. However, it is more practical to prevent the lines or craft personnel from becoming energized by following special installation procedures. It is preferable to equip poles and ladders with a protective arrangement which will prevent energization of craft personnel.

**2.07** A variety of factors can increase or decrease the influence of the EHV power line. Local terrain, vegetation, and structures can significantly distort the electrostatic field. A telephone line running near trees, houses, or other grounded or low-voltage power lines will be partially shielded from the EHV influence. The weather can also play a role; recent rain or high humidity can ground an otherwise ungrounded object.

**2.08** Many transmission corridors carry several power lines in parallel. The total electrostatic field may vary depending upon the relative phasing of the transmission lines. When multiple power lines are encountered, the total electrostatic field should be considered as the contribution of each individual line and the affected zone as the union of the individual affected zones.

**2.09** The effects described above may be encountered near power lines of voltages below the EHV range. However, experience has indicated that lower voltage lines do not typically cause significant difficulty, and the EHV distinction provides a convenient differentiation. If effects similar to those described above occur in the immediate vicinity of any high-voltage power line, the special procedures described in this section should be employed.

## 3. ELECTRIC FIELD CONFIGURATION

**3.01** The electric field which surrounds an EHV power line is the source of the undesirable effects which occur in the regions near the line. The variation of the field is important in defining the affected zone about the power line. In the plane transverse to the power line, the electric field varies in precisely the same way as an electrostatic field; this is true for both dc and ac power lines. Consequently, the electric field in this transverse plane can be visualized by means of an electrical potential (voltage) relative to ground. For an ac power line, the voltage at any point with respect to ground varies sinusoidally at 60 Hz.

**3.02** Figure 1 illustrates the peak voltage to ground attained at points in the vicinity of a pair of 345 kV (phase-to-phase) power lines using "superbundle" phasing. The three phases in Fig. 1 are designated a, b, and c.

**3.03** The contours shown in Fig. 1 represent equipotential surfaces; that is, all points along any given contour attain the same peak voltage. (Note: Although two points may experience the same peak voltage, their peaks need not occur at the same time in the cycle.) Physically, these potentials represent the peak voltages which would be induced on an ungrounded object suspended parallel to the power line at the given location.

**3.04** Considering the distance scales on the axes, it is apparent that substantial voltages can appear on ungrounded objects suspended at telephone cable height at considerable distances from the power line. The voltage increases as the object approaches the power line or is elevated from the earth's surface.

**3.05** A model of electrostatic induction is depicted in Fig. 2 for a single energized power conductor coupling to a parallel TELCO cable. The induction process can be understood as a voltage-divider action where some fraction of the power line voltage $V_L$ appears on the TELCO cable $V_O$ depending upon the relative impedances of the coupling capacitance $C_{LO}$ and the parallel combination of the TELCO cable capacitance to ground $C_{OG}$ and resistance to ground $R_{OG}$.

**3.06** If $R_{OG}$ is infinite, the cable is said to be "ungrounded" or "floating", the voltage to ground appearing on the cable is maximized, and no current flows from the cable to ground through $R_{OG}$. If $R_{OG}$ is zero, the cable is "grounded", the voltage to ground on the cable is zero, and the current to ground from the cable through $R_{OG}$ is maximized.

**3.07** Some idea of the typical magnitudes involved can be obtained by considering the case of 100m of 1-inch diameter cable suspended at 6m. The capacitance to ground ($C_{OG}$) of such a cable is

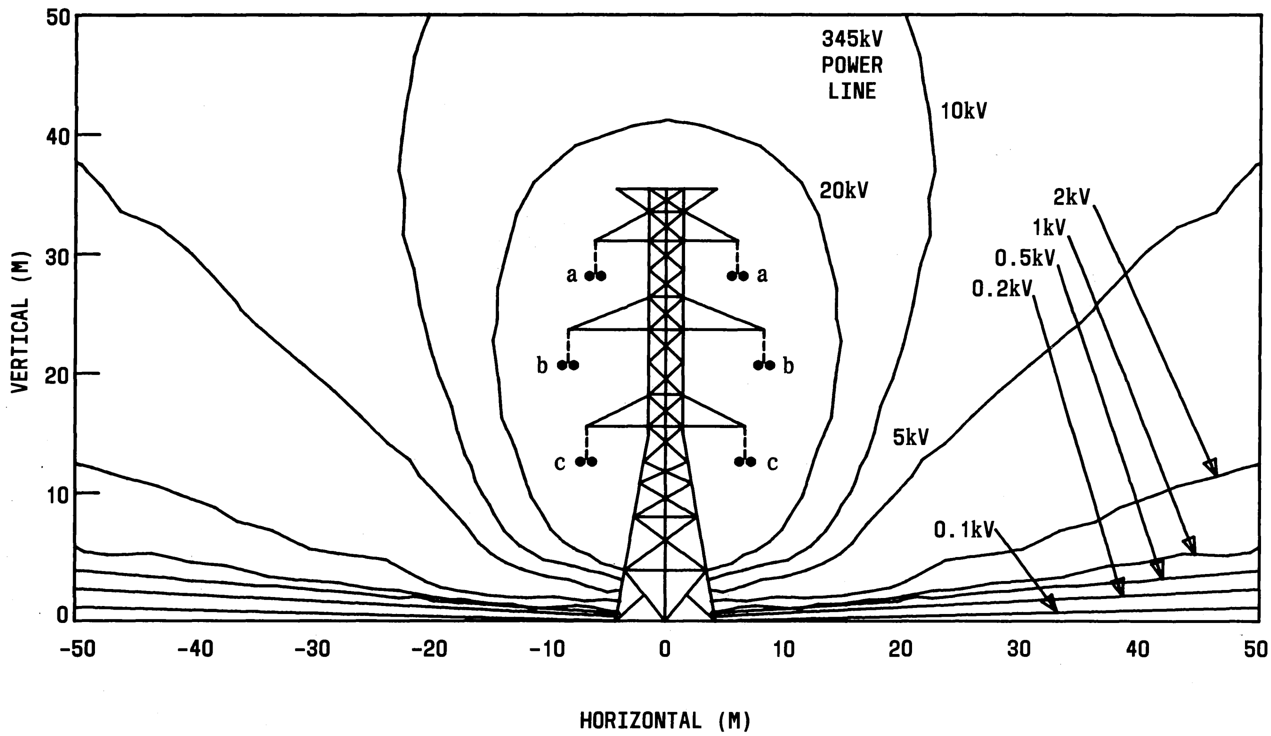


**Fig. 1—Equipotential Contours Surrounding A Pair of 345 KV Power Lines**

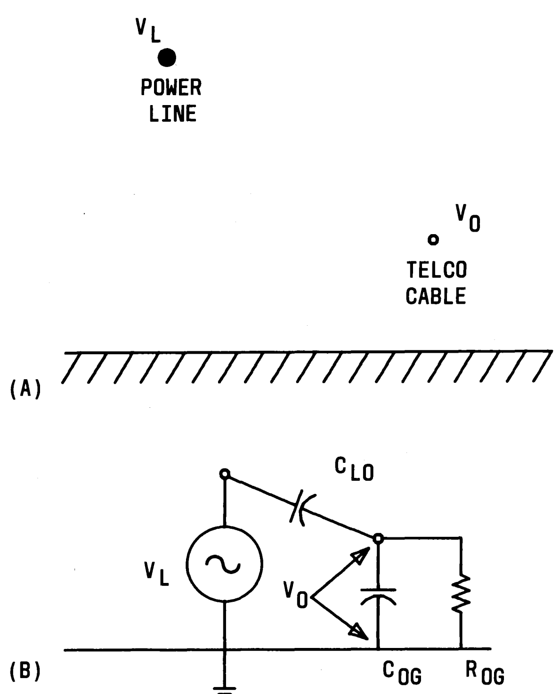


**Fig. 2—The Electrostatic Induction Process**

nearly 1 nanofarad which represents an impedance of 2.65 megohms at 60 Hz. Clearly, even if $R_{OG}$ is several tens of kilohms, it will effectively short out the capacitive impedance to ground. Therefore, "grounding" the line can readily be accomplished even with what would be high impedance for most applications.

**3.08** For the power line shown in Fig. 1, if the above cable were 50m from the power line, the ungrounded cable would experience a peak voltage of nearly 1 kilovolt or 1/200 of the peak voltage of the power line. (345 kV phase-to-phase is roughly 200 kV phase-to-ground.) For such a case, the coupling capacitance $C_{LO}$ is roughly 1/200 nanofarad, representing an impedance of 530 megohms at 60 Hz. The short-circuit current which 200 kV can deliver through 500 megohms is only 0.4 milliamps. If $R_{OG}$ is 10 kilohms, the voltage on the cable will be only 4 volts as compared to an ungrounded voltage of 1000 volts. Therefore, eliminating the electrostatic potential on telephone cables can be accomplished by conventional grounding techniques.

## 4. HUMAN SENSITIVITY

**4.01** As illustrated in Fig. 1, personnel and telephone facilities in the vicinity of an EHV line can become energized to high-voltage levels. Since physical responses generally depend upon the amount of current passing through the body, most "safe voltage limits" are concerned with high-current sources such as generators or batteries. These high-current sources may cause a direct electrical injury by fibrillation, suffocation, burns, or inability to release.

**4.02** The currents resulting from the grounding of an electrostatically energized section of cable or elevated craft person are typically less than a milliampere. Contacting this low current, high-voltage source produces a continuous 60-Hz spark-like discharge. This discharge can be uncomfortable or startling when contact is made and can lead to secondary accidents. The "safe voltage limit" of an electrostatic source must be based on empirical evidence of the human response to such a static discharge.

**4.03** Information available on human response to ac spark discharge is summarized in Fig. 3. As is shown, a person's ability to perceive an ac spark discharge is dependent upon both the open-circuit voltage developed on a charge-collecting object and upon its capacitance to ground. In the present application, two classes of objects are of interest: first, an elevated telephone cable and, second, a craft person at working height (ie, on a pole, ladder, or in a bucket).

**4.04** The capacitance of a horizontal cable of length L and radius a at height H above the earth is

$$C = (2\pi \epsilon_0 L)/\ell n(2H/a)$$

Where C is in farads, L in meters, H in meters or feet, a in the same units as H and $\epsilon_0 = 8.854 \times 10^{-12}$ FARAD/m. A 100m length (2-3 spans) of 1-inch diameter cable at 6 meters above the earth has a capacitance to ground of 800 pF. The capacitance is directly proportional to the length but relatively insensitive to cable radius or height. This capacitance (Fig. 3) suggests a level of 500 volts rms is just perceptible to 50 percent of the population tested.

**4.05** The points labeled F in Fig. 3 pertain to a person standing on an insulated mat touching a driven ground rod. The capacitance being discharged is the capacitance of the body of the person to ground and represents nearly 200 pF. (A person suspended some distance above the earth will exhibit a lower capacitance to ground, so 200 pF represents the worst case.) Depending upon the humidity, a spark discharge from 200 pF can be perceived at about 600 volts rms. Conservatively, we take the 500-volt rms limit of the cable as the overall voltage limit. ***This voltage limit is safe only for such current-limited sources.***

## 5. THE AFFECTED ZONE

### A. Definition

**5.01** The boundary of the affected zone is defined as: The horizontal distance on either side of a power line at which the voltage-to-ground, at a working height of 6m, is 500-volt rms.

**5.02** The working definition of the affected zone is:

- Where its boundaries are apparent, the power line right-of-way is an acceptable working definition of the affected zone.

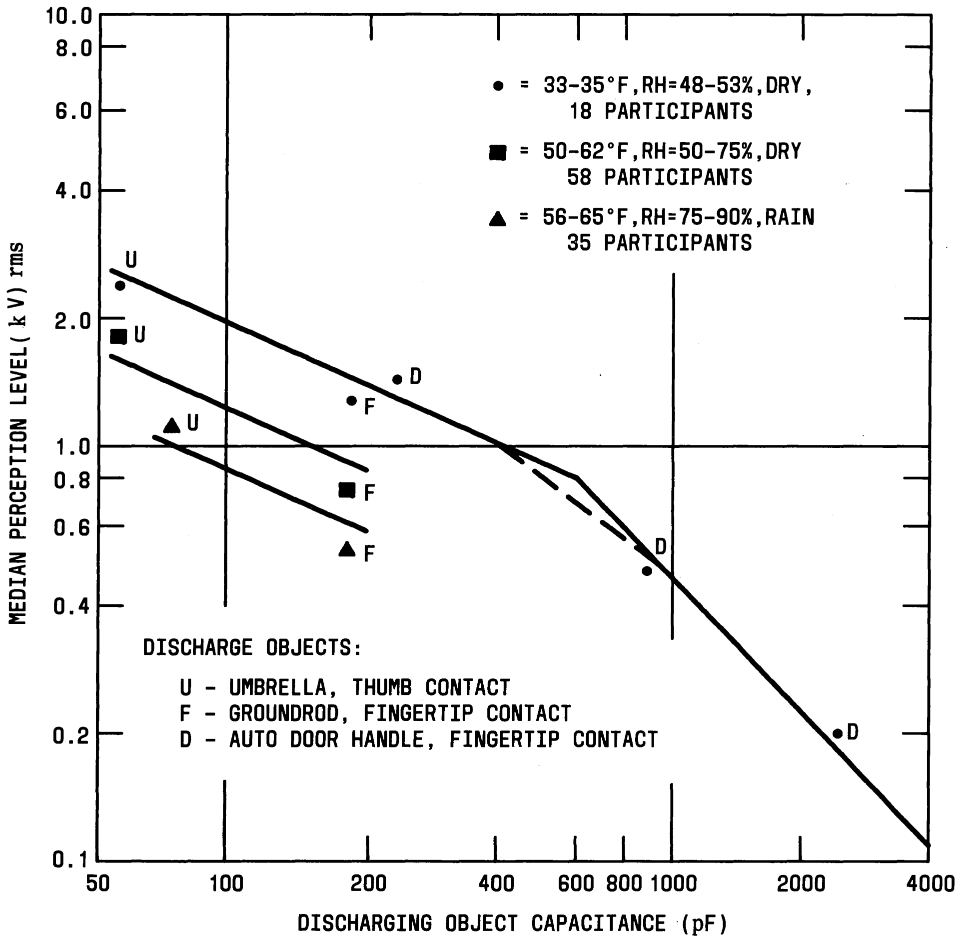


**Fig. 3—Median Perception Level For Repeated Touch Contact**

- If the boundaries of the power line right-of-way are not apparent, the affected zone can extend (depending upon local terrain, vegetation, and structures) over the region within distance d on either side of the power line where d is defined below:

| Line Voltage, Phase-to-Phase (KV) | d (Yards) | d (Meters) |
|---|---|---|
| 350 ± 50 | 65 | 59 |
| 500 ± 100 | 120 | 110 |
| 700 ± 100 | 150 | 137 |

**5.03** The orientation of the telephone line with respect to the power line (parallel, oblique, perpendicular) is irrelevant.

### B. Identification

**5.04** Due to the variety of electric transmission tower configurations, conductor arrangements, and insulator requirements, EHV power lines are not always identifiable by visual inspection. The surest means of identification is to contact the local power company for information as to the location, routing, and voltage of any EHV power lines in the area. Both ac and dc transmission lines require the same special precautions.

**5.05** Many, but not all, EHV lines have more than one in-phase conductor supported by a given insulator string (bundled conductors). In general, a power line employing bundled conductors should be assumed to be EHV.

## 6. RECOMMENDED PRECAUTIONS IN THE AFFECTED ZONE

**6.01** The primary approach to decreasing the voltage induced on a suspended object is to decrease the impedance between the object and ground by either increasing the capacitance to ground or decreasing the resistance to ground.

**6.02** A simple means of increasing the capacitance to ground of a person on a pole (or ladder) is to equip the pole with a pair of grounded vertical wires. The wires are attached to a ground rod at the base of the pole and run up opposite sides of the pole. The wires should run up to near the top of the telephone work space to adequately shield the craft person.

**6.03** In addition, the wires are connected together (and to the strand and down guys, if present) at working height. This step serves the dual purposes of maintaining the aerial hardware at ground potential and ensuring that a single break in a vertical wire or a loss of connection to the ground rod does not remove the protection afforded by the wires (since they are grounded at both ends).

**6.04** The effect of these wires can equivalently be visualized as distorting or perturbing the electrostatic field near the pole as shown in Fig. 4. A dry wood pole (on the left) distorts the field but slightly whereas the vertical wires produce a sharp localized perturbation which reduces the free-space potential to which a person is exposed. Experiments performed beneath the phase wires of 345 kV power line revealed a nearly 15:1 reduction (from 730V rms to 50V rms) in the potential induced on a craft person on a given pole after it was equipped with the grounded vertical wires. It is important to note the localized nature of the protection offered by these vertical wires. Craft persons leaning far to the side from the pole or climbing above the tops of the wires will be subject to increased potentials.

**6.05** If the pole is stepped and the vertical wires are connected to the steps, the potential induced on a person climbing the steps will be further reduced. The steps offer increased capacitance to ground and decreased resistance to ground for the person standing on the step.

**6.06** When a metallic bucket is used in the affected zone, the bucket must be grounded. For this special purpose, a high impedance ground is sufficient. If the bucket, boom and truck chassis are in continuous electrical contact, the truck chassis should be grounded to a temporary ground. The truck outriggers are an acceptable ground for this special purpose. If the truck chassis is not electrically continuous to the bucket, a temporary jumper should be used to connect the bucket to a temporary ground.

**6.07** When a fiberglass bucket is used in the affected zone, protection should be provided by installing a 5 inch or wider aluminum band around the bucket about 36″ from the floor, bonding the band to the truck boom and chassis and grounding the vehicle to a temporary ground or to the outriggers. If the bucket is to be used while the truck is moving, a steel chain drag can be used as a ground.

**6.08** Both the grounded vertical wire, grounded step, and the banded fiberglass bucket approaches primarily depend upon capacitive effects (ie, distorting the field) for their effectiveness. Should these measures prove inadequate in an intense exposure (or for a particularly sensitive person), further decrease in the impedance to ground is necessary. The ultimate in capacitive-coupling protection is to enclose the worker in a grounded metal mesh "tent" (Faraday cage shielding) which, though effective, may be difficult to implement practically. A partial Faraday cage may be temporarily or permanently installed on a pole by adding one or more down guys to form a grounded "tent" over the worker. Alternatively, adding one or more grounded support strands can provide an additional "electrostatic umbrella" effect. Like an umbrella, these additional conductors are most effective when placed between the person and the power line.

**6.09** Decreasing the resistance of the craft person to ground is feasible, but must be done carefully to avoid creating a second problem. A very low impedance contact to ground (say, by holding a grounded wire in one hand) will deenergize the individual but may make contact with the operational voltages on the telephone pairs uncomfortable.

**6.10** Fortunately, a fairly high impedance ground connection is adequate to minimize the

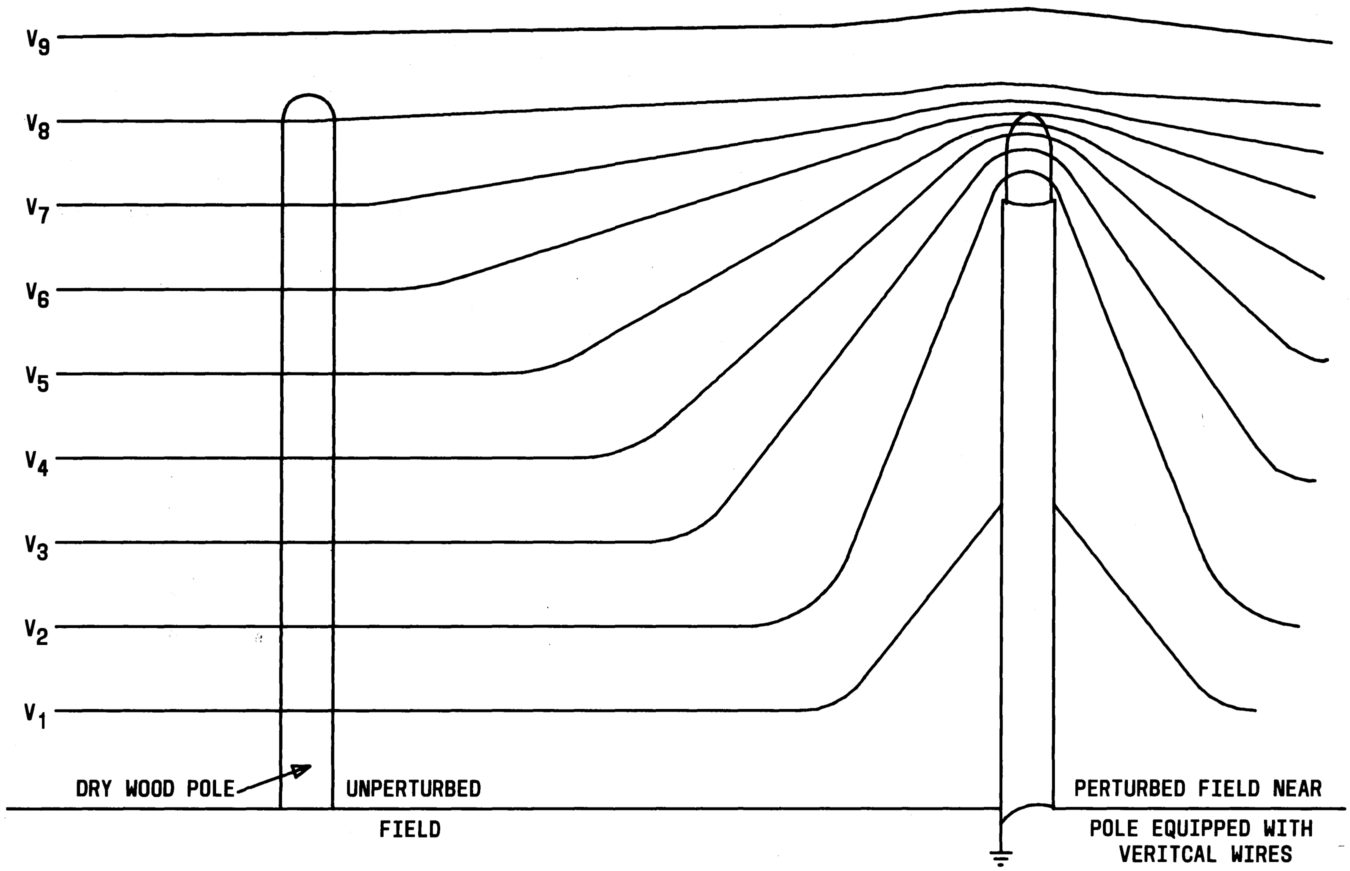


**Fig. 4—Typical Field Distortion Produced by Grounded Vertical Wire**

electrostatic effect and should not pose the difficulty discussed above. Conductive plastic ground straps with impedances of roughly 100 kilohms are commercially available to disperse static charges on individuals working with integrated circuits. In use, one end of a grounding strap is attached to the wearer's wrist and the other clipped to a ground point. In the present application, consider an individual working aloft on a pole equipped with grounded vertical wires who is still uncomfortably affected due to a severe exposure. By clipping one of these plastic straps to the grounded wire and slipping the other end on his wrist, the person may be safely "grounded." This approach should be equally effective for craft working on poles, ladders, or in insulated buckets. However, since it requires an obvious connection to ground which ordinarily should be avoided, ***this approach should not be used in normal situations but reserved for extreme exposures when other methods prove inadequate.***

**6.11** Telephone line routes should maintain the maximum feasible separation from EHV affected zones. In dense EHV power corridors or near future UHV (ultra high voltage, above 800 kV) lines, buried plant offers an advantage as it is effectively immune to the electrostatic influence of the power lines. Similarly, craft servicing the buried telephone line are minimally affected by the power line.

**6.12** ***Before performing any work in an EHV affected zone, refer to the detailed procedures in Section 620-100-015.***

## 7. REFERENCES

**7.01** The following references contain additional information regarding electrostatic effects near EHV lines.

| | |
|---|---|
| 620-100-015 | Guidelines for Working in the Vicinity of Extra High Voltage Power Lines |
| 919-117-096 | Protection Considerations Near Extra High Voltage |

*EHV Transmission Line Reference Book,* Edison Electric Institute, 1968.

*Transmission Line Reference Book, 345 kV and Above,* Electric Power Research Institute, 1975.

*Electrostatic and Electromagnetic Effects of Ultrahigh-Voltage Transmission Lines,* Electric Power Research Institute, EPRI EL-802, Project 566-1, Final Report, June 1978.

*"Field Measurements and Calculations of Electrostatic Effects of Overhead Transmission Lines",* T. D. Bracken, *"IEEE Transaction on Power Apparatus and Systems",* Vol. PAS-95, No. 2 March/April 1976, pp. 494-504.