Harold Kirkham

Measurement of Electric Fields Generated from Alternating Current

In my previous column, I discussed the electric field that you might expect to see in the vicinity of a power line. The electric field is a few kV per meter, elliptically polarized at the ground, and a few kV per centimeter, with a cylindrical geometry near the conductor. It is controlled by the shape and spacing of the conducting surfaces at the high and low potential ends of the field lines.

These conducting surfaces are called the boundary conditions. The idea is to solve Laplace's equation in a coordinate system and get the field in the region between the electrodes. You must know what approximations and assumptions can be made in order to get a solution. Otherwise, a measurement is much more useful. For example, how do you mathematically describe the boundary conditions of the object in Figure 1?

In this column we will consider only the ac field near an irregular object (such as a moose) in the vicinity of a power line. Why might you care about the field around a moose? Because electric power lines were blamed for creating adverse health effects in the 1970s, and we are all interested in knowing about things that affect our health, and we ask if it is true or not. (I gave my answer to the question "is it true or not" about power lines creating an adverse health effect in my previous column, when I discussed the statistics that show no correlation.)

The topic of health problems caused by power lines was widely discussed in the 1970s. One person who fanned the flames of the topic was Louise B. Young. Back in the early 1970s, the local power company wanted to put a 765-kV transmission line across her far. She decided to fight against the construction of these lines. She wrote the book *Power Over People* that alleged that various adverse health effects were caused by the fields from the lines [3]. On the back cover of her book, she was photographed standing under a power line in the dark. Dark that is, except for light from the fluorescent tube she was holding up, to demonstrate the electricity "leaking" from the power line.

When John Witzel wrote "Lights in the Night" in his December 2005 "My Favorite Experiment" column, he used a picture of fluorescent lights glowing under power lines and discussed his boyhood experiment of holding an unconnected fluorescent bulb, and watching it glow. The use of the bulbs associated the two publications and prompted the explanations that I have written of this effect.

Back to the seventies. Power engineers already knew there were electric fields near power lines. But they probably did not really have a firm idea of how these fields varied with time and terrain, or exactly how they interacted with animals. After the publication of Ms Young's book, they had new interest in measuring the fields so the allegations could be addressed, and any health risk scientifically evaluated.

Let us review the measurement.

Measuring Electric Fields

The first measurement of alternating fields made specifically to understand the interaction of living things with power lines was probably by Dr. Don Deno of GE, in Pittsfield, Massachussettes (circa 1970). For many years, there was a research project there investigating high voltage (HV) power line designs and their interaction with the environment. It has gone by the names Project EHV, Project UHV, and HV transmission research facility (HVTRF). At first, ac lines at various voltages were studied, then in later years, HV dc lines. Generally, the fields measured were those undisturbed by the presence of an animal, but as interest grew in the possibility of a biological effect, new instrumentation was developed.

To measure the field near an animal, it is necessary to have the measuring instrument float at the potential of the local space. Otherwise, both the instrument and the animal will greatly distort the field—a combination that renders the measurement meaningless. Consider the fields drawn in Figure 2. The figures show a cross section through a conducting cylindrical object.

In Figure 2(a), the field is what results from an isolated conducting cylinder being inserted into a uniform field. The uniform field is slightly modified—there is enhancement

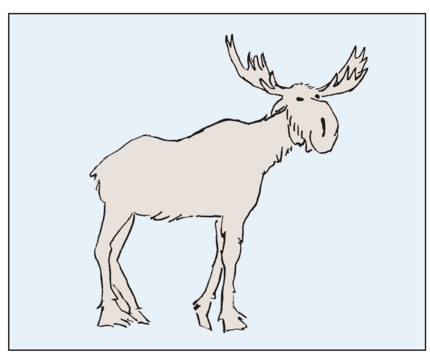

Fig. 1. Difficult boundary conditions.

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at the top and bottom of the cylinder. It can be shown that the original field is doubled when the object is a cylinder and tripled when it is a sphere, regardless of the diameter [1].

As the external field is applied, charges move inside the conductor, and a steady state is reached where (in the case of a field with positive charges aloft) there are negative charges at the top of the object and positive charges underneath. The charges arrange themselves so that the field lines intersect the conductor at right angles. (If this were not the case, there would be a field in the conductor surface that would further move the charges.) There is no net charge on the conductor. The surface charges are called the *induced* charges.

With no net charge, the cylinder in Figure 2(a) is nevertheless at the potential of the local space. If the field is 5 kV/m and the cylinder is 1 m off the ground, the potential of the cylinder is 5 kV. I must say, this goes against my intuition!

Figure 2(b) shows the "opposite" situation. The field here is what results from the addition of a net charge to the cylinder with no externally applied field and therefore no induced charges. The result is identical to the single-phase power line field shown in the previous article and quite unlike the field of Figure 2(a).

In Figure 2(c), these two fields are combined, using the principle of superposition (i.e., the field at any point in the air is the vector sum of the two constituents). The magnitude of the net charge on the object in Figure 2(b) is adjusted so that the field underneath it is equal and opposite to that in Figure 2(a).

Two features are immediately evident. First, because of the way we adjusted the charge in Figure 2(b), there is a region under the cylinder where there is no field. Second, the field at the top of the cylinder is greatly enhanced.

Here is something else that is not intuitively obvious: the field shown in Figure 2(c) is identical to the field that results when a grounded object is inserted into a previously uniform field. The fields are the same because the charge distribution is the same. There is no net charge (by definition, it would be *grounded*); there is only an induced charge on the upper surface. You can see that the lower part of the induced charges on the cylinder in Figure 2(a) is cancelled by the net charge of Figure 2(b), whereas the upper induced charges are augmented.

In Figure 2(a), with no net charge on the cylinder, the field enhancement is minor. In Figure 2(c), the enhancement is *not* minor. Further, while the enhancement in Figure 2(a) is not dependent on the radius of the object, the fields in Figure 2(b) and (c) *are* dependent on the radius. A smaller object will produce a larger field. A grounded object with a pointed tip will result in considerable field intensification. (This is what lightning rods are supposed to do.)

The field around a person standing upright under a power line might be very similar to that shown in Figure 2(c). The field concentrates at the top of the head and is relatively small lower down. This assumes, of course, that the body is a conductor and the head is therefore grounded. The fluorescent light bulb held above the head will experience a higher field than the undisturbed field of the power line. Held down at knee level, it will likely be shielded by the body and see a much lower field.

The field shown in Figure 2(c) might also be that of a field meter that was grounded: then it would not matter whether there was an object under the meter—there is no field there. Deno recognized that to measure a field like that shown in Figure 2(c), the meter must not itself be grounded.

He produced an electrically floating field meter. There are several possible mechanisms to choose from: for example, the field can be made to vibrate something via induced charges, or the fluorescent light can be made to light. Deno made his meter by splitting the conducting object into two parts (a top and a bottom) and measuring the current between the two halves as the induced charges rearranged themselves as the external field alternated at power frequency. This is equivalent to the measurement of the current through two capacitors in series. In this case, the upper capacitor is between the top part of the field meter and the power line, while the lower capacitor is between the lower part of the meter and the ground. The device was approximately the size and shape of a dictionary, and it was held in position near the measurement subject by a long fiberglass pole. The reading was displayed on a large moving coil instrument.

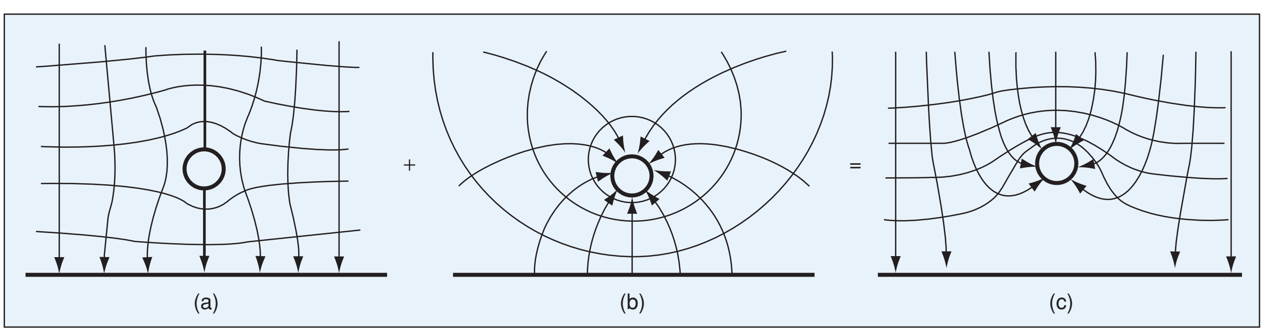

Fig. 2. The sum of external and added fields. (a) Undisturbed field. (b) Field due to net charge. (c) Combined field.

Because the instrument was supported by a pole, the observer could remain at a sufficient distance from the subject and the meter that further distortion was minimized. The capacitances of the instrument to the line above and the ground below formed a voltage divider that held the instrument at the potential of the local space. The field was distorted by the shape of the meter, but by calibrating it in a situation similar to the intended use, the error was reduced to an acceptable value.

Meters of this general design were used in laboratories around the world and appear in the relevant IEEE standards (e.g., ANSI/IEEE Std 644-1987, Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from Power Lines; IEEE Std 1308-1994, IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters—10 Hz to 3 kHz; and IEEE Std 1460-1996: IEEE Guide for the Measurement of Quasi-Static Magnetic and Electric Fields).

Later designs used fiber optics to transmit the readings to a data system, and the probe became smaller. Designs like this were made by several groups, including my team in the United States. With a miniature probe, it became possible not only to measure the electric field near an animal under a power line but also the electric field near an energized high-voltage insulator. Figure 3 shows a representative profile of the vertical component of electric field of a 765-kV line with line height 15 m measured 1.5 m above the ground.

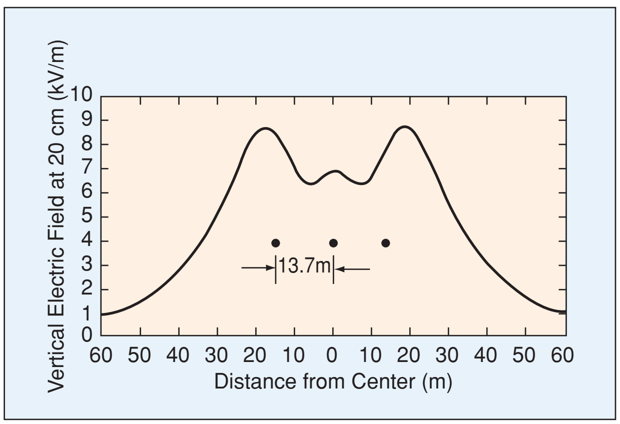

Fig. 3. Electric field across a 765-kV line.

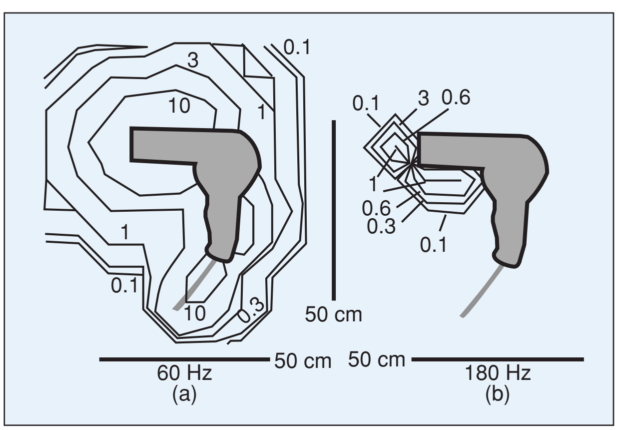

Fig. 4. Magnetic field of hairdryer. Field values shown are in units of microTesla (μT).

As the instrumentation for measuring the electric field improved, however, attention was turning elsewhere. Interest was growing in the magnetic field and the home environment.

Magnetic Field Measurement

At some time in the 1980s, people started to realize that we spend a lot more time at home than we do under power lines. Even power engineers. So, while there are probably a few people who would care about how much electric or magnetic field a wandering moose might experience as it walks under a power line, most of us are more interested in the fields that we ourselves experience, on the couch or in the kitchen.

The calculation is impossible. Since even the location of the many wires in most houses is not known, and the current they carry from minute to minute is also not known, there is no way to calculate the exposure of anyone living and moving around in the house. Measurement becomes necessary. IEEE has established guidelines for the measurements, e.g., IEEE 1460 cited earlier.

(Before measured exposure data were available, some of the earliest work on the biological effects of magnetic fields used the type of wiring as a surrogate. I have met some of the researchers who did this work [2]. I believe they were making a well-intentioned effort to solve a difficult problem. However, this approach has been more or less discredited in the subsequent literature.)

The measurement principle is very simple: the open-circuit voltage in a loop of wire is proportional to the derivative of the magnetic field. (This well-known contribution of Michael Faraday dates from 1831.) The field measurement can therefore be made by integrating the open circuit voltage of a coil of wire. Beware some commercial instruments that purport to measure magnetic fields—they do not all include the integrator!

You can find some statistics of magnetic fields in houses in the IEEE standards. A typical value might be 0.1 μT, but the variability is considerable. Fields a few times larger and perhaps ten times smaller might be observed in any given room at some locations.

Using an electrically isolated probe 2 cm in diameter, my team measured the magnetic field in the plane of a hairdryer. The result is shown in Figure 4. There is also a 120 Hz field. It is broadly similar to the 60 Hz field in shape and magnitude. We thought the third harmonic field, which is likely due to the magnetics of the motor, was curious.

Note that the field shown here is smaller than the Earth's magnetic field (25–65 μT at the surface), though the Earth's field is not alternating. Well, not at 60 Hz, anyway.

Next Column

In the next (and last) of these columns, I will look at the measurement of dc electric fields. The measurement of such fields is complicated by the need for motion and presence of ions in the atmosphere. For these and other reasons we will examine, the dc measurement is actually very challenging. It is perhaps an exaggeration to say that dc fields do not behave like ac fields, but there are often significant differences, and the results are sometimes unexpected.

Further Reading

If you would like to learn more about the topics covered here, a good place to start would be "Biological influences of power frequency electric fields—A tutorial review from a physical and experimental viewpoint," by Jack E. Bridges and Maurline Preache, *Proc. IEEE*, vol. 69, no. 9, pp. 1092–1120, Sept. 1981. This review paper gives an excellent overview of the experimental challenges and presents many results. It has 145 references. (Figure 3 here is adapted from the paper.)

A thoughtful review of many epidemiological studies is given in "Magnetic fields and cancer," by Edwin L. Cartenson, *IEEE Engineering in Medicine and Biology*, vol. 14, no. 4, pp. 362–369, July/Aug. 1995.

An amusing and different perspective is given in "Animal magnetism and quackery," by R. North, *IEE Colloquium on Magnets in Medicine—Hazards and Health Care*, 9 Oct. 1995, pp. 8/1–8/2.

The area is still being researched, and the literature is growing steadily. It will likely continue to do so as long as research grants can be obtained. Meanwhile, just remember that because you are an engineer, people will think you may be a little different. But if you wear a metal hat to shield your brain, they will know you are!

References

[1] W.E. Rogers, *Electric Fields*. New York: McGraw-Hill, 1954.

[2] N. Wertheimer and E. Leeper, "Electrical wiring configurations and childhood cancer," *Amer. J. Epidemiology*, vol. 109, pp. 273–284, 1979.

[3] L.B. Young, *Power over People*. Oxford, U.K.: Oxford Univ. Press, 1973.

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