PUBLIC-HEALTH ASPECTS OF THE ENERGY FLUX OF HIGH-VOLTAGE POWERLINES

F. X. HART, A. A. MARINO

ABSTRACT:

Overhead high-voltage powerlines facilitate the movement of electrical energy over large distances by employing the region of space surrounding the wires to route the energy. We show that the Poynting Vector can be interpreted as a true energy flux and thus that the energy flux of high-voltage powerlines can be uniquely calculated from knowledge of their operating characteristics and geometry. For a typical 765 kV powerline, most of the ground-level energy flux exists beyond the vicinity of the wires resulting in chronic exposure of the general population. Hygienic standards to govern permissable human exposure should be based on energy flux, and not only on the strength of the individual constituent fields until it is proved that the latter approach is sufficient.

KEY WORDS:
HIGH-VOLTAGE POWERLINES, POYNTING VECTOR, ENERGY FLUX

ASPECTS CONCERNANT LA SANTE PUBLIQUE DU FLUX D'ENERGIE DES LIGNES ELECTRIQUES HAUTE TENSION.

RESUME :

Les lignes électriques aériennes haute tension facilitent le transport de l'énergie électrique sur de longues distances en utilisant la région de l'espace entourant les fils pour acheminer l'énergie. Nous montrons que le Vecteur de Poynting peut être interprété comme un veritable flux d'énergie et donc que le flux d'énergie des lignes électriques haute tension peut être calculé uniquement à partir de la connaissance de leurs caractériqtiques de fonctionnement at de leur géométrie. Pour une ligne électrique classique de 765 KV, la plus grande partie du flux d' énergie au niveau du sol se rencontre au delà de la proximité des fils, il en résulte une exposition chronique d'une grande population. Les normes d' hygiène définissant les limites de l'exposition humaine, devraient être basées sur le flux d'énergie et pas seulement sur l'intensité d'une composante particulière des champs jusqu'à ce qu'il soit prouvé que cette dernière approche est suffisante.

MOTS CLES :
LIGNES ELECTRIQUES HAUTE TENSION, VECTEUR DE POYNTING, FLUX D'ENERGIE.

PUBLIC-HEALTH ASPECTS OF THE ENERGY FLUX OF HIGH-VOLTAGE POWERLINES

F. X. HART, A. A. MARINO*

Department of Physics, The University of the South, Sewanee, TN 37375, U.S.A.

*Louisiana State University Medical Center, Department of Orthopaedic Surgery, P. O. Box 33932, Shreveport, LA 71130-3932, U.S.A.

INTRODUCTION

High voltage powerlines facilitate movement of electrical energy between the points of generation and consumption. Typically, powerlines operate at 50 hertz in Europe and 60 hertz in North America. In the overhead method of construction, wires are suspended in air and supported by towers located at sufficient distances from one another to prevent sagging of the wires below a predetermined height. Alternatively, the wires may be placed underground in a metal conduit filled with a dielectric material to provide insulation and a means of heat dissapation. Powerlines operating at 765 kV and above are built overhead, but at lower voltages they can be placed underground if warranted by economic factors.

The energy carried by underground powerlines is physically contained within the metal conduit that surrounds the wires. Such physical localization of the transported energy does not occur for overhead powerlines which employ the region of space surrounding the wires to transport the energy. Thus, underground powerlines exhibit high-density, physically-localized energy fluxes, whereas those associated with overhead powerlines are more diffuse: they are most intense in the vicinity of the wires and decrease laterally.

The wide-spread construction of overhead powerlines raises an important public-health question: What is the nature and extent of any health risks associated with exposure to the energy flux of a powerline? Many reports have appeared describing biological effects of electric fields and magnetic fields (1), but there have been virtually no studies designed to simulate actual exposure conditions experienced by the general public -- exposure to an energy flux consisting of phased simultaneous electric and magnetic fields. In this communication, we show that the energy flux for an overhead powerline can be uniquely calculated from knowledge of the line's basic operating characteristics, and that a significant portion of the energy flux of a typical overhead powerline exists at large lateral distances from the powerline.

*Name and address for all correspondence.

RESULTS

Uniqueness of the Energy Flux: The Poynting Vector $\mathbf{S} = \mathbf{E} \times \mathbf{H}$ satisfies the following Theorem:

$$\mathbf{S} = -\mathbf{E} \cdot \partial \mathbf{D}/\partial t - \mathbf{H} \cdot \partial \mathbf{B}/\partial t - \mathbf{E} \cdot \mathbf{J} \qquad (1)$$

$\mathbf{S}$ is valid for radiation fields, uncoupled fields such as those near overhead powerlines, and static fields. In each case $\mathbf{S}$ could be interpreted as an energy flux if it were unique. An apparent problem is presented by the fact that $\mathbf{S}' = \mathbf{S} + \mathbf{F}$, where $\mathbf{F}$ is a solenoidal vector, also satisfies equation (1). This has led to the suggestion that $\mathbf{S}$ is not a true energy flux (2). But the only known function that: (a) preserves both energy, linear and angular momentum; (b) yields the correct non-relativistic expression for the radiation from an accelerated charge; and (c) is consistent with the Lorentz transformations is $\mathbf{F} = 0$. For these reasons, $\mathbf{S}$ is unique, and can therefore validly be interpreted as a true energy flux.

Calculation of Energy Flux. Mathematical details of the actual calculation are presented elsewhere (3). The results applied to a typical 765 kV power line are shown in Figure 1. At ground level, only a small portion (darker shading shown in Figure 1) of the energy transmitted by the powerline exists directly under the wires. The remaining energy is transmitted through parallel corridors located on either side of the powerline extending out to approximately 200 meters. Comparable results are obtained from powerlines operating at other voltages. Powerlines having a vertical geometry (wires in the individual phases suspended above one another) result in an even higher percentage of their transmitted power being located away from the region near the powerline (4). The penetration of powerline energy flux into ellipsoidal models of human beings has been described (5).

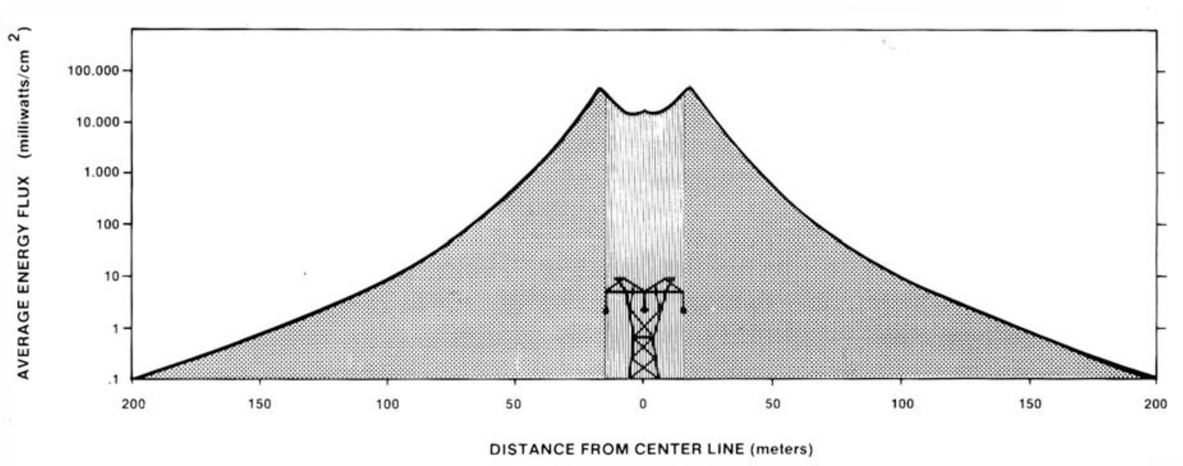

Figure 1: Average ground-level energy flux associated with a typical 765 kV powerline as a function of lateral distance from the center line of the powerline.

DISCUSSION

Although it was once believed that alternate mathematical expressions exist for the energy flux (6), modern authorities are in agreement that the energy flux can be uniquely calculated (7-14). Such a calculation applied to a typical high-voltage powerline shows that significant energy levels exist at various lateral distances. The energy flux can also be directly measured as follows. Consider a thin sheet of metal (mass im, area a) suspended by a thread in a plane perpendicular to the direction of a nearby unenergized powerline. When the line is energized the momentum flux incident upon the sheet is $\mathbf{S} / c^2$, and the sheet will experience a force per unit area of $2\ \mathbf{S} / c$. If the sheet has mass m and area a, the thread will experience an angular deflection of $\theta = \tan^{-1}(2\ \mathbf{S}\ a/mgc)$ where g is the acceleration of gravity. The corresponding linear displacement of the sheet will be $d = 2\ \mathbf{S}\ al/mgc$, where 1 is the length of the thread. If the dimensions of the sheet are small compared to those of the transmission line, the energy flux will not be significantly changed from its value in the absence of the sheet. Using the maximum energy flux shown in Figure 1 (10^5 mW/cm^2), we find that a sheet with an area of 0.12 m^2 and a mass of 0.01 kg would experience a deflection of 0.12 m if suspended by a 15-m thread. (If a non-zero $\mathbf{F}$ did exist, it could be determined by comparing the observed deflection to the corresponding theoretical value.)

Even though the energy flux can be measured directly, it is generally not practical to do so. Normally, measuring instruments are made to couple with either the electric or magnetic field created by the powerlines. This should not, however, obscure the fact that the physical entity that actually exists near an ordinary overhead powerline is an energy flux that consists of simultaneous electric and magnetic fields that bear a fixed phase relationship to one another. It follows, therefore, that assessment of health risks and determination of exposure limits should be based on energy flux, and not merely on the individual fields that constitute the flux. Future work may show that the biological effects of each of the fields are separable, but such a result cannot presently be presumed.

REFERENCES

(1) BECKER, R.O. and MARINO, A.A.: Electromagnetism and Life, SUNY Press, Albany, NY, 1982.

(2) SETO, Y.J. and CRONVICH, J.A.: Comments on ' Energy Flux Along High Voltage Transmission Lines, IEEE Trans. Biomed. Eng. BME-26, 182-183, 1979.

(3) HART, F.X. and MARINO, A.A.: Energy Flux Along High Voltage Transmission Lines, IEEE Trans. Biomed. Eng. BME-26, 182-182, 1979.

(4) REICHMANIS, M. and MARINO, A.A.: Bioelectric Considerations in the Design High-Voltage Power Lines, J. Bioelectricity 1, 329-339, 1982.

(5) HART, F. X. and MARINO, A.A.: ELF Dosage in Ellipsoidal Models and Man due to High Voltage Transmission Lines, J. Bioelectricity 1, 129-154, 1982.

(6) SLEPIAN, J.: Energy and Energy Flow in the Electromagnetic Field, J. Appi. Phys. 13, 512-518, 1942.

(7) HINES, C.0.: Electromagnetic Energy Density and Flux, Can. J. Phys. 30, 123-129, 1952.

(8) LORRAIN, P.: Alternative Choice for the Energy Flow Vector of the Electromagnetic Field, Am. J. Phys. 50, 492, 1982.

(9) PUGH, E.M. and PUGH, G.E.: Principles of Electricity and Magnetism, Addison-Wesley, Reading, MA, 1970.

(10) CORINALDESI, E.: Angular Momentum of a Static Electromagnetic Field, Am. J. Phys. 48, 83-84, 1980.

(11) LAHOZ, E.G. and GRAHAM, G.M.: Observation of Electromagnetic Angular Momentum Within Magnetite, Phys. Rev. Lett. 42, 1137-1140, 1979.

(12) GRAHAM, G.M. and LAHOZ, D.G.: Observation of Static Electromagnetic Angular Momentum in Vacuo, Nature 285, 154-155, 1980.

(13) PENFIELD, JR., P. and HAUS, J.A.: Electrodynamics of Moving Media, Research Monograph No. 40, The M.I.T. Press, Cambridge, MA, 237-239, 1967.

(14) HEALD, M.A.: Electric Fields and Changes in Elementary Circuits, Am. J. Phys. 52, 522-526, 1984.

Article reçu le : 23 août 1984 ; Accepté le : 4 octobre1984.