

IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields From AC Power Lines

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Abstract: Uniform procedures for the measurement of power frequency electric and magnetic fields from alternating current (ac) overhead power lines and for the calibration of the meters used in these measurements are established. The procedures apply to the measurement of electric and magnetic fields close to ground level. The procedures can also be tentatively applied (with limitations, as specified in the standard) to electric fields near an energized conductor or structure.

Keywords: ac power lines, electric field, magnetic field, measurement

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Introduction

(This introduction is not part of IEEE Std 644-1994, IEEE Standard Procedures for This Measurement of Power Frequency Electric and Magnetic Fields From AC Power Lines.)

This standard is a revision of IEEE Std 644-1987 (a revision of IEEE Std 644-1979), which establishes uniform procedures for measuring power frequency electric and magnetic fields in the vicinity of ac power lines. The following revisions have been made and are intended to improve the usefulness of the document:

- a) Text has been introduced that permits the measurement of the resultant magnetic field using three-axis (or single-axis) magnetic field meters. This change required revisions in the calibration procedure clauses and an explanation of the difference between maximum field value and resultant field value.
- b) Text (with appropriate bibliographical references) has been added to note that magnetic field calibration coil systems other than the one described in the standard may be used for calibration purposes, provided that the fields produced have comparable uniformity.
- c) Corrections in the text and improved figures.
- d) Clarification of text related to calibration uncertainty in the calibration clauses.

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IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields From AC Power Lines

1. Overview

The purpose of this standard is to establish uniform procedures for the measurement of power frequency electric and magnetic fields from alternating current (ac) overhead power lines and for the calibration of the meters used in these measurements. A uniform procedure is a prerequisite to comparisons of electric and magnetic fields of various ac overhead power lines. These procedures apply to the measurement of electric and magnetic fields close to ground level. They can also be tentatively applied to electric field measurements near an energized conductor or structure with the limitations outlined in 4.5.

2. References

This standard shall be used in conjunction with the following publication.

IEEE Std 100-1992 , The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).¹

3. Definitions

For additional definitions, see IEEE Std 100-1992 .²

3.1 crosstalk: The noise or extraneous signal caused by ac or pulse-type signals in adjacent circuits (measurement of power frequency magnetic fields).

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

²Information on references can be found in clause 2.

3.2 electric field strength (electric field): At a given point in space, the ratio of force on a positive test charge placed at the point to the magnitude of the test charge, in the limit that the magnitude of the test charge goes to zero. The electric field strength (E -field) at a point in space is a vector defined by its space components along three orthogonal axes. For steady-state sinusoidal fields, each space component is a complex number or phasor. The magnitudes of the components, expressed by their root-mean-square (rms) values in volts per meter (V/m), and the phases need not be the same [B1].³ See also: **phasor**.

Note: The space components (phasors) are not vectors. The space components have a time dependent angle, while vectors have space angles. For example, the sinusoidal electric field E can be expressed in rectangular coordinates as

$$\vec{E} = \hat{a}_x E_x + \hat{a}_y E_y + \hat{a}_z E_z \quad (1)$$

The space component in the x -direction is

$$E_x = \operatorname{Re}(E_{x0} e^{j\phi_x} e^{j\omega t}) = E_{x0} \cos(\phi_x + \omega t)$$

The magnitude, phase angle, and time dependent angle are given by E_{x0} , ϕ_x , and $(\phi_x + \omega t)$, respectively. In this representation the space angle of the x -component is specified by the unit vector $\hat{a}_x$.

An alternative general representation of a steady-state sinusoidal E -field, derivable algebraically from equation (1) and perhaps more useful in characterizing power line fields, is a vector rotating in a plane where it describes an ellipse whose semimajor axis represents the magnitude and direction of the maximum value of the electric field, and whose semiminor axis represents the magnitude and direction of the field a quarter cycle later [B1], [B4]. The electric field in the direction perpendicular to the plane of the ellipse is zero. See also: **single-phase ac fields; polyphase ac fields**.

3.3 frequency: The number of complete cycles of sinusoidal variation per unit time. *Notes:* 1) Electric and magnetic field components have a fundamental frequency equal to that of the power line voltages and currents. 2) For ac power lines, the most widely used frequencies are 60 and 50 Hz.

3.4 harmonic content: Distortion of a sinusoidal waveform characterized by indication of the magnitude and order of the Fourier series terms describing the wave. *Note:* For power lines, the harmonic content is small and of little concern for the purpose of field measurements, except at points near large industrial loads (saturated power transformers, rectifiers, aluminum and chlorine plants, etc.) where certain harmonics may reach 10% of the line voltage. Laboratory installations also may have voltage or current sources with significant harmonic content.

3.5 magnetic flux density (magnetic field): The vector quantity (B -field) of divergence zero at all points, which determines the component of the Coulomb-Lorentz force, that is proportional to the velocity of the charge carrier.

Note: In a zero electric field, the force F is given by $\vec{F} = q\vec{v} \times \vec{B}$ where $\vec{v}$ is the velocity of the electric charge q . The vector properties of the field produced by currents in power lines are the same as those given above for the electric field. The magnitudes of the field components are expressed by their rms values in tesla ($1T = 10^4 G$).

3.6 maximum value of the electric field strength: At a given point, the rms value of the semimajor axis magnitude of the electric field ellipse. See also: **electric field strength**.

3.7 maximum value of the magnetic field: At a given point, the rms value of the semimajor axis magnitude of the magnetic field ellipse.

3.8 perturbed field: A field that is changed in magnitude or direction, or both, by the introduction of an object. *Note:* The electric field at the surface of the object is, in general, strongly perturbed by the presence of the object. At power frequencies the magnetic field is not, in general, greatly perturbed by the presence of objects that are free of magnetic materials. Exceptions to this are regions near the surface of thick electric conductors where eddy currents alter time-varying magnetic fields.

³The numbers in brackets correspond to those bibliographical items listed in clause 9.

3.9 phasor: A complex number expressing the magnitude and phase of a time-varying quantity. Unless otherwise specified, it is used only within the context of steady-state alternating linear systems. In polar coordinates, it can be written as $Ae^{j\phi}$, where A is the amplitude or magnitude (usually rms, but sometimes indicated as peak value) and ϕ is the phase angle. The phase angle ϕ should not be confused with the space angle of a vector. *See also:* **electric field strength**.

3.10 polyphase ac fields: Fields whose space components may not be in phase. These fields will be produced by polyphase power lines. The field at any point can be described by the field ellipse—that is, by the magnitude and direction of the semimajor axis and the magnitude and direction of its semiminor axis. *Note:* Such fields are sometimes referred to as being elliptically polarized. Certain power line geometries can produce circularly polarized fields. For polyphase power lines, the electric field at large distances (≥ 15 m) away from the outer phases (conductors) can frequently be considered a single-phase field because the minor axis of the electric field ellipse is only a fraction ($<10\%$) of the major axis when measured at a height of 1 m above ground level. *See also:* **electric field strength**.

3.11 resultant magnetic field: The resultant magnetic field is given by the expression

$$B_R = \sqrt{B_x^2 + B_y^2 + B_z^2} \quad (2)$$

where

B_x , B_y , and B_z are the rms values of the three orthogonal field components.

NOTES:

1 — The resultant magnetic field is also given by the expression

$$B_R = \sqrt{B_{\max}^2 + B_{\min}^2} \quad (3)$$

where $B_{\max}$ and $B_{\min}$ are the rms values of the semimajor and semiminor axes of the magnetic field ellipse, respectively. The resultant B_R is always $\geq B_{\max}$. If the magnetic field is linearly polarized, $B_{\min} = 0$ and $B_R = B_{\max}$. If the magnetic field is circularly polarized, $B_{\max} = B_{\min}$ and $B_R = 1.41B_{\max}$.

2 — A three-axis magnetic field meter simultaneously measures the rms values of the three orthogonal field components and combines them according to equation (2) to indicate the resultant magnetic field. Although power line magnetic fields are typically two dimensional in nature, i.e., elliptically polarized, unless two axes of a three-axis probe are in the plane of the ellipse, each of the three probes will sense a component of the rotating magnetic field vector.

3.12 single-phase ac fields: Fields whose space components are in phase. These fields will be produced by single-phase power lines. The field at any point can be described in terms of a single direction in space and its time-varying magnitude. *Note:* Such fields are sometimes referred to as being linearly polarized.

3.13 uniform field: A field whose magnitude and direction are uniform at each instant in time at all points within a defined region.

3.14 vertical component of the electric field strength: The rms value of the component of the electric field along the vertical line passing through the point of measurement. This quantity is often used to characterize electric field induction effects in objects close to ground level.

3.15 weakly perturbed field: At a given point, a field whose magnitude does not change by more than 5% or whose direction does not vary by more than 5 degrees when an object is introduced into the region.

4. Electric field strength meters

4.1 General characteristics

Two types of meters used to measure the electric field strength from ac power lines are described in technical literature.

- Free-Body meter: Measures the steady-state induced current or charge oscillating between two halves of an isolated conductive body in an electric field [B2], [B23].
- Ground-Reference-Type meter: Measures the current-to-ground from a flat probe introduced into an electric field [B16].

The free-body meter is suitable for survey-type measurements because it is portable, allows measurements above the ground plane, and does not require a known ground reference. Therefore, this type of meter is recommended for outdoor measurements near power lines.

This standard presents measurement techniques for only the free-body type meter. Flat ground-reference-type meters can be used only under special conditions described in 6.2. Electric field strength meters intended for characterization of radio-frequency electric fields should not be used to measure the electric field strength from ac power lines.

Basically, an electric field strength meter consists of two parts, the probe and the detector. For commercially available free-body meters, the detector is usually contained in, or is an integral part of, the probe. The probe and detector are introduced into an electric field on an insulating handle. The detector measures the steady-state induced current or charge oscillating between the conducting halves (electrodes) of the probe. The observer is sufficiently removed from the probe to avoid significant perturbation of the electric field at the probe (see 5.1). The size of the probe should be such that charge distributions on the boundary surfaces generating the electric field (energized and ground surfaces) are, at most, weakly perturbed when the probe is introduced for measurement. The electric field should be approximately uniform in the region where the probe will be introduced. Probes can be of any shape; however, meters commercially available in the U.S. are generally in the shape of rectangular boxes, with side dimensions ranging from ~7 to ~20 cm. The meters are calibrated to read the rms value of the power frequency electric field component along the electrical axis (the axis of greatest electric field strength sensitivity).

There also exist free-body meters designed for remote display of the electric field strength. In this case, a portion of the signal processing circuit is contained in the probe and the remainder of the detector is in a separate enclosure with an analog or digital display. A fiber-optic link connects the probe to the display unit. This type of probe is also introduced into an electric field on an insulating handle.

In order to characterize the instrumentation adequately, the manufacturer should provide a detailed description of the electronics, as well as other relevant information, as indicated in figure 1, section G. For example, if the field meter reading has a temperature dependence, the temperature coefficient should be provided. This permits the operator to correct *E*-field readings made outdoors using an instrument calibrated at room temperature. If the electrical axis of the field strength meter is not coincident with the geometric axis, the departure in degrees and direction shall be specified.