



IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions

IEEE Power and Energy Society

Developed by the
Power System Instrumentation and Measurements Committee

IEEE Std 1459™-2025
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STANDARDS

IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions

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Power System Instrumentation and Measurements Committee
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IEEE SA Standards Board

Abstract: Definitions used for measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced, or unbalanced conditions are provided in this standard. Mathematical formulas for measurements and the appropriate notations for expressing quantity values are given. Informative annexes discuss (A) the measurement observation period, (B) combining Fourier decomposition and phase-sequence components, (C) a systems approach to measurement, (D) filtering, (E) a Trust Metric and a No-trust Metric, (F) Source Apparent Power, and (G) omissions from the previous version of Std 1459. Expressions that were used in the past, as well as new expressions, are listed, as well as explanations of the features of the new definitions.

Keywords: apparent power, average power, IEEE 1459™, legal metrology, operational measurement, power factor, reactive power, representational measurement, scientific meaning

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Introduction

This introduction is not part of IEEE Std 1459-2025, IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions.

In the introduction to the 2010 edition of this standard, there was a complaint that there was no “generalized power theory” able to cope with all the problems of measuring the power quantities for the many possible applications. It was seen to be problematic that there was a need for multiple, *different* methods of measurement of ostensibly the *same quantity*. Nothing in the history of the power system had resolved this problem.

Since 2010, some underlying causes of long-standing problems with power system measurements have come into focus. In fact, it had never been a power theory that was lacking, but an appreciation of measurement theory, and an understanding of its implications. Consider the ten events listed below. Each is relevant to the measurement problems we have experienced in the power system.

- a) The physical world and our *representation of it* are distinct. Maxwell knew this in 1870 when he wrote about the relation between mathematics and physics. “In themselves, one is an operation of the mind, the other is a dance of molecules” (Maxwell [B28], p. 422).⁶ That notion underlies all our thinking about measurement.
- b) Maxwell’s Treatise [B29] opens with a chapter on measurement, the first paragraph of which is this:

Every expression of a Quantity consists of two factors or components. One of these is the name of a certain known quantity of the same kind as the quantity to be expressed, which is taken as a standard of reference. The other component is the number of times the standard is to be taken in order to make up the required quantity. The standard quantity is technically called the Unit, and the number is called the Numerical Value of the quantity.

That simple-seeming statement imposes strict structural requirements on the scale of measurement, a concept that would not be formalized until 1946. [See item d).]

- c) Differences between measurements of quantity (such as weight) and measurements of quality (such as density) were explored in a foundational book by Campbell, who also clarified differences between what we now know as direct and indirect measurements [B9].
- d) Measurements of the kind indicated by Maxwell require that the measurement result be linearly related to the physical quantity (the measurand), and must go to zero as the measurand becomes immeasurably small. That statement also means that one reference quantity is required. Four measurement scales were elucidated by Stevens [B42]. Only one scale met this structural requirement. It is called the *rational* scale because it allows mathematical ratios. *It is the only scale that supports scientific measurements in our field.*
- e) Eisenhart, of the U.S. National Bureau of Standards [B13], gave a useful definition of measurement in 1963:

The object of measurement is to obtain symbolic representation of properties of things as a basis for conceptual analysis and . . . to effect the representation in a form amenable to the powerful tools of mathematical analysis. . . . Measurement always pertains to properties of things, not to the things themselves. (p. 163)
- f) Carnap [B10] clarified a requirement for measurements on the rational scale (in Chapter 7). It is simple to add two numbers in the mathematical domain, but if the numbers are measurement results, they cannot be meaningfully added unless the corresponding physical quantities can be subject to a similar combining operation, called a *concatenation*. Weights are concatenated by placing them on the same pan of the balance. Rulers are concatenated by aligning them end to end.
- g) A measurement that meets the requirements listed above uses a mathematical relationship called the *measurement model*. Simpson ([B40], p. 2) notes that this model must be “based on the laws of physics or our understanding of the universe.” That means that the measure is subject to an *appeal to experiment*. The act of measurement consists of finding the values of the parameters of the

⁶ The numbers in brackets correspond to those of the bibliography in Annex H.

measurement model. In practice, measurement is often the act of finding the “best fit” of the parameter set to the observed variables. (See Potter [B36], p. 9.) Often, “best fit” means least-square error.

- h) There is an isomorphism between concatenation and the addition of numbers that is consistent with the view of measurement being a mapping between the physical world and the conceptual. Hand ([B16], p. 65) shows that a structure such as Maxwell’s satisfies an equation known as Cauchy’s functional equation. Applied to measurements, it can be written as $m(A) + m(B) = m(A \circ B)$, which is read as “the sum of the measured value of A and the measured value of B is the same as the measured value of A and B concatenated.” Measurements satisfying this equation exhibit a 1:1 relationship between the measurements and the quantities, an essential step in demonstrating the utility of measurement results in mathematical models.
- i) The *Guide to the Expression of Uncertainty in Measurement* (Joint Committee for Guides in Metrology, WG 1 [B21]) lists several possible sources of uncertainty (see p. 6). The first three reflect differences between the measurement model and the observed signal, identified as “definitional uncertainty” because the measurement model is regarded as the definition of the measurand.

For the most part, this timeline recounting of advances in measurement theory leads to the sort of measurements expected by engineers and scientists and for which there is a coherent and well-understood theoretical underpinning.

However, a book published in 1927 told a different story.

- j) The foundations of *operationalism* were laid by Bridgman [B7]. These are measurements whose results are essentially defined by the operations involved in their measurement, responding to Bridgman’s observation that:

In general, we mean by any concept nothing more than a set of operations; *the concept is synonymous with the corresponding set of operations*. If the concept is physical, as of length, the operations are actual physical operations, namely, those by which length is measured. (Italics in the original)

The definitions of the quantities considered in this standard are definitions of sets of operations. They are not measurement models: *Each measure is defined operationally*. This characteristic arose because, as the electric power system developed, the need for metering preceded a theoretical understanding of measurement. The things we measure departed quite early in our history from the apparently linear sequence indicated in item a) to item i) above, the route to modern scientific measurements.

For example, Power Factor fails at item c) and at item f) because it is a bounded quantity, which cannot be concatenated. Reactive Power fails at item f) because it cannot be meaningfully concatenated. Czarnecki [B12] demonstrated that. Even average power and apparent power fail to meet these characteristics. Berrisford [B6] pointed out that modern metering should be able to correct the deficiency that some loads inject harmonic power into the delivery system, and that power is subtracted from the bill for their “average power.” Kitzig et al. [B27] show that even a simple passive nonlinear load consumes more power than it would be billed for.

Since the measurements considered in this standard are operational, they all fail the appeal to experiment at item g) in the list. Operational measurements are defined by a consensus-based procedure. Since their operational character has not been recognized, *no consensus has so far been reached*.

NEMA Technical Report C12.24 TR-2022 [B33] demonstrates the problem of *unacknowledged* operationalism. The title of the technical report is “Definitions for calculations of VA, VAh, VAR, and VARh for Electricity Meters,” and its content does indeed comprise definitions for calculations of quantity values. However, multiple different methods are given for what may be supposed to be the same quantity. The results presented in the report show that the various methods give inconsistent results: that inconsistency is a characteristic of “unmanaged” operational measurements. A paper on the topic (Riepnieks et al. [B38]) used the data from an earlier version (NEMA Technical Report C12.24 TR-2011 [B32]), to illustrate the point graphically.

In operational measurements, *procedure* plays the definitive role in establishing what is measured. That means that in order for operational measurements to produce consistent results (when the instruments are made by different manufacturers), many details of the measurement process must be specified by the standard. Indeed, that is one of the main purposes of a documentary standard such as this one. As a standard for a series of operational measurements, this standard is required to specify sufficient detail to ensure consistent results. The standard no longer provides multiple ways to measure power factor or reactive power, as it did in the previous edition.

The present standard specifies methods for the single-phase and three-phase measurements of the quantities considered, and it allows only the choice of using a fundamental-only method or an unfiltered method. The standard recognizes the need to define the period over which the measurement is made, also a measurement that is operational. It allows the choice of one of only two described methods. The topic is discussed in Annex A.

Representational measurements (those with complete mathematical models) may be preferred, but in power system engineering, they have been elusive. There is good reason for that. In a representational measurement, the observable quantities must be represented by models of matching complexity. A three-phase voltage, with just two harmonics, would require a measurement model with 21 degrees of freedom, corresponding to 21 independent parameters in the model, all of which would have to be measured to give unambiguous results. Even if this aspect of the measurements had been recognized in the last 100 years or so, the required complexity would have led, not unreasonably, to the use of operational measurements anyway.

Whereas all the quantities of this standard are measured by operational measurements, some, like average power, seem “scientific.” Other operational measurements appear to make no sense from the scientific point of view. These continue to exist because they have been found to be useful in some applications. Measurement methods of this sort are sometimes approved and specified as an important part of legal metrology by authorities such as NEMA. (Legal metrology deals with measurements used to ensure compliance with a law or a regulation or generally a matter of trade.)

Other methods are merely in common use. For example, the expression “rms weighted average responding” is used to describe a voltmeter that is not a “True rms” voltmeter. Their presence in this standard shall not be interpreted as bestowing scientific repute on them as a substitute for the “True rms” voltmeter. They are included for completeness.

The 2010 version of this standard hinted of a new measurement solution. Put simply, if the Fortescue symmetrical-component transform is applied to a Fourier decomposition of the signals, a measurement scheme of arbitrary complexity can be logically and straightforwardly developed. The multiple degrees of freedom are segregated by frequency. The idea is described more fully in Annex B to this standard. Such a scheme, if adopted, would allow the creation of models for many new quantities. Most of these would be of quantities that, at present, have no firm conceptualization, for example, third-harmonic negative-sequence reactive power. It is for the power engineering community to meet the challenge of understanding the usefulness (or otherwise) of such “new” measurands.

Contents

1. Overview	12
1.1 Scope	12
1.2 Purpose	12
1.3 Word usage	12
2. Normative references	13
3. Definitions	13
3.1 Observable quantities	15
3.2 Single-phase indirect measurements	16
3.3 Three-phase indirect measurements	22
Annex A (informative) Observation period	29
A.1 Why this matter is important	29
A.2 NEMA C12.31 method	30
A.3 IEC 61000-4-30 testing and measurement techniques—Power quality measurement methods	30
A.4 The rms “quantity”	30
Annex B (informative) Fourier and Fortescue components	36
B.1 Phasor representation	37
B.2 Three-phase spectral power definitions	38
B.3 Fortescue transformation (symmetrical components)	38
B.4 Use case	40
Annex C (informative) Systems approach to the measurement process	43
Annex D (informative) Filtering	45
Annex E (informative) Trust Metric and No-trust Metric	47
E.1 Trust Metric	47
E.2 No-trust Metric	48
Annex F (informative) Source apparent power (Source VA)	49
F.1 Rationale	49
F.2 Source versus load VA, 4-wire wye system	49
F.3 Source VA, 3-wire delta system	51
F.4 Source VA equation for 3-wire delta systems	52
Annex G (informative) Omissions from the 2010 release of IEEE Std 1459	54
G.1 Distortion Power	54
G.2 Instantaneous power	55
G.3 Reactive power interpretation	55
G.4 Vector apparent power and effective apparent power	56
G.5 Other omissions	56
Annex H (informative) Bibliography	57

IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions

1. Overview

1.1 Scope

This document provides quantity definitions for designing and using instrumentation for the measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced, and unbalanced conditions.

1.2 Purpose

This standard is intended for use in designing and using instrumentation for the measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced, and unbalanced conditions. Because there are major differences between this document and its 2010 predecessor, some of the material is pedagogical in nature.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{7, 8}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should equals is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may equals is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can equals is able to*).

⁷ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁸ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 61000-4-30, Electromagnetic compatibility (EMC)—Part 4-30: Testing and measurement techniques—Power quality measurement method.⁹

NEMA C12.31G-TR-2024, Guide for measurement of voltage, current, power, energy, and power factor.¹⁰

3. Definitions

The scope of this standard is to specify “quantity definitions.” The standard acknowledges the operational nature of the measurements it covers: The quantity definitions are method definitions. An operational method cannot guarantee measurement consistency or interoperability without a specification of the complete measurement process. Some parts of the measurement process are not completely specified in this standard.

The definitions below shall be applied to all power system conditions, that is, sinusoidal, nonsinusoidal, balanced, or unbalanced conditions, as it is not possible to know in advance what state the power system will be in.

Sometimes the signals are sufficiently distorted to render the results of some measurements less meaningful. This condition may be detected by the use of a Trust Metric as described in Annex E. It is a matter for the user to decide on an appropriate action should a situation of reduced trust be indicated in the measurement result.

The methods described in this standard were developed on the assumption of a power system operating at 50 Hz/60 Hz. The methods are expected to apply for frequencies such as 400 Hz (aerospace) or 25 Hz (traction). However, care is needed to fully define the operational aspects of the measurement. An overview of why operational measurements are needed is given in Annex C. The high-level definitions are shown in this clause. Operational overlays that may be required to get consistent calculations are described in the annexes. For example, Annex A discusses methods of measuring the frequency or period of the signals so that boundaries of the measurement can be determined. Filtering requirements to achieve a given level of measurement accuracy are discussed in Annex D.

The notation in Table 1 is used throughout this standard.

Many of the definitions in this standard are shown in integral form. However, it is recognized that they will usually be implemented digitally by a summation with a finite sampling rate. This standard does not specify a sampling rate.

⁹ IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

¹⁰ NEMA publications are available from the National Electrical Manufacturers Association (<https://www.nema.org/>).

Table 1—Notation used for parameters¹¹

Description	Notation
Whole number of cycles	k
Harmonic order	h
Number of contained harmonics	H
Time period of a cycle	T
Starting time	t_0
Phase name	A, B, C
Neutral	N
Fundamental	$subscript_1$
rms weighted average See NOTE 2	$subscript_{rwa}$
Three-phase 4-wire wye system	λ
Three-phase 3-wire delta system	Δ
Single-phase 3-wire system	ψ
Counter	m
Number of averaging entities	M
Phase name placeholder	X, Y
Angular frequency	ω
Initial phase	φ
NOTE 1—This standard considers only the four most common connection types; 2-wire single-phase, 3-wire single-phase (also known as split phase), 4-wire wye, and 3-wire delta. It is recommended that definitions for other types of systems be formulated and recorded for traceability when used. Examples of these other systems can be found in ANSI C12.1 [B2]. In three-phase ac electricity generation, transmission, and distribution systems, the convention of labeling the three ac phase conductors varies from country to country. Typical phase labeling conventions are A, B, C; a, b, c; L1, L2, L3; H1, H2, H3; R, S, T; U, V, W; and R, Y, B. In this standard A, B, and C is used, which is popular in North America. IEC 60446 [B19] uses L1, L2, and L3 for ac phase conductors. NOTE 2—The rms weighted average is also known as the <i>rms calibrated average</i>. The rms weighted average value of a periodic signal represents the average value of the rectified signal multiplied (or scaled) by a factor of $\left(\frac{\pi}{2\sqrt{2}}\right)$, or ≈ 1.11. Based on this definition, an <i>rms responding instrument</i> and an <i>rms weighted average responding instrument</i> will indicate the same value given a sinusoidal input signal. Derivation of equations in a typical use case is shown in A.4.5. NOTE 3—Alternating quantities are commonly represented by a mathematical sinusoid with three parameters, amplitude, frequency, and initial phase. These are sometimes termed <i>phasor quantities</i>. Annex B discusses the phasor notation. <i>Initial phase</i> is not to be confused with <i>phase name</i>. NOTE 4—In Microsoft Word, the symbol “人” can be inserted as a Symbol by selecting character code 2144 from the Unicode (hex) set.	

¹¹ Notes in the text, tables, or figures of a standard are given for information only and do not contain mandatory requirements. Notes that are identified with a superscript lowercase letter and set immediately below the border of a table are normative, and contain requirements for compliance with this standard.

3.1 Observable quantities

Each entry in Table 2 specifies the notations for the observable parameters and indicates the value of a single observable quantity, including fundamental-filtered quantities.

All other quantities in this standard are indirectly measured quantities derived from those in Table 2.

Table 2—Notations for observable quantities

Description	Notation
Instantaneous voltage for a single-phase	$v(t)$ or $v_{XN}(t)$ where X is the phase voltage measurement (A or C) with respect to N the reference voltage. See NOTE 1 and NOTE 3
Instantaneous fundamental voltage for a single-phase	$v_1(t)$ or $v_{XN1}(t)$ See NOTE 2 and NOTE 3
Instantaneous current for a single-phase	$i(t)$ or $i_X(t)$ where X is the phase current measurement (A,C) See NOTE 1 and NOTE 3
Instantaneous fundamental current for a single phase	$i_1(t)$ or $i_{X1}(t)$ See NOTE 2 and NOTE 3
Instantaneous voltage for any of three phases	$v_{XY}(t)$ where X is the phase voltage measurement (A,B,C) with respect to Y the reference voltage (A,B,C,N) See NOTE 3
Instantaneous fundamental voltage for any of three phases	$v_{XY1}(t)$ See NOTE 2 and NOTE 3
Instantaneous phase current in a three-phase 4-wire system or 3-wire delta system	$i_X(t)$ where X is the phase current measurement (A,B,C) See NOTE 3
Instantaneous fundamental phase current in a three-phase 4-wire system or 3-wire delta system	$i_{X1}(t)$ See NOTE 2 and NOTE 3
NOTE 1—In an electric meter, the terminals for a 3-wire single-phase service are in the phase A and phase C locations. Consequently, the terminology V_{AN} and V_{CN} is often used where phase C is nominally 180° out of phase with A. NOTE 2—The question of filtering as a requirement for some of these measurements is an operation discussed in Annex D. NOTE 3—The instantaneous value of an observable quantity can be taken as equivalent to a sampled value. To calculate the fundamental component requires a time delay. Therefore, the value of the “instantaneous fundamental” of a quantity is not obtained “instantaneously.” However, the value of the fundamental of the signal can be associated with a time t, as indicated in the formulas. The value is obtained by accounting for this delay.	

3.2 Single-phase indirect measurements

3.2.1 RMS voltage

Table 3 specifies the notations and operational formulas for measuring these various single-phase rms quantities.

Table 3—Notations and formulas for measuring single-phase rms voltage

Description	Notation	Formula
RMS voltage over k cycles	V	$V = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (v(t))^2 dt} \quad (1a)$
	or V_{XN} See NOTE 1 and NOTE 2	or $V_{XN} = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (v_{XN}(t))^2 dt} \quad (1b)$
Fundamental rms voltage over k cycles	V_1	$V_1 = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (v_1(t))^2 dt} \quad (2a)$
	or V_{XN1} See NOTE 2	or $V_{XN1} = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (v_{XN1}(t))^2 dt} \quad (2b)$
Average rms voltage over k cycles	$\bar{V}$	$\bar{V} = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mKT} (v(t))^2 dt} \quad (3a)$
	or $\overline{V_{XN}}$ See NOTE 2	or $\overline{V_{XN}} = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mKT} (v_{XN}(t))^2 dt} \quad (3b)$
Average fundamental RMS voltage over k cycles	$\bar{V}_1$	$\bar{V}_1 = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mKT} (v(t))^2 dt} \quad (4a)$
	or $\overline{V_{XN1}}$ See NOTE 3	or $\overline{V_{XN1}} = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mKT} (v_{XN1}(t))^2 dt} \quad (4b)$
RMS weighted average voltage over k cycles	$\overline{V_{rwa}}$	$\overline{V_{rwa}} = \left(\frac{\pi}{2\sqrt{2}} \right) \frac{2}{kT} \int_{t_0}^{t_0+\frac{kT}{2}} v(t) dt \quad (5a)$
	or $\overline{V_{rwaXN}}$ See NOTE 3	or $\overline{V_{rwaXN}} = \left(\frac{\pi}{2\sqrt{2}} \right) \frac{2}{kT} \int_{t_0}^{t_0+\frac{kT}{2}} v_{XN}(t) dt \quad (5b)$
Fundamental rms weighted average voltage over k cycles	$\overline{V_{rwa}}$	$\overline{V_{rwa}} = \left(\frac{\pi}{2\sqrt{2}} \right) \frac{2}{kT} \int_{t_0}^{t_0+\frac{kT}{2}} v(t) dt \quad (6a)$
	or $\overline{V_{rwaXN}}$ See NOTE 3	or $\overline{V_{rwaXN}} = \left(\frac{\pi}{2\sqrt{2}} \right) \frac{2}{kT} \int_{t_0}^{t_0+\frac{kT}{2}} v_{XN}(t) dt \quad (6b)$

NOTE 1—Root mean square (rms) is replaced by some users with the expression “effective value.” The equivalence of these terms is limited to the consideration of “heating value,” as indicated by Riepnieks et al. [B38]. When the application is electrodeposition, the effective value of an alternating current is its average, not its rms. In terms of a voltage giving rise to a current, the effective value may involve the integral or the derivative of the voltage if the load is reactive. For clarity, this standard uses only the term rms.

NOTE 2—This standard recognizes that the textbook definition for these measurands assumes the integral over one cycle or many (denoted here by k). The practicability of the implementation of various techniques of determining the period for the purposes of measurement is discussed in Annex A.

NOTE 3—This quantity is used commonly to determine peak flux density in a transformer. The derivation is in Annex A.

3.2.2 RMS current

Table 4 specifies the notations and operational formulas for measuring single-phase rms current quantities.

Table 4—Notations and formulas for measuring single-phase rms current

Description	Notation	Formula
RMS current over k cycles	I	$I = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (i(t))^2 dt} \quad (7a)$
	or I_X See NOTE 1	or $I_X = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (i_X(t))^2 dt} \quad (7b)$
Fundamental rms current over k cycles	I_1	$I_1 = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (i_1(t))^2 dt} \quad (8a)$
	or I_{X1} See NOTE 1	or $I_{X1} = \sqrt{\frac{1}{kT} \int_{t_0}^{t_0+kT} (i_{X1}(t))^2 dt} \quad (8b)$
Average rms current over k cycles	$\bar{I}$	$\bar{I} = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mkT} (i(t))^2 dt} \quad (9a)$
	or $\bar{I}_X$ See NOTE 1	or $\bar{I}_X = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mkT} (i_X(t))^2 dt} \quad (9b)$
Average fundamental rms current over k cycles	$\bar{I}_1$	$\bar{I}_1 = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mkT} (i_1(t))^2 dt} \quad (10a)$
	or $\bar{I}_{X1}$ See NOTE 1	or $\bar{I}_{X1} = \frac{1}{M} \sum_{m=1}^M \sqrt{\frac{1}{kT} \int_{t_0+(m-1)kT}^{t_0+mkT} (i_{X1}(t))^2 dt} \quad (10b)$

NOTE 1—This standard recognizes that the textbook definition for these measurands assumes the integral over one cycle or many (denoted here by k). The practicability of the implementation of various techniques of determining the period for the purposes of measurement is discussed in Annex A.

NOTE 2—In any mathematical model involving time, it is not possible to determine all parameter values from measurements taken at a single instant. In the calculations above, the value of rms voltage and current (required in the formula) are not known until after the measurement is complete. The calculations of instantaneous real and reactive components are therefore not accurately described and not included as they are based on the incorrect assumption about representations that include time.

3.2.3 Energy (E)

Table 5 specifies the notations and operational formulas for measuring single-phase energy quantities.

Table 5—Notations and formulas for measuring single-phase energy

Description	Notation	Formula
Single-phase 2-wire energy	E	$E = \int_{t_0}^{t_1} v(t)i(t)dt \quad (11)$
Single-phase 2-wire fundamental energy	E_1	$E_1 = \int_{t_0}^{t_1} v_1(t)i_1(t)dt \quad (12)$
Single-phase 3-wire energy	E_ψ	$E_\psi = \int_{t_0}^{t_1} (v_{AN}(t)i_A(t) + v_{CN}(t)i_C(t))dt \quad (13)$
Single-phase 3-wire fundamental energy	$E_{\psi 1}$	$E_{\psi 1} = \int_{t_0}^{t_1} (v_{AN1}(t)i_{A1}(t) + v_{CN1}(t)i_{C1}(t))dt \quad (14)$
NOTE 1—The limits of integration in the formulas are not related to the number or completeness of the alternating cycles during the interval. NOTE 2—In an electric meter, the terminals for a 3-wire single-phase service are in the phase A and phase C locations. Consequently, the terminology V_{AN} and V_{CN} is often used. NOTE 3—The method that uses the ANSI C12.10 Form 2S meter [B3] used in North America (one of several non-Blondel metering methods) is deprecated and is to be used only in systems that can be reasonably assumed to be balanced. The result is given by formula (15). $E_{NB\psi} = 1/2 \int_{t_0}^{t_1} (i_A(t) + i_B(t))v_{AB}(t)dt \quad (15)$		