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

## IEEE Power & Energy Society

Sponsored by the
Power System Instrumentation and Measurements Committee

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**Abstract:** Definitions used for measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced, or unbalanced conditions are provided in this standard. Mathematical 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:** active power, apparent power, nonactive power, power factor, reactive power, total harmonic distortion

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## Introduction

This introduction is not part of IEEE Std 1459-2010, IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions.

The definitions for active, reactive, and apparent powers that are currently used are based on the knowledge developed and agreed on during the 1940s. Such definitions served the industry well, as long as the current and voltage waveforms remained nearly sinusoidal.

Important changes have occurred in the last 50 years. The new environment is conditioned by the following facts:

a) Power electronics equipment, such as Adjustable Speed Drives, Controlled Rectifiers, Cycloconverters, Electronically Ballasted Lamps, Arc and Induction Furnaces, and clusters of Personal Computers, represent major nonlinear and parametric loads proliferating among industrial and commercial customers. Such loads have the potential to create a host of disturbances for the utility and the end-user's equipment. The main problems stem from the flow of nonactive energy caused by harmonic currents and voltages.

b) New definitions of powers have been discussed in the last 30 years in the engineering literature (Filipski and Labaj [B9][a]). The mechanism of electric energy flow for nonsinusoidal and/or unbalanced conditions is well understood today.

c) The traditional instrumentation designed for the sinusoidal 60/50 Hz waveform is prone to significant errors when the current and the voltage waveforms are distorted (Filipski and Labaj [B9]).

d) Microprocessors and minicomputers enable today's manufacturers of electrical instruments to construct new, accurate, and versatile metering equipment that is capable of measuring electrical quantities defined by means of advanced mathematical models.

e) There is a need to quantify correctly the distortions caused by the nonlinear and parametric loads, and to apply a fair distribution of the financial burden required to maintain the quality of electric service.

This standard lists new definitions of powers needed for the following particular situations:

— When the voltage and current waveforms are nonsinusoidal

— When the load is unbalanced or the supplying voltages are asymmetrical

— When the energy dissipated in the neutral path due to zero-sequence current components has economical significance

The new definitions were developed to give guidance with respect to the quantities that should be measured or monitored for revenue purposes, engineering economic decisions, and determination of major harmonic polluters. The following important electrical quantities are recognized by this standard:

— The power frequency (60/50 Hz or fundamental) of apparent, active, and reactive powers. These three basic quantities are the quintessence of the power flow in electric networks. They define what is generated, transmitted, distributed, and sold by the electric utilities and bought by the end users. This is the electric energy transmitted by the 60/50 Hz electromagnetic field. In poly-phase systems, the power frequency positive-sequence powers are the important dominant quantities. The power frequency positive-sequence power factor is a key value that helps determine and adjust the flow of power frequency positive-sequence reactive power. The

[a] The numbers in brackets correspond to those of the bibliography in Annex C.

fundamental positive-sequence reactive power is of utmost importance in power systems; it governs the fundamental voltage magnitude and its distribution along the feeders and affects electromechanical stability as well as the energy loss.

— The effective apparent power in three-phase systems is $S_e = 3V_eI_e$, where $V_e$ and $I_e$ are the equivalent voltage and current. In sinusoidal and balanced situations, $S_e$ is equal to the conventional apparent power $S = 3V_{\ell n}I = \sqrt{3}V_{\ell\ell}I$, where $V_{\ell n}$ and $V_{\ell\ell}$ are the line-to-neutral and the line-to-line voltage, respectively. For sinusoidal unbalanced or for nonsinusoidal balanced or unbalanced situations, $S_e$ allows rational and correct computation of the power factor. This quantity was proposed in 1922 by the German engineer Buchholz [B1] and in 1933 was explained by the American engineer Goodhue [B11].

— The non-60 Hz or nonfundamental apparent power is $S_N$ (for brevity, 50 Hz power is not always mentioned). This power quantifies the overall amount of harmonic pollution delivered or absorbed by a load. It also quantifies the required capacity of dynamic compensators or active filters when used for nonfundamental compensation alone.

— Current distortion power $D_I$ identifies the segment of nonfundamental nonactive power due to current distortion. This is usually the dominant component of $S_N$.

— Voltage distortion power $D_V$ separates the nonfundamental nonactive power component due to voltage distortion.

— Apparent harmonic power $S_H$ indicates the level of apparent power due to harmonic voltages and currents alone. This is the smallest component of $S_N$ and includes the harmonic active power $P_H$.

To avoid confusion, it was decided not to add new units. The use of the watts (W) for instantaneous and active powers, volt-amperes (VA) for apparent powers, and (var) for all the nonactive powers maintains the distinct separation among these three major types of powers.

There is not yet available a generalized power theory that can provide a simultaneous common base for

— Energy billing

— Evaluation of electric energy quality

— Detection of the major sources of waveform distortion

— Theoretical calculations for the design of mitigation equipment such as active filters or dynamic compensators

This standard is meant to provide definitions extended from the well-established concepts. It is meant to serve the user who wants to measure and design instrumentation for energy and power quantification. It is not meant to help in the design of real-time control of dynamic compensators or for diagnosis instrumentation used to pinpoint to a specific type of annoying event or harmonic.

These definitions are meant to serve as a guideline and as a useful benchmark for future developments.

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At the time this standard was submitted to the IEEE-SA Standards Board for approval, the Non-Sinusoidal Situations Working Group had the following membership:

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## Contents

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## 1. Overview

This standard is divided into three clauses. Clause 1 lists the scope of this document. Clause 2 lists references to other standards that are useful in applying this standard. Clause 3 provides the definitions, among which there are several new expressions.

The preferred mathematical expressions recommended for the instrumentation design are marked with a || sign. The additional expressions are meant to reinforce the theoretical approach and to facilitate a better understanding of the explained concepts.

### 1.1 Scope

This document provides definitions of electric power to quantify the flow of electrical energy in single-phase and three-phase circuits under sinusoidal, nonsinusoidal, balanced, and unbalanced conditions.