

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

Sponsor

**Power System Instrumentation and Measurements Committee
of the
IEEE Power Engineering Society**

Approved 30 January 2000

IEEE-SA Standards Board

Abstract: This is a standard for definitions used for measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced, or unbalanced conditions. It lists the mathematical expressions that were used in the past, as well as new expressions, and explains the features of the new definitions.

Keywords: active power, apparent power, nonactive power, power factor, reactive power, total harmonic distortion

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2000 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 21 June 2000. Printed in the United States of America.

Print: ISBN 0-7381-1962-8 SH94823
PDF: ISBN 0-7381-1963-6 SS94823

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

IEEE is the sole entity that may authorize the use of certification marks, trademarks, or other designations to indicate compliance with the materials set forth herein.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (978) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

(This introduction is not part of IEEE Std 1459-2000, 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 upon 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 [B6]). 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 [B6]).
- 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:

- 1) The power frequency (60/50 Hz or fundamental) apparent, active, and reactive powers. These three basic quantities are the quintessence of the power flow in electric networks. They define the product 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 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.

- 2) The effective apparent power in three-phase systems, $S_e = 3V_e I_e$, 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 $S = 3V_{ln}I = \sqrt{3}V_{ll}I$, where V_{ln} and V_{ll} 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 F. Buchholz [B1] and in 1933 was explained by the American engineer W. M. Goodhue [B7].
- 3) The non-60 Hz or nonfundamental apparent power, 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.
- 4) 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 .
- 5) Voltage distortion power, D_V , separates the nonfundamental nonactive power component due to voltage distortion.
- 6) 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 varistor (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.

To the working group's knowledge, no commercially available instruments are fully capable of quantifying S_e and S_N according to the definitions given in this standard. These definitions are meant to serve as a guideline and a useful benchmark for future developments.

Participants

At the time this standard was completed, the Working Group on Nonsinusoidal Situations had the following membership:

Alexander E. Emanuel, *Chair*

Rejean Arseneau
Yahia Bagzouz
Joseph M. Belanger
Keneth B. Bowes
James A. Braun
David Cooper
Mikey D. Cox
Alexander Domijan

Larry Durante
David Elmore
Lazhar Fekih-Ahmed
Piotr S. Filipski
Prasanta K. Ghosh
Erich Gunther
Dennis Hansen
Gilbert C. Hensley
Ole W. Iwanusiw

Dan McAuliff
Terrence McComb
Alexander McEachern
Herman M. Millican
Thomas L. Nelson
George Stephens
Raymond H. Stevens
Douglas Williams

The following members of the balloting committee voted on this standard:

Warren A. Anderson
William J. Buckley
Steven W. Crampton
Alexander E. Emanuel
Erich Gunther

Ernst Hanique
Dennis Hansen
John Kuffel
William Larzelere
Blane Leuschner
Terrence McComb

Herman M. Millican
Daleep C. Mohla
Eddy So
Rao Thallam
Barry H. Ward

When the IEEE-SA Standards Board approved this standard on 30 January 2000, it had the following membership:

Richard J. Holleman, *Chair*

Donald N. Heirman, *Vice Chair*

Judith Gorman, *Secretary*

Satish K. Aggarwal
Dennis Bodson
Mark D. Bowman
James T. Carlo
Gary R. Engmann
Harold E. Epstein
Jay Forster*
Ruben D. Garzon

James H. Gurney
Lowell G. Johnson
Robert J. Kennelly
E. G. "Al" Kiener
Joseph L. Koepfinger*
L. Bruce McClung
Daleep C. Mohla
Robert F. Munzner

Louis-François Pau
Ronald C. Petersen
Gerald H. Peterson
John B. Posey
Gary S. Robinson
Akio Tojo
Hans E. Weinrich
Donald W. Zipse

*Member Emeritus

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Robert E. Hebner

Catherine K.N. Berger
IEEE Standards Project Editor

Contents

1. Overview.....	1
1.1 Scope.....	1
1.2 Purpose.....	1
2. References.....	2
3. Definitions.....	2
3.1 Single-Phase.....	2
3.2 Three-Phase systems.....	10
Annex A (informative) Theoretical examples.....	28
Annex B (informative) Practical studies and measurements	39
Annex C (informative) Bibliography	44

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

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 $\parallel$ sign. The additional expressions are meant to reinforce the theoretical approach and facilitate a better understanding of the explained concepts.

1.1 Scope

This is a standard for definitions used for measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced, or unbalanced conditions. It lists the mathematical expressions that were used in the past, as well as new expressions, and explains the features of the new definitions.

1.2 Purpose

This standard is meant to provide organizations with criteria for designing and using metering instrumentation.

2. References

This standard shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.

DIN 40110-1997, Quantities Used in Alternating Current Theory.¹

IEEE Std 280-1985 (Reaff 1997), IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering.²

ISO 31-5:1992, Quantities and Units—Part 5: Electricity and Magnetism.³

3. Definitions

Mathematical expressions that are considered appropriate for instrumentation design are marked with the sign $\parallel$. When the sign $\parallel$ appears on the right side, it means that the last expression that is listed is favored. Each descriptor of a power type is followed by its measurement unit in parentheses.

3.1 Single-Phase

3.1.1 Single-Phase sinusoidal

A sinusoidal voltage source

$$v = \sqrt{2}V \sin(\omega t)$$

supplying a linear load, will produce a sinusoidal current of

$$i = \sqrt{2}I \sin(\omega t - \theta)$$

where

V	is the rms value of the voltage (V)
I	is the rms value of the current (A)
ω	is the angular frequency $2\pi f$ (rad/s)
f	is the frequency (Hz)
θ	is the phase angle (rad)
t	is the time (s)

¹DIN publications are available from the Deutsches Institut für Normung, Burggrafenstrasse 6, Postfach 1107, 12623 Berlin 30, Germany (011 49 30 260 1362).

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

³ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iso.ch/>). ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

3.1.1.1 Instantaneous power (W)

The instantaneous power p is given by

$$p = vi$$

$$p = p_a + p_q$$

where

$$p_a = VI \cos \theta [1 - \cos(2\omega t)] = P[1 - \cos(2\omega t)]; \quad P = VI \cos \theta$$

$$p_q = -VI \sin \theta \sin(2\omega t) = -Q \sin(2\omega t); \quad Q = VI \sin \theta$$

NOTES

1—The instantaneous power is produced by the active component of the current, i.e., the component that is in phase with the voltage. It is the rate of flow of the energy

$$w_a = \int p_a dt = Pt - \frac{P}{2\omega} \sin(2\omega t)$$

This energy flows unidirectionally from the source to the load. Its rate of flow is not negative, $p_a \geq 0$.

2—The instantaneous power p_q is produced by the reactive component of the current, i.e., the component that is in quadrature with the voltage. It is the rate of flow of the energy

$$w_q = \int p_q dt = \frac{Q}{2\omega} \cos(2\omega t)$$

This type of energy oscillates between the source and inductances, capacitances, and moving masses pertaining to electromechanical systems (motor and generator rotors, plungers, and armatures). The average value of this rate of flow is zero, and the net transfer of energy to the load is nil.

3.1.1.2 Active power (W)

The active power P is the mean value of the instantaneous power during the observation time interval τ to $\tau + kT$

$$P = \frac{1}{kT} \int_{\tau}^{\tau+kT} p dt$$

where

$T = 1/f$ is the cycle (s),

k is an integer number,

τ is the moment when the measurement starts.

$$P = VI \cos \theta$$

3.1.1.3 Reactive power (var)

The reactive power Q is the amplitude of the oscillating instantaneous power p_q .

$$Q = \frac{1}{2\pi} \oint v di = \frac{-1}{2\pi} \oint i dv = \frac{1}{kT} \int_{\tau}^{\tau+kT} v \frac{di}{dt} dt = \frac{-1}{kT} \int_{\tau}^{\tau+kT} i \frac{dv}{dt} dt = \frac{-\omega}{kT} \int_{\tau}^{\tau+kT} v [\int i dt] dt$$

$$Q = \frac{\omega}{kT} \int_{\tau}^{\tau+kT} i [\int v dt] dt$$

$$Q = VI \sin \theta$$

NOTE— If the load is inductive, then $Q > 0$. If the load is capacitive, then $Q < 0$.

3.1.1.4 Apparent power (VA)

The apparent power S is the product of the root-mean-square (rms) voltage and the root-mean-square (rms) current.

$$\| S = VI$$

$$S = \sqrt{P^2 + Q^2}$$

NOTE—Instantaneous power p follows a sinusoidal oscillation with a frequency $2f = 2\omega/2\pi$ biased by the active power P . The amplitude of the sinusoidal oscillation is the apparent power S .

3.1.1.5 Power factor

$$\| P_F = \frac{P}{S}$$

3.1.1.6 Complex power (VA)

$$S = VI^* = P + jQ$$

where

$V = V\angle 0^\circ$ is the voltage phasor,

$I^* = I\angle \theta$ is the conjugated current phasor.

This expression stems from the power triangle, S , P , Q , and is useful in power flow studies. Figure 1 summarizes the conventional power flow directions as interpreted in literature (Stevens [B12]⁴).

3.1.2 Single-Phase nonsinusoidal

For steady-state conditions a nonsinusoidal instantaneous voltage or current has two distinctive components: the power system frequency components v_1 and i_1 , and the remaining terms v_H and i_H that contains all integer and noninteger number harmonics.

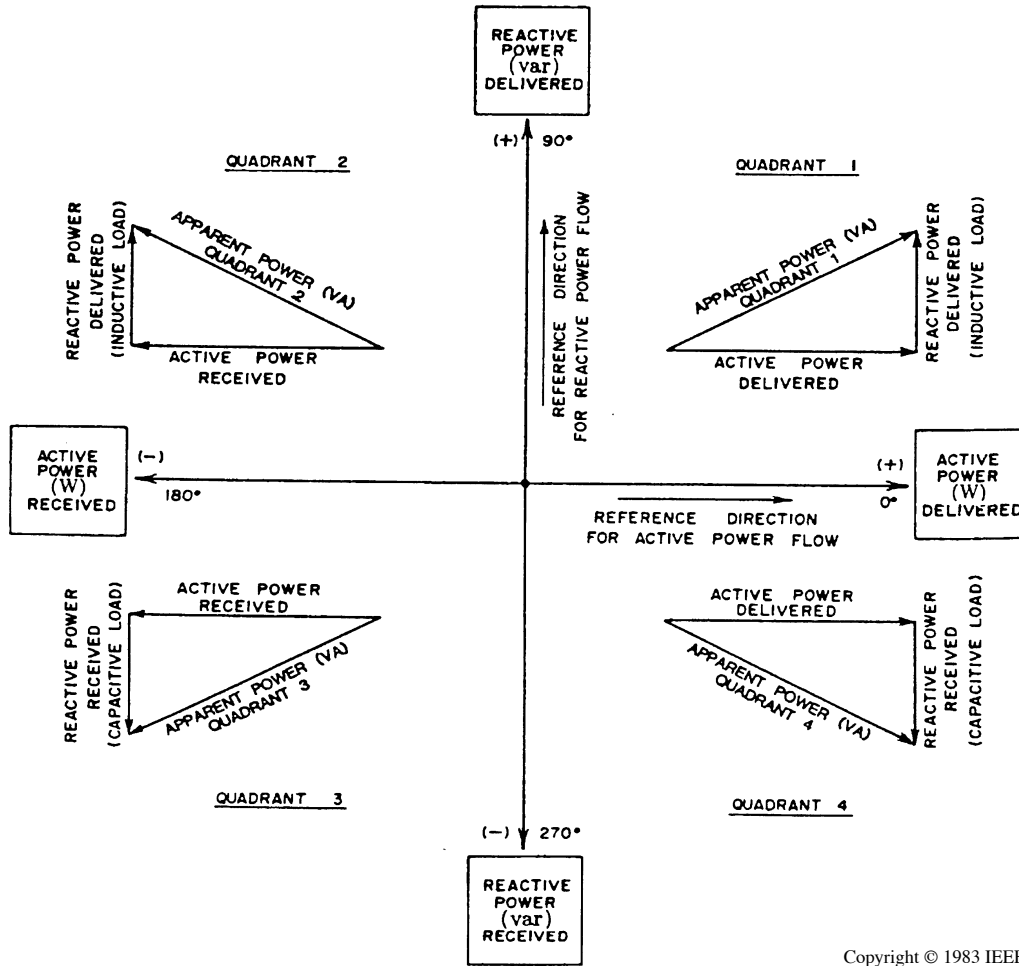
$$v_1 = \sqrt{2}V_1 \sin(\omega t - \alpha_1)$$

$$i_1 = \sqrt{2}I_1 \sin(\omega t - \beta_1)$$

$$v_H = \sqrt{2} \sum_{h \neq 1} V_h \sin(h\omega t - \alpha_h)$$

$$i_H = \sqrt{2} \sum_{h \neq 1} I_h \sin(h\omega t - \beta_h)$$

⁴The numbers in brackets correspond to those of the bibliography in Annex C.



Copyright © 1983 IEEE

Figure 1—Four-quadrant power flow directions (see [B12])

The corresponding rms values squared are as follows:

$$V^2 = \frac{1}{kT} \int_{\tau}^{\tau+kT} v^2 dt = V_1^2 + V_H^2$$

$$I^2 = \frac{1}{kT} \int_{\tau}^{\tau+kT} i^2 dt = I_1^2 + I_H^2$$

where

$$V_H^2 = \sum_{h \neq 1} V_h^2 = V^2 - V_1^2 \quad ||$$

$$I_H^2 = \sum_{h \neq 1} I_h^2 = I^2 - I_1^2 \quad ||$$

NOTE—The direct voltage and the direct current terms V_0 and I_0 , obtained for $h = 0$, must be included in V_H and I_H . They correspond to a hypothetical $\alpha_0 = \beta_0 = -45^\circ$; $(\sin(-\alpha_0) = \sin(-\beta_0) = \sin 45^\circ = 1/\sqrt{2})$. Significant dc components are rarely present in ac power systems; however, traces of dc are not uncommon.

3.1.2.1 Total harmonic distortion

The overall deviation of a distorted wave from its fundamental can be estimated with the help of the total harmonic distortion. The total harmonic distortion of the voltage is as follows:

$$\| THD_v = \frac{V_H}{V_1} = \sqrt{\left(\frac{V}{V_1}\right)^2 - 1}$$

The total harmonic distortion of the current is as follows:

$$\| THD_I = \frac{I_H}{I_1} = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1}$$

3.1.2.2 Instantaneous power (W)

$$p = vi$$

$$P = P_a + P_q$$

where

$$P_a = \sum_h V_h I_h \cos \theta_h [1 - \cos(2h\omega t)]$$

is a term that contains all the components that have non-zero average value, and

$$P_q = \sum_h V_h I_h \sin \theta_h \sin(2h\omega t) + \sum_{\substack{m \neq n \\ m, n \neq 1}} 2V_m I_n \sin(m\omega t + \alpha_m) \sin(n\omega t + \beta_n)$$

is a term that does not contribute to the net transfer of energy, i.e., its average value is nil.

The angle $\theta_h = \beta_h - \alpha_h$ is the phase angle between the phasors V_h and I_h .

3.1.2.3 Active power (W)

$$\| P = \frac{1}{kT} \int_{\tau}^{\tau+kT} p dt$$

$$P = P_1 + P_H$$

3.1.2.4 Fundamental or 60 Hz active power (W)

$$\| P_1 = \frac{1}{kT} \int_{\tau}^{\tau+kT} v_1 i_1 dt = V_1 I_1 \cos \theta_1$$

3.1.2.5 Harmonic active power (W)

$$P_H = \sum_{h \neq 1} V_h I_h \cos \theta_h = P - P_1$$

NOTE—For ac motors, which make up the vast majority of loads, the harmonic active power is not a useful power. Consequently, it is useful to separate the fundamental active power P_1 from the harmonic active power P_H .

3.1.2.6 Fundamental reactive power (var)

$$\begin{aligned} \| Q_1 &= \frac{\omega_1}{kT} \int_{\tau}^{\tau+kT} i_1 [v_1 dt] dt \\ &= V_1 I_1 \sin \theta_1 \end{aligned}$$

3.1.2.7 Budeanu's reactive power (var)

$$Q_B = \sum_h V_h I_h \sin \theta_h$$

$$Q_B = Q_1 + Q_{BH}$$

where

$$Q_{BH} = \sum_{h \neq 1} V_h I_h \sin \theta_h$$

NOTE—The usefulness of Q_B for quantifying the flow of harmonic nonactive power has been questioned by many engineers (Czarnecki [B2], Lyon [B10]). Field measurements and simulations (Pretorius, van Wyk, and Swart [B11]) prove that in many situations $Q_{BH} < 0$, thus leading to situations where $Q_B < Q_1$.

3.1.2.8 Apparent power (VA)

$$\| S = VI$$

NOTE—An important practical property of S is that the power loss ΔP , in the feeder that supplies the apparent power S , is a nearly linear function of S^2 (Emanuel [B4]).

$$\Delta P = \frac{r_e}{V^2} S^2 + \frac{V^2}{R}$$

where

R is an equivalent shunt resistance, representing transformer core losses and cable dielectric losses,
 r_e is the effective Thevenin resistance. Theoretically r_e can be obtained from the equivalence of losses as follows:

$$r_e I^2 = r_{dc} \sum_h K_{sh} I_h^2$$

where

K_{sh} is the skin effect coefficient for the h harmonic,
 r_{dc} is the Thevenin dc resistance (Ω).

3.1.2.9 Fundamental or 60/50 Hz apparent power (VA)

Fundamental apparent power S_I and its components P_I and Q_I are the actual quantities that help define the rate of flow of the electromagnetic field energy associated with the 60/50 Hz voltage and current. This is a product of high interest for both the utility and the end-user.

$$\| S_I = V_I I_I$$

$$S_I^2 = P_I^2 + Q_I^2$$

3.1.2.10 Nonfundamental apparent power (VA)

The separation of the rms current and voltage into fundamental and harmonic terms (see 3.1.2) resolves the apparent power in the following manner (Emanuel [B5]):

$$S^2 = (VI)^2 = (V_1^2 + V_H^2)(I_1^2 + I_H^2) = (V_1 I_1)^2 + (V_1 I_H)^2 + (V_H I_1)^2 + (V_H I_H)^2 = (S_I^2 + S_N^2)$$

$$\| S_N = \sqrt{S^2 - S_I^2}$$

is the nonfundamental apparent power, and is resolved in the following three distinctive terms:

$$S_N^2 = D_I^2 + D_V^2 + S_H^2$$

3.1.2.11 Current distortion power (var)

$$D_I = V_I I_H = S_I (THD_I) \parallel$$

3.1.2.12 Voltage distortion power (var)

$$D_V = V_H I_1 = S_I (THD_V) \parallel$$

3.1.2.13 Harmonic apparent power (VA)

$$S_H = V_H I_H = S_I (THD_I)(THD_V) \parallel$$

$$S_H = \sqrt{P_H^2 + D_H^2}$$

3.1.2.14 Harmonic distortion Power (var)

$$\| D_H = \sqrt{S_H^2 - P_H^2}$$

NOTE—In practical power systems, $THD_V < THD_I$ and S_N can be computed using the following expression (Emanuel [B5]):

$$S_N \approx S_I \sqrt{(THD_I)^2 + (THD_V)^2}$$

When $THD_V \leq 5\%$ and $THD_I \leq 200\%$, this expression yields an error less than 0.15%.

For $THD_V < 5\%$ and $THD_I > 40\%$, an error less than 1.00% is obtained using the following expression (Emanuel [B5]):

$$S_N \approx S_1(THD_I)$$

3.1.2.15 Nonactive power (var)

$$\| N = \sqrt{S^2 - P^2}$$

This power lumps together both fundamental and nonfundamental nonactive components. In the past, this power was called *fictitious power*.

3.1.2.16 Budeanu's distortion power (var)

This power results from the resolution of S using Budeanu's reactive power Q_B (see 3.1.2.7) that leads to the following:

$$S^2 = P^2 + Q_B^2 + D_B^2$$

hence,

$$D_B = \sqrt{S^2 - P^2 - Q_B^2}$$

NOTE—This distortion power is affected by the deficiency of Q_B (Pretorius, van Wyk, and Swart [B11]).

3.1.2.17 Fundamental or 60/50 Hz power factor

$$P_{F1} = \cos \theta_1 = \frac{P_1}{S_1} \parallel$$

This ratio helps evaluate separately the fundamental power flow conditions. It can be called the *fundamental power factor* or *60/50 Hz power factor*. It is also often referred to as the *displacement power factor*.

3.1.2.18 Power factor

$$\parallel P_F = \frac{P}{S}$$

$$P_F = \frac{P}{S} = \frac{P_1 + P_H}{\sqrt{S_1^2 + S_N^2}} = \frac{(P_1/S_1)[1 + (P_H/P_1)]}{\sqrt{1 + (S_N/S_1)^2}} = \frac{[1 + (P_H/P_1)]P_{F1}}{\sqrt{1 + THD_I^2 + THD_V^2 + (THD_I THD_V)^2}}$$

NOTES

1—The apparent power S can be viewed as the maximum active power that can be transmitted to a load while keeping its load voltage V constant and line losses constant. The result is that for a given S and V , maximum utilization of the line is obtained when $P = S$; hence, the ratio P/S is a utilization factor indicator.

2—The overall degree of harmonic injection produced by a large nonlinear load, or by a group of loads or consumers, can be estimated from the ratio S_N/S_I . The effectiveness of harmonic filters also can be evaluated from such a measurement. The measurements of S_I , P_I , P_{F1} , or Q_I help establish the characteristics of the fundamental power flow.