

NEMA C12.24 TR-2022

*Definitions for Calculations of VA, VAh, VAR, and VARh for
Electricity Meters*

A Technical Report prepared by NEMA and registered with ANSI

Secretariat:

National Electrical Manufacturers Association

Registered March 21, 2021

American National Standards Institute, Inc.

NOTICE AND DISCLAIMER

The information in this publication was considered technically sound by the consensus of persons engaged in the development and approval of the document at the time it was developed. Consensus does not necessarily mean that there is unanimous agreement among every person participating in the development of this document.

NEMA standards and guideline publications, of which the document contained herein is one, are developed through a voluntary consensus standards development process. This process brings together volunteers and/or seeks out the views of persons who have an interest in the topic covered by this publication. While NEMA administers the process and establishes rules to promote fairness in the development of consensus, it does not write the document and it does not independently test, evaluate, or verify the accuracy or completeness of any information or the soundness of any judgments contained in its standards and guideline publications.

NEMA disclaims liability for any personal injury, property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this document. NEMA disclaims and makes no guaranty or warranty, express or implied, as to the accuracy or completeness of any information published herein, and disclaims and makes no warranty that the information in this document will fulfill any of your particular purposes or needs. NEMA does not undertake to guarantee the performance of any individual manufacturer or seller's products or services by virtue of this standard or guide.

In publishing and making this document available, NEMA is not undertaking to render professional or other services for or on behalf of any person or entity, nor is NEMA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. Information and other standards on the topic covered by this publication may be available from other sources, which the user may wish to consult for additional views or information not covered by this publication.

NEMA has no power, nor does it undertake to police or enforce compliance with the contents of this document. NEMA does not certify, test, or inspect products, designs, or installations for safety or health purposes. Any certification or other statement of compliance with any health or safety-related information in this document shall not be attributable to NEMA and is solely the responsibility of the certifier or maker of the statement.

Foreword

Foreword (This Foreword is not part of Technical Report NEMA C12.24 TR-2022.)

Publication of this Technical Report that has been registered with ANSI has been approved by the Accredited Standards Developer (NEMA, 1300 North 17th Street, Suite 900, Rosslyn, VA 22209). This document is registered as a Technical Report according to the Procedures for the Registration of Technical Reports with ANSI. This document is not an American National Standard and the material contained herein is not normative in nature. Comments on the content of this document should be sent to:

National Electrical Manufacturers Association
Vice President, Technical Services
1300 North 17th Street, Suite 900
Rosslyn, VA 22209

Changes in technology and increasing computing power have resulted in a number of methods for determining reactive power and apparent power. In some cases, configuration of electrical service or connection metering elements introduces complications. This Technical Report documents methods that have been used, approximated, or conceived of, by the metering community.

This revision of the Technical Report includes:

- Edits to formulas and text for consistency and clarity.
- The concept of measuring Source VA.
- Two Annexes that show measurement results of different methods given different shapes of current and voltage waveforms.
- An Annex to document harmonic content of a number of waveforms, including waveforms initially used by the National Research Council Canada in the 1980s.

This Technical Report defines methods for calculations of VA, VAh, VAR, and VARh for electricity meters. It is intended to ease identification of algorithms used in electricity meters and to facilitate accurate testing. No evaluations of relative benefits or inconveniences of the methods are offered.

This Technical Report was processed and approved for submittal to ANSI by Accredited Standards Committee for Electricity Metering, C12. At the time the committee approved this Technical Report, the C12 Committee had the following members:

David Ellis, Chairperson, ANS C12 SC24
Tom Nelson, Chairperson, ANS C12
Paul Orr, Secretary

ANS C12 Main Committee

Organization Represented:

Aclara
Baltimore Gas and Electric Company
Brooks Utility Products
Luke Energy
Private Energy
EnerNex
ERCOT
Eurofins MET Labs
Florida Power & Light Company
Future DOS R&D Inc.
Greenville Light & Power
Honeywell Smart Energy
Hydro Quebec

Name of Representative:

Curt Crittenden
Sean Gorman
Robert Kiessling
Kerry Barnette
Lawrence Kotewa
Aaron Snyder
Don Tucker
Jim Reed
Eduardo Sotolongo
Avygdor Moise
Ron Zook
Scott Holdsclaw
Jean-Luc Sabourin

Itron, Inc.	Brent Cain
Milbank Manufacturing Company	Shawn Glasgow
NIST	Tom Nelson
Oncor Electric Delivery Company LLC	Zach Hughes
Pacific Gas and Electric Company	Alex Yan
Power Measurements, LLC	William Hardy
Public Service Electric & Gas	David Ellis
Radian Research, Inc.	Joel Canine
Radian Research, Inc.	Frank Boudreau
Sask Power	Bin Lu
Schneider Electric	Piotr Przydatek
Schweitzer Engineering Laboratories, Inc.	Don MacArthur
Sensus, A Xylem Brand	Andrew Dudding
Southern Company	Anthony Bell
Technology for Energy Corporation	Steve Hudson
TESCO - The Eastern Specialty Company	Tom Lawton
UL LLC	Scott Hunter
Watthour Engineering Company, Inc.	Lea Wren
Xcel Energy	Dan Nordell

ANS C12 C12.24 Subcommittee

Organization Represented:

Edwards Precision Power
ERCOT
Florida Power & Light Company
Future DOS R&D Inc.
Honeywell Smart Energy
Itron, Inc.
Radian Research, Inc.
Landis+Gyr
Measurement Canada
Oncor Electric Delivery LLC
Power Measurements, LLC
Public Service Electric & Gas
Schneider Electric
Sensus, A Xylem Brand
Watthour Engineering Company, Inc.
Xcel Energy

Name of Representative:

S. Edwards
D. Tucker
E. Sotoloro
A. Moise
Scott Holdrege
B. Cain
F. Boudreau
J. Voisine
M. Rashid
Z. Hughes
W. Hardy
D. Ellis
P. Prydatek
A. Dudding
L. Wren
D. Nordell

Published by

National Electrical Manufacturers Association
1300 North 17th Street, Rosslyn, VA 22209

© Copyright 2022 by National Electrical Manufacturers Association

All rights reserved including translation into other languages, reserved under the Universal Copyright Convention, the Berne Convention for the Protection of Literary and Artistic Works, and the International and Pan American Copyright Conventions.

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.

Printed in the United States of America

Note: The user's attention is called to the possibility that compliance with this standard could require use of an invention covered by patent rights.

By publication of this Technical Report, no position is taken with respect to the validity of any such claim(s) or of any patent rights in connection therewith. If a patent holder has filed a statement of willingness to grant a license under these rights on reasonable and non-discriminatory terms and conditions to applicants desiring to obtain such a license, then details may be obtained from the Secretary.

Currently in preview, click buy full version

Contents

		Page
1	Scope	1
2	Abbreviations and Letter Symbols	1
2.1	Abbreviations	1
2.2	Letter Symbols	1
3	Definitions for Single-Element VAR	2
3.1	Fundamental Waveform Method	2
3.2	Integral Phase-Shift Methods	3
3.2.1	Integral Phase-Shift: Exact Frequency Method	3
3.2.2	Integral Phase-Shift: 50 Hz Fixed Method.....	3
3.2.3	Integral Phase-Shift: 60 Hz Fixed Method.....	3
3.3	Differential Phase-Shift Method	3
3.4	Quarter-Cycle Delay Method	4
3.5	Vector Methods.....	4
3.5.1	Vector Method Using VA rms	4
3.5.2	Vector Method Using VA Average Responding	5
3.5.3	Signed Vector Method Using VA rms and Fundamental Waveforms	5
3.5.4	Signed Vector Method Using VA rms and Manufacturer-Specified Sign Assignment Technique	6
3.6	Cross-Connected Phase-Shift Method	7
3.7	Individual Harmonic Method	7
4	Definitions for Polyphase VAR (VAR Across All Elements)	8
4.1	Addition of Element Methods.....	8
4.1.1	Three Elements Method	8
4.1.2	Two Elements Method.....	8
4.1.3	Two Elements Cross-Connected Method.....	9
4.2	Vector Method	10
5	Definition for Single-Element VARh	10
6	Definitions for Polyphase VARh (VARh Across All Elements)	11
6.1	Single-Element VARhs Method	11
6.2	VAR Method	11
7	Definitions for Single-Element VA	11
7.1	Vector Method	11
7.2	rms Method.....	11
7.3	Average Responding Method.....	12
7.4	Individual Harmonic Method.....	12
8	Definitions for Polyphase VA (VA Across All Elements)	13
8.1	Element Methods.....	13
8.1.1	Three Elements Method	13
8.1.2	Two Elements Method.....	13
8.2	Vector Method	14
8.3	Source VA rms Method.....	14
8.3.1	1-Wire Y.....	15
8.3.2	3-Wire Network.....	16
8.3.3	3-Wire Delta.....	17
8.3.4	3-Wire Open Delta.....	18
8.3.5	4-Wire Delta.....	19
8.3.6	4-Wire Open Delta.....	21
8.3.7	3-Wire Wye with Open Neutral.....	21
8.3.8	Scott-T	22
8.4	Fundamental Waveform Source VA Method.....	23
9	Definition for Single-Element VAh	23
10	Definitions for Polyphase VAh (VAh Across All Elements)	23
10.1	Sum of Single-Element VAh Method	23

10.2	VA Method	24
Annex A:	Formulae Performance with Example Waveforms	25
Annex B:	Comparison of Source VA, Element (Arithmetic) VA, and Vector VA, for Various Polyphase Loadings	32
Annex C:	Example Waveform Coefficients	37

Tables

Table A1	VAR Formulae Comparison Using Example 60 Hz Waveforms of 1 A rms Current and 1 V rms Voltage (1 VA rms) (see Note 1)	25
Table B1	Load Element Nomenclature Examples	32
Table B2	4 Wire Y - VA Method Comparison	34
Table B3	3 Wire Delta - VA Method Comparison	36
Table C1	Coefficients for Sine Wave, Sine Wave 60° Lag, and Phase Dimming, 160° Conduction Angle	37
Table C2	Coefficients for Phase Dimming, 90° Conduction Angle, Narrow Pulse, and Triangular	40
Table C3	Coefficients for Square, NRC WF 2, and NRC WF 3	43
Table C4	NRC WF 4, NRC WF 5, and NRC WF 137	46
Table C5	NRC WF 138, NRC WF 139, and NRC WF 140	49
Table C6	NRC WF 143, NRC WF 144, and NRC WF 256	52
Table C7	NRC WF 257, NRC WF 1362, and NRC WF 1363	55

Figures

Figure 1	4-Wire Y	15
Figure 1a	4-Wire Y and L-L Load	16
Figure 2	4-Wire Y	17
Figure 3	3-Wire Delta Service	17
Figure 4	3-Wire Open Delta	18
Figure 5	4-Wire Delta Service	19
Figure 6	4-Wire Open Delta Service	21
Figure 7	3-Wire Y Open Neutral	22
Figure 8	Scott-T Service	23
Figure A1	Wave Set 1: Sine Wave Voltage and Sine Wave Current	27
Figure A2	Wave Set 2: Sine Wave Voltage and Sine Wave Current -60°, (60° Lag)	27
Figure A3	Wave Set 3: Sine Wave Voltage and Phase Dimming Current, 160° Conduction Angle	27
Figure A4	Wave Set 4: Sine Wave Voltage and Phase Dimming Current, 90° Conduction Angle	28
Figure A5	Wave Set 5: Sine Wave Voltage and Narrow Pulse Current	28
Figure A6	Wave Set 6: Sine Wave Voltage and Triangular Wave Current	28
Figure A7	Wave Set 7: Sine Wave Voltage and Square Wave Current	29
Figure A8	Wave Set 8: NRC WF 2 Voltage and WF 3 Current	29
Figure A9	Wave Set 9: NRC WF 4 Voltage and WF 5 Current	29
Figure A10	Wave Set 10: NRC WF 137 Voltage and WF 138 Current	30
Figure A11	Wave Set 11: NRC WF 139 Voltage and WF 140 Current	30
Figure A12	Wave Set 12: NRC WF 143 Voltage and WF 144 Current	30
Figure A13	Wave Set 13: NRC WF 256 Voltage and WF 257 Current	31
Figure A14	Wave Set 14: NRC WF 1362 Voltage and WF 1363 Current	31
Figure B1	4-Wire Y	33
Figure B2	3-Wire Δ	35

< This page is left blank intentionally. >

Currently in preview, click buy full version

Definitions for Calculations of VA, VAh, VAR, and VARh for Electricity Meters

1 Scope

This Technical Report establishes names and mathematical definitions for the Volt-Ampere (VA), Volt-Ampere hours (VAh), Volt-Amperes Reactive (VAR), and Volt-Ampere Reactive hours (VARh) formulae used by electricity meters. The mathematical definitions assume static waveforms.

2 Abbreviations and Letter Symbols

2.1 Abbreviations

rms	root mean square
VA	Volt-Ampere
VAh	Volt-Ampere hours
VAR	Volt-Ampere reactive
VARh	Volt-Ampere reactive hours

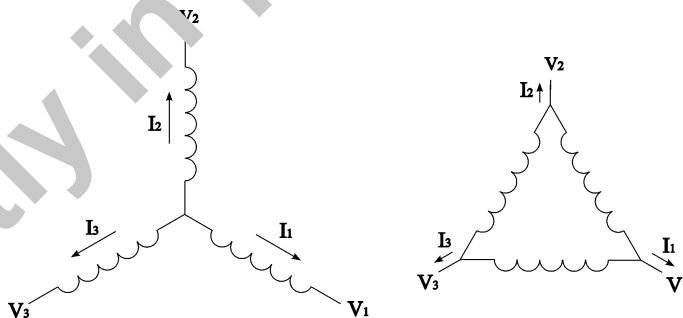
2.2 Letter Symbols

- $\alpha_{(h),i}$ = phase angle of the voltage potential for harmonic order (h) of phase i , relative to a common reference phase angle, such as the phase angle of $V_{(1),1}$ (i.e., $\alpha_{(1),1} = 0$)
- $\beta_{(h),i}$ = phase angle of the current flow for harmonic order (h) of phase i , relative to a common reference phase angle, such as the phase angle of $\alpha_{(1),i}$
- $\theta_{(1),i}$ = phase angle between the fundamental components of $V_{(1),i}$ and $I_{(1),i}$ of phase i , equals to $\alpha_{(1),i}$ minus $\beta_{(1),i}$
- $\theta_{(h),i}$ = phase angle between the harmonic order (h) components of $V_{(1),i}$ and $I_{(1),i}$ of phase i (h harmonic order), equals to $\alpha_{(h),i}$ minus $\beta_{(h),i}$
- τ = start time of integration
- ω = fundamental angular frequency, $2\pi f_0$, where f_0 is the fundamental frequency in hertz
- bV_i = Blondel's theorem transformed voltages:

$$bV_1 = V_1 - V_2$$

$$bV_2 = 0$$

$$bV_3 = V_3 - V_2$$



Δt = VARh and VAh integration interval measured in seconds