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(Revision of
IEEE Std C37.118™-2005)

IEEE Standard for Synchrophasor Measurements for Power Systems

Sponsor

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Abstract: Synchronized phasor (synchrophasor) measurements for power systems are presented. This standard defines synchrophasors, frequency, and rate of change of frequency (ROCOF) measurement under all operating conditions. It specifies methods for evaluating these measurements and requirements for compliance with the standard under both steady-state and dynamic conditions. Time tag and synchronization requirements are included. Performance requirements are confirmed with a reference model, provided in detail. This document defines a *phasor measurement unit* (PMU), which can be a stand-alone physical unit or a functional unit within another physical unit. This standard does not specify hardware, software, or a method for computing phasors, frequency, or ROCOF.
Keywords: data concentrator, DC, FE, frequency error, IEEE C37.118.1, IRIG-B, PDC, phasor, phasor measurement, phasor measurement unit, PMU, RFE, ROCOF, ROCOF error, synchronized phasor, synchrophasor, total vector error, TVE

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

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Introduction

This introduction is not part of IEEE Std C37.118.1-2011, IEEE Standard for Synchrophasor Measurements for Power Systems.

The original synchrophasor standard was IEEE Std 1344™-1995 [B5].[a] It was replaced by IEEE Std C37.118-2005 [B8]. This has now been split into two standards: IEEE Std 37.118.1-2011 (this standard), covering measurement provisions, and IEEE Std 37.118.2™-2011 [B9], covering data communication. Both standards contain the previous material with updates and additional provisions.

In this standard, additional clarification is provided for the phasor and synchronized phasor definitions. The concepts of total vector error (TVE) and compliance tests are retained and expanded, tests over temperature variation have been added, and dynamic performance tests have been introduced. In addition, limits and characteristics of frequency measurement and rate of change of frequency (ROCOF) measurement have been developed. Annex C includes a system model intended to verify the ability to implement the required performance measures. The model is meant as a reference benchmark only; it is assumed that many real implementations will surpass this model in performance.

Phasors are used in many protection and data acquisition functions. By referencing them to a common time base they become comparable over a wide area of measurement. A synchrophasor is a phasor value obtained from voltage or current waveforms and precisely referenced to a common time base. Simultaneous measurement sets derived from synchronized phasors provide a vastly improved method for tracking power system dynamic phenomena for improved power system monitoring, protection, operation, and control.

The intent of any instrument connected to the power grid is to monitor power system parameters. The intent of this standard is to describe and quantify the performance of the *phasor measurement unit* (PMU) instrument deployed to monitor the power grid. The PMU extracts the parameters magnitude, phase angle, frequency, and ROCOF from the signals appearing at its input terminals. These signals may be corrupted by harmonic content, noise, and changes in state caused by system loads, and control and protective actions. Some examples are harmonics introduced by large non-linear loads, step changes in phase introduced by switched reactive elements, and random noise from arc furnaces. These artifacts complicate the process of measuring the generation and load characteristics at or near the system fundamental frequency.

The filtering associated with the computation of the synchrophasors rejects the undesirable signal components appearing at the PMU input within the limits provided by the filter attenuation. The frequency is computed as the first derivative of the synchrophasor phase angle, and ROCOF is computed as the second derivative of the same phase angle. These two quantities are less reliable measurements, particularly ROCOF, because they are more sensitive to undesirable components in the signal like harmonics, off-nominal components, or noise.

This standard presents a set of PMU performance requirements to ensure that compliant instruments will perform similarly when presented with this suite of test signals. The user shall be aware that in the presence of the previously mentioned undesirable components in the input signal, higher measurement errors could result. These errors may be substantial, particularly where higher order derivatives (such as ROCOF) are used. Signal processing alternatives may be employed to reduce or eliminate these errors. They are difficult to implement in a real-time environment and could adversely affect the measurement latency or the synchrophasor measurement response time. Alternatives are neither described nor evaluated in this document.

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

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Kenneth Martin, *Chair*
Bogdan Kasztenny, *Vice Chair*

Mark Adamiak
Scott Anderson
Galina Antonova
Miroslav Begovic
Gabriel Benmouyal
Gustavo Brunello
Bill Dickerson
Juan Gers
Allen Goldstein
Hank Hechun
Yi Hu
Mladen Kezunovic
Harold Kirkham
Jay Murphy
Krish Narendra
Arun Phadke
Tevfik Sezi
Veselin Skendzic
Jerry Stenbakken
Eric Udren
John Wang

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

William J. Ackerman
Mark Adamiak
Eric Allen
M. Victoria Alonso
Galina Antonova
James Ariza
Jack Arnold
Ali Al Awazi
David Bassett
Philip Beaumont
Kenneth Behrendt
Oscar Bolado
Gustavo Brunello
Arvind K. Chaudhary
Luis Coronado
Randall Crellin
Gary Donner
Michael Dood
Randall Dotson
Gary Engmann
Herbert Falk
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Vasudev S. Gharpure
Jeffrey Gilbert
Mietek Glinkowski
Jalal Gohari
Allen Goldstein
Roman Graf
Stephen Grier
Randall C. Groves
Roger Hedding
Jerry Hohn
C. Huntley
Gerald Johnson
Innocent Kamwa
Bogdan Kasztenny
Yuri Khersonsky
James Kinney
Joseph L. Koepfinger
Jim Kulchisky
Chung-Yiu Lam
Raluca Lascu
Kenneth Martin
Pierre Martin
John McDonald
Michael McDonald
Harish Mehta
Gary Michel
Adi Mulawarman
Jerry Murphy
R. Murphy
Bruce Muschlitz
Michael S. Newman
Mohamed Omran
Dean Ouellette
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Steven Sano
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Jose Antonio De La O Serna
Gil Shultz
Mark Simon
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James Smith
Jerry Smith
Gary Stoedter
Charles Sufana
Richard Taylor
William Taylor
Demetrios Tziouvaras
Joe Uchiyama
Eric Udren
John Vergis
Ilia Voloh
Roel Vries
John Wang
Kenneth White
Thomas Wiedman
Ray Young
Jian Yu
Sergio Zimath

When the IEEE-SA Standards Board approved this standard on 7 December 2011, it had the following membership:

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IMPORTANT NOTICE: This standard is not intended to ensure safety, security, health, or environmental protection. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.

1. Overview

1.1 Scope

This standard is for synchronized phasor measurement systems in power systems. It defines a synchronized phasor (synchrophasor), frequency, and rate of change of frequency (ROCOF) measurements. It describes time tag and synchronization requirements for measurement of all three of these quantities. It specifies methods for evaluating these measurements and requirements for compliance with the standard under both static and dynamic conditions. It defines a *phasor measurement unit* (PMU), which can be a stand-alone physical unit or a functional unit within another physical unit. This standard does not specify hardware, software, or a method for computing phasors, frequency, or ROCOF.

1.2 Purpose

This standard defines synchronized phasor and frequency measurements in substations along with methods and requirements for measurement verification. Measurements compliant with the standard and taken at various locations in the power system can be readily and accurately combined for power system analysis and operations. Time tag and other essential associations are also described to facilitate communication and reliable data application. Communication and recording of phasor measurements are covered in other standards, such as the companion standard IEEE Std C37.118.2™-2011 [B9].[1]

[1] The numbers in brackets correspond to those of the bibliography in Annex A.

1.3 General overview

This standard covers synchronized phasor measurements used in electric power systems. It defines the measurement, provides methods of quantifying the measurements, defines performance tests, and specifies acceptable limits. The following clauses are provided:

— Clause 1 provides the scope and needs for the standard.

— Clause 2 references other standards that are related or may be useful in the study and application of this standard.

— Clause 3 defines terms and abbreviations found in this standard.

— Clause 4 defines the measurement.

— Clause 5 defines measurement requirements, a method of quantifying the measurement, a test method, and accuracy limits.

Six informative annexes are also provided to clarify the standard and give supporting information, as follows:

— Annex A is a bibliography.

— Annex B explores the effects of time tagging and transient response relevant to this measurement technique.

— Annex C provides the algorithms that were used to confirm the performance requirements.

— Annex D discusses time synchronization.

— Annex E explains the total vector error (TVE) concept of measurement quality and gives plots of error results.

— Annex F describes two methods that can be used for measuring the internal voltages and power angles of generators.

1.4 Need for this standard

The 2005 version of the standard, commonly followed by equipment manufacturers and system integrators, specifies the performance of phasor measurements only under steady-state conditions. Synchrophasor applications, particularly during severe system disturbances, will utilize dynamic synchronized measurements. This revision of the standard extends the synchrophasor definition and specifies measurement requirements and test conditions to include practical dynamic power system conditions.

The original synchrophasor standard, IEEE Std 1344™-1995 [B5], and its successor, IEEE Std C37.118™-2005 [B8], provide for reporting of system frequency and rate of change of system frequency. These quantities are not defined, however, and no measurement requirements are mandated.

This revision provides definition and measurement requirements for power system frequency and ROCOF under practical power system conditions. A number of issues in the standard have been identified that require clarification or modification. This revision also separates the measurement and communication subclauses of IEEE Std C37.118-2005 [B8] into individual standards. This simplifies widespread adoption and aids deployment by allowing freer use of other standards for synchrophasor communication.

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.

IEEE Std 754™-1985, IEEE Standard for Binary Floating-Point Arithmetic.[2, 3]

3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary: Glossary of Terms & Definitions* [B2] should be consulted for terms not defined in this clause.[4]

3.1 Definitions

anti-aliasing: The process of filtering a signal before sampling to remove components of that signal whose frequency is equal to or greater than the Nyquist frequency (one-half the sample rate). If not removed, these signal components would appear as a lower frequency component (an alias).

Coordinated Universal Time (UTC): (Initials are ordered based on French language.) The time of day at the Earth's prime meridian (0° longitude). It is distributed by various media, including the Global Positioning System (GPS) system.

data concentrator (DC): A device that combines data from several measurement devices.

frequency error (FE): The measure of error between the theoretical frequency and the measured frequency for the given instant of time.

Global Positioning System (GPS): A U.S. Department of Defense (DoD) navigation system that uses a constellation of 24 satellites broadcasting a precision signal for location and time synchronization. Basic time synchronization accuracy is ± 0.2 microseconds (μs).

IEEE floating point: A 32-bit representation of a real number.

NOTE—This definition is in accordance with IEEE Std 754-1985.[5]

leap second: A positive or negative one-second adjustment to the Coordinated Universal Time (UTC) that keeps it close to mean solar time.

Nyquist frequency: A frequency that is one-half the sampling frequency of a discrete signal processing system.

Nyquist rate: A sampling rate that is twice the bandwidth of a band-limited signal. It is the minimum sample rate that will result in an alias-free representation of a signal. It must therefore be greater than twice the highest frequency component in the signal.

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