

IEEE Standard for Synchrophasors for Power Systems

Sponsor

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of the
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Abstract: *The synchronizing input and the data output for phasor measurements made by substation computer systems is discussed. Processes involved in computing phasors from sampled data, data-to-phasor conversions, and formats for timing inputs and phasor data output from a Phasor Measurement Unit (PMU) are also addressed.*

Keywords: *anti-aliasing, digital computer based measurement, Global Positioning System (GPS), Nyquist rate, phase lock, phasor, satellites, synchronism, synchronized phasor, time input*

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Introduction

(This introduction is not a part of IEEE Std 1344-1995, IEEE Standard for Synchrophasors for Power Systems.)

Digital computer-based measurement, protection, and control systems have become common features of electric power substations. These systems use sampled data to compute various quantities such as voltage and current phasors. Phasors are of great value in many functions, and their utility is increased further if they can be referenced to a common time base. This can be accomplished if the signal input processes at various measuring sites are synchronized with respect to each other. 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 standard defines the synchronizing input and the data output for phasor measurements made by substation computer systems. It also discusses the processes involved in computing phasors from sampled data. It is hoped that this standard will be of considerable value to the developers and users of digital computer-based substation systems.

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IEEE Standard for Synchrophasors for Power Systems

1. Overview

1.1 Scope

This is a standard for synchronized phasor measurement systems in substations. It addresses synchronization of data sampling, data-to-phasor conversions, and formats for timing input and phasor data output from a Phasor Measurement Unit (PMU). It does not specify response time, accuracy, hardware, software, or a process for computing phasors.

1.2 Purpose

This standard defines synchronized phasor measurements in substations so that the measurement equipment can be readily interfaced with associated systems. It specifies data formats and synchronization requirements to allow correlating phasors from various sources and comparing them with similar data from different measurement systems.

1.3 Need for this standard

Recent developments in the field of power system data acquisition provide users with the ability to record, time-tag, transmit, and analyze power system phasor quantities in real time. Given the emphasis on future system development, many different hardware and software approaches are being implemented to make the phasor data available. A standard is needed for integrating measurement systems into substation environments, to specify data output formats, and to assure that the measurement processes are producing comparable results. The synchrophasor standard will help ensure maximum benefits from the phasor measurements and will allow interchange of data between a wide variety of users of both real time and off-line phasor measurements.

2. References

This standard shall be used in conjunction with the following publications:

IEEE Std C37.111-1991, , IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems (ANSI).¹

IRIG STANDARD 200-89, Telecommunications Group, Range Commanders Council, U.S. Army White Sands Missile Range, NM.²

Network Time Protocol (Version 3) "Specification, Implementation, and Analysis," D. L. Mills, DARPA Network Working Group, RFC-1305, University of Delaware, March, 1992.³

3. Definitions

This clause contains key terms as they are used in this standard.

3.1 anti-aliasing: By the Nyquist Theorem, the maximum reproducible frequency is one-half the sampling rate. Aliasing is caused when frequencies higher than one half of the sampling rate are present. This results in the higher frequencies being "aliased" down to look like lower frequency components. Anti-aliasing is providing low pass filtering to block out frequencies higher than those that can be accurately reproduced by the given sampling rate.

3.2 Nyquist rate: The minimum rate that an analog signal must be sampled in order to be represented in digital form. This rate is twice the frequency of that signal.

3.3 phase lock: The state of synchronization between two ac signals in which they remain at the same frequency and with constant phase difference. This term is typically applied to a circuit that synchronizes a variable oscillator with an independent signal.

3.4 phasor: A complex equivalent of a simple sine wave quantity such that the complex modulus is the sine wave amplitude and the complex angle (in polar form) is the sine wave phase angle. *See also:* **vector**.

3.5 synchronism: The state where connected alternating-current systems, machines, or a combination operate at the same frequency and where the phase angle displacement between voltages in them are constant, or vary about a steady and stable average value.

3.6 synchronized phasor: A phasor calculated from data samples using a standard time signal as the reference for the sampling process. In this case, the phasors from remote sites have a defined common phase relationship. *Syn:* **synchrophasor**.

3.7 abbreviations and acronyms:

- BCD: Binary Coded Decimal
- CRC₁₆: 16 b Cyclic Redundancy Check, calculated by the generating polynomial $X^{16} + X^{12} + X^5 + 1$
- DoD: Department of Defense
- DoT: Department of Transportation
- FRP: Federal Radionavigation Plan
- GOES: Geostationary Operational Environmental Satellite—consists of two satellites in a geostationary orbit.
- GPS: Global Positioning System—a DoD navigation system that uses a constellation of 24 satellites broadcasting a precision signal for location and time synchronization. Basic time synchronization accuracy is $\pm 0.2 \mu\text{s}$.
- INMARSAT: International Maritime Satellite System
- IRIG-B: InterRange Instrumentation Group Time Code Format B

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway NJ 08855-1331, USA.

²This IRIG standard may be obtained from Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range, NM, 88002, USA.

³This document is available from EE Department, University of Delaware, Newark, DL, 19716, USA. It is also available via the World Wide Web: <http://www.eeeis.udel.edu/~mills.bib.html>.

- Loran C: LOnG RANge navigation system that uses pulsed 100 kHz broadcasts from shore based transmitters for location, particularly in maritime applications. It also provides precise frequency and limited time synchronization.
- NTP: Network Time Protocol
- PMU: Phasor Measurement Unit—in this standard a generic device that produces synchronized phasors from voltage and/or current inputs and synchronizing signal.
- PPS: Pulse Per Second
- ROM: Read Only Memory
- SA: Selective Availability
- SBS: Straight Binary Seconds
- SCADA: Supervisory Control and Data Acquisition
- SMPCNT: Sample Count
- SOC: Second-Of-Century
- UTC: Universal Time Coordinated as distributed by the U.S. Naval Observatory through the GPS system
- WWV: Radio broadcast of time and selected weather information. They are provided by the U.S. National Institute for Standards and Technology using several formats including WWV, WWVB, and WWVH.

4. Sources of synchronizing signals

4.1 Requirements for a synchronizing source

Phasors measured throughout an interconnected grid require a common timing reference provided by a synchronizing source. The synchronizing source may be local or global, and the signal may be distributed by broadcast or direct connection.

The signal provided by the synchronizing source shall be referenced to Coordinated Universal Time (UTC). It shall provide enough time information to determine second-of-century in agreement with UTC. The synchronizing signal shall have a basic repetition rate of 1 pulse per second (1 PPS) with a stability of at least $1\text{E}-07$.

The synchronizing signal must be available without interruption at all measurement locations throughout the interconnected grid. Reliability should exceed 99.87% (1 h of outage per month). The signal shall be accurate enough to allow the phasor measurement equipment to maintain synchronism within $1\text{ }\mu\text{s}$ of UTC including both synchronizing source and local receiving equipment error.

4.2 Broadcasts from satellites

Time signals broadcast from satellites have a wide area of coverage, are synchronized to a national standard, and are little affected by atmospheric conditions. Sites with unobstructed views of satellites have little problem with reliable, continuous signal reception. Users of satellite based systems do not have to provide primary time and time dissemination systems, nor do they have to operate and maintain those systems. The only user cost is for the receiver equipment, although fees may be levied in future satellite systems.

Transit, Geostationary Operational Environmental Satellite (GOES), and Global Positioning System (GPS) are the three principal satellite systems available today for disseminating time. Once policy issues are resolved, INMARSAT system satellites will provide precise time in a GPS-like navigation message. Of the three systems available now, only GPS meets all requirements for this application.

The GPS is a U.S. Department of Defense (DoD) satellite based radio-navigation system. It consists of 24 satellites arrayed to provide a minimum worldwide visibility of four satellites at all times. Each satellite transmits a timed navigation signal, from which a receiver can decode time synchronized to within 0.2 ms of UTC. The inherent availability, redundancy, reliability, and accuracy make it a system well suited for synchronized phasor measurement systems.

The new INMARSAT system satellites will carry a GPS-like transponder. The signal will be similar to existing GPS transmissions, so it can be used with slightly modified GPS receivers. Since the signal will not be degraded by the effects of SA, it should be a better source for time than standard GPS. INMARSAT satellites are geostationary, which may make reception difficult at some locations. The INMARSAT system will provide an alternative to GPS.

4.3 Broadcasts from a central location

Synchronizing signals may also be broadcast from a central location. The viable alternatives include AM radio broadcasts, microwave, and fiber-optic transmission systems. While AM broadcasts are the least expensive, they are characterized by the lowest accuracy. Microwave and fiber-optics systems can achieve high accuracy but have high installation costs.

The most popular and affordable AM systems, WWV, WWVB, and WWVH, rarely achieve accuracy better than 1 ms. Interference poses problems with the reliability of reception. The Loran C impulse broadcast system is well supported by a number of countries, including the U.S., through the end of the century and is a popular navigation system. Its practical accuracy limit is of the order of 1 μ s, but careful monitoring and well-designed human interfaces are required for the best performance.

Fiber-optic and microwave systems can deliver synchronization reliably at 1 μ s and better. This, however, requires a specialized interface that bypasses the usual digital telecommunication interface. The problem with the usual digital interface is its packet switching, which can cause a 70 μ s uncertainty in signal transmission. Until digital systems are developed with a standard, direct, synchronizing signal, this method of transmission will remain expensive.

5. Synchronization

5.1 UTC synchronization

Phasor measurements shall be synchronized to UTC time derived from the synchronizing source described in 4.1. A PMU may receive the synchronizing signal directly or from an independent receiver. If an independent receiver is used, it shall provide time to the PMU using the codes described in 5.3. The basic synchronizing signal is a 1 PPS pulse train where the rising edge of the pulse marks the second change of UTC time. The PMU shall maintain a timing accuracy of 1 μ s between the synchronizing pulses. The 1 μ s synchronization accuracy has been chosen because it is available and meets all foreseeable data accuracy needs. This corresponds to an angular accuracy of 0.022 degrees for a 60 Hz system, and 0.018 degree for a 50 Hz system.

If synchronized phasors are calculated from synchronized data samples, the data sampling shall be synchronized to within 1 μ s of UTC time. Details for PMUs that use fixed frequency synchronized sampling are provided in 5.2, 5.4, and 5.5.

If synchronized phasors are calculated from non-synchronized data samples, the calculating process shall determine an equivalent UTC time and sample number as described for synchronized sampling techniques. The phasor thus determined shall have the same magnitude and phase angle as a phasor bearing the same time and sample number derived from synchronized samples using the same data window. Annex G includes a discussion of other techniques for achieving synchronization of phasor measurements.

5.2 Phase-locked sampling pulses

In synchronized sampling systems, pulses that trigger data sampling shall be locked in phase with the 1 PPS signal. The number of sample pulses per second shall be an integer and evenly spaced throughout the second. The sample point error shall not exceed 1% of the sample period (0.01/sampling rate). The samples shall be numbered from 0 to

$N-1$, where N is the sample rate. Sample 0 is the first sample in the new second and shall coincide with the rising edge of the 1 PPS pulse within ± 100 ns. It is recommended that the sample rate be chosen from the list of Least Common Multiple sample frequencies as defined in IEEE Std C37.111-1991⁴ (COMTRADE), repeated here in tables 1 and 2 for convenience.

Table 1—Sampling frequencies—corresponding to $f_{LCM} = 384 \times f_{base}$

Samples/Cycle	Sample 60 Hz	Frequency 50 Hz
4	240	200
6	360	300
8	480	400
12	720	600
16	960	800
24	1440	1200
32	1920	1600
48	2880	2400
64	3840	3200
96	5760	4800
128	7680	6400
192	11 520	9600
384	23 040	19 200

If time or sample pulses are provided by a device external to the PMU, a flag shall be provided to indicate a loss of time sync or phase lock. Upon loss of sync or lock, the PMU shall set a flag in the status word indicating that the resultant data was computed with "Un-Locked" data. If sampling is being resynchronized to the 1 PPS signal after a period of being unsynchronized, the sample pulses shall be slewed into alignment at a maximum rate of $70 \mu\text{s/s}$. The $70 \mu\text{s/s}$ will generate a 0.004 Hz computed frequency error but allows synchronization in 2 h from a worst case 0.5 s offset.

⁴Information on references can be found in clause 2..