



IEEE Standard for Synchrophasors for Power Systems

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee

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**Power System Relaying Committee
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IEEE Power Engineering Society**

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Abstract: This standard defines synchronized phasor measurements used in power system applications. It provides a method to quantify the measurement, tests to be sure the measurement conforms to the definition, and error limits for the test. It also defines a data communication protocol, including message formats for communicating this data in a real-time system. Explanation, examples, and supporting information are also provided.

Keywords: data concentrator, DC, GPS synchronization, IRIG, PDC, phasor, phasor measurement, phasor measurement unit, PMU, synchrophasor, total vector error, TVE

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Introduction

This introduction is not part of IEEE Std C37.118-2005, IEEE Standard for Synchrophasors for Power Systems.

The synchrophasor standard has been completely revised. The original standard was IEEE Std 1344-1995, which was reaffirmed in 2001. A working group was established in January 2001 to update the standard. This new synchrophasor standard, IEEE Std C37.118-2005, replaces the original.

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 used in many protection and data acquisition functions, and their utility is increased further by referencing them to a common time base. This can be accomplished by synchronizing the signal input processes at various measuring sites. 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.

In this standard, additional clarification is provided for the phasor and synchronized phasor definitions. The concepts of total vector error (TVE) and compliance tests have been introduced. The message formats have been updated from the original standard to improve information exchange with other systems, such as a master station. Specifically, the sync, frame size, and station identification fields have been added to the data frame, configuration frame, header frame, and command frame. The CRC-CCITT is the only valid check word. In the data frame, analog data can now be included, the fraction of second field has replaced the sample count field, and the status field has been significantly modified to include time quality.

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IEEE Standard for Synchrophasors for Power Systems

1. Overview

This standard covers synchronized phasor measurements used in electric power systems. It defines the measurement, provides a method of quantifying the measurements, and quality test specifications. It also defines data transmission formats for real-time data reporting. 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 acronyms 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. Clause 6 defines the real-time communication protocol and message formats.

Eight informative annexes are provided to clarify the standard and give supporting information. Annex A is a bibliography. Annex B gives information about cyclic redundancy check (CRC) codes and the CRC required by this standard. Annex C explores the effects of timetagging and transient response relevant to this measurement technique. Annex D illustrates the message formats defined in Clause 6 with complete message examples. Annex E provides background on time synchronization sources needed for this measurement. Annex F discusses time synchronization. Annex G provides examples of tests that can be made to characterize these measurements. Annex H explains the total vector error (TVE) concept of measurement quality and gives plots of error results. Annex I defines message mapping into standard communication protocols.

1.1 Scope

This is a standard for synchronized phasor measurement systems in power systems. It addresses the definition of a synchronized phasor, time synchronization, application of timetags, method to verify measurement compliance with the standard, and message formats for communication with a phasor measurement unit (PMU). In this context, a PMU can be a stand-alone physical unit or a functional unit within another physical unit. This standard does not specify limits to measurement response time, accuracy under transient conditions, hardware, software, or a method 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 compares 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 calculate power system phasor quantities in real time. Different hardware and software approaches are being implemented to record, transmit, and analyze these measurements, both in real time and post event. A standard is needed for integrating measurement systems into power system environments, to specify data output formats, and to ensure that the measurement processes are producing comparable results. The synchrophasor standard will help ensure maximum benefits from the phasor measurements and allow interchange of data between a wide variety of systems for users of both real-time and off-line phasor measurements.

2. Normative references

The following referenced documents are indispensable for the application of this document. 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™, IEEE Standard for Binary Floating-Point Arithmetic.^{1, 2}

IEEE Std 1588™, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IRIG Standard 200, IRIG Serial Time Code Formats, Telecommunications and Timing Group, Range Commanders Council, U.S. Army White Sands Missile Range.³

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purpose of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standard Terms* [B4]⁴ should be referenced for terms not defined in this subclause.

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

3.1.2 IEEE floating point: A 32-bit representation of a real number in accordance with IEEE Std 754.

3.1.3 Nyquist rate: A rate that is twice the highest frequency component in the input analog signal. The analog signal must be sampled at a rate greater than the Nyquist rate to be represented accurately in digital form.

3.1.4 phasor: A complex equivalent of a simple cosine wave quantity such that the complex modulus is the cosine wave amplitude and the complex angle (in polar form) is the cosine wave phase angle.

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³This standard is available at <http://www.jcte.jcs.mil/RCC/manuals/200-04/TT-45.pdf>.

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

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

3.1.6 synchronized phasor: A phasor calculated from data samples using a standard time signal as the reference for the measurement. Synchronized phasors from remote sites have a defined common phase relationship. *Syn:* **synchrophasor.**

3.2 Acronyms and abbreviations

BCD	binary coded decimal
C/A code	coarse acquisition code
CRC-CCITT	16-bit cyclic redundancy check ⁵
DC	data concentrator
DoD	U.S. Department of Defense
DoT	U.S. Department of Transportation
FRP	Federal Radionavigation Plan
GALILEO	Proposed European radionavigation system
GLONASS	Russian satellite-based radionavigation system
GOES	Geostationary Operational Environmental Satellite.
GPS	Global Positioning System
INMARSAT	International Maritime Satellite System
IRIG-B	InterRange Instrumentation Group Time Code Format B
Loran C	LOng RANge navigation system
NTP	network time protocol
PDC	phasor data concentrator
PMU	phasor measurement unit
PPS	pulse per second
ROM	read-only memory
rms	root-mean-square
SA	selective availability

⁵The CRC-CCITT is calculated using the generating polynomial $X^{16} + X^{12} + X^5 + 1$, seed value 0xFFFF (−1), no final mask.

SBS	straight binary second
SCADA	Supervisory Control and Data Acquisition
SMPCNT	sample count
SOC	second of century
THD	total harmonic distortion
TVE	total vector error
UTC	Universal time coordinated
WWV	U.S. National Institute of Standards and Technology (NIST) time broadcast radio station

4. Synchrophasor measurement

4.1 Phasor definition

The pure sinusoidal waveform $x(t) = X_m \cos(\omega t + \phi)$ is commonly represented as a phasor $X = X_r + jX_i = (X_m/\sqrt{2})(e^{j\phi})$, where ϕ depends on the definition of the time scale. For this standard, this basic concept is adapted as the representation of power system sinusoidal signals.

4.1.1 Off-nominal frequency signals

The phasor representation of a sinusoid is independent of its frequency. A sinusoid $x(t) = X_m \cos(2\pi f t + \phi)$ has a phasor representation $X = (X_m/\sqrt{2}) e^{j\phi}$. The phase angle ϕ of the phasor is determined by the starting time ($t = 0$) of the sinusoid.

Consider that such a sinusoid is observed at intervals $\{0, T_0, 2T_0, 3T_0, \dots, nT_0, \dots\}$, leading to corresponding phasor representations $\{X_0, X_1, X_2, X_3, \dots\}$. This is equivalent to having the time reference for observation initialized at the beginning of each interval.

If the observation interval T_0 is equal to an integer multiple of the period of the sinusoid $T = 1/f$, then a constant phasor is obtained at each observation. On the other hand, if the observation interval T_0 is not an integer multiple of T , the observed phasor has a constant magnitude, but the phase angles of the sequence of phasors $\{X_0, X_1, X_2, X_3, \dots\}$ will change uniformly at a rate $2\pi(f-f_0)T_0$, where $f_0 = 1/T_0$. This is illustrated in Figure 1.

4.2 Synchrophasor definition

The synchrophasor representation X of a signal $x(t)$ is the complex value given by Equation (1):

$$\begin{aligned}
 X &= X_r + jX_i \\
 &= (X_m/\sqrt{2}) e^{j\phi} \\
 &= X_m/\sqrt{2} (\cos \phi + j \sin \phi)
 \end{aligned}
 \tag{1}$$

where $X_m/\sqrt{2}$ is the rms value of the signal $x(t)$ and ϕ is its instantaneous phase angle relative to a cosine function at nominal system frequency synchronized to Universal time coordinated (UTC). This angle is defined to be 0° when the maximum of $x(t)$ occurs at the UTC second rollover [1 pulse per second (PPS) time signal], and -90° when the positive zero crossing occurs at the UTC second rollover. Figure 2 illustrates this relationship.

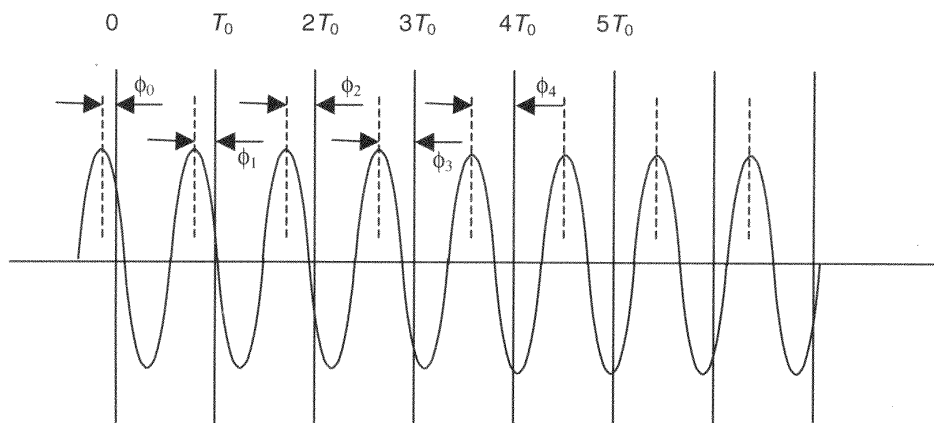


Figure 1—A sinusoid with a period of T observed at instants that are multiples of T_0 apart. T_0 is not an integer multiple of T .

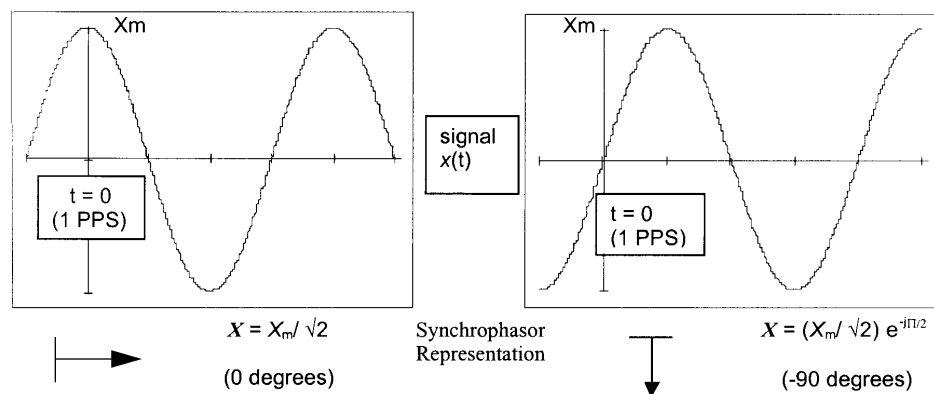


Figure 2—Convention for synchrophasor representation

4.3 Measurement timetag for synchrophasors

Synchrophasor measurements shall be tagged with the UTC time corresponding to the time of measurement. This shall consist of three numbers: a second-of-century (SOC) count, a fraction-of-second count, and a time status value. The SOC count shall be a 4-byte binary count in seconds from midnight (00:00) of January 1, 1970, to the current second. Leap seconds shall be added to or deleted from this count as necessary to keep it synchronized with UTC. Insertion of a leap second results in two successive seconds having the same SOC count which are differentiated by the leap second bit in the FRACSEC word defined in 6.2.1. (With this convention, time count can always be determined from current time by multiplying the number of days since 1/1/70 by the number of seconds per day, 86 400). This SOC time stamp is the same as is used by the UNIX computer system, and similar to those used by other computer systems including DOS, MAC OS, and networks [network time protocol (NTP)].

The second shall be divided into an integer number of subdivisions by the TIME_BASE integer specified in Table 10. The fraction-of-second count shall be an integer representing the numerator of the fraction of second with TIME_BASE as the denominator. Compatibility with IEC 61850:2000 [B3] requires a TIME_BASE value of 2^{24} . The fraction-of-second count shall be 0 when it coincides with the 1 s rollover. This timetag shall be applied to all communication frames as described in Clause 6.

4.4 System time synchronization

Synchrophasor measurements shall be synchronized to UTC time with accuracy sufficient to meet the accuracy requirements of this standard (see 5.2). Note that a time error of 1 μ s corresponds to a phase error of 0.022° for a 60 Hz system and 0.018° for a 50 Hz system. A phase error of 0.01 radian or 0.57° will by itself cause 1% TVE as defined in Equation (2). This corresponds to a maximum time error of $\pm 26 \mu$ s for a 60 Hz system, and $\pm 31 \mu$ s for a 50 Hz system.

The system must be capable of receiving time from a highly reliable source, such as the Global Positioning System (GPS), which can provide sufficient time accuracy to keep the TVE within the required limits and provide indication of loss of synchronization. The flag in the data output (see Table 8, STAT word Bit 13) is provided to indicate that a loss of time synchronization shall be asserted when loss of synchronization could cause the TVE to exceed the limit or within 1 min of actual loss of synchronization, whichever is less. The flag shall remain set until data acquisition is resynchronized to the required accuracy level.

Annex E and Annex F discuss time sources and distribution formats.

5. Synchrophasor measurement requirements and compliance verification

5.1 Synchrophasor estimation

Synchrophasor estimates shall be made and transmitted as data frames at a rate F_s that is an integer number of times per second or integer number of seconds per frame as specified by the DATA_RATE variable in the configuration frame (see Table 10). These estimates shall be equally spaced within the 1 s interval. Data frames may include multiple channels of phasor estimates, analog words, and digital words combined with a single timetag as defined in Clause 6.

5.1.1 Reporting rates

The PMU shall support data reporting (by recording or output) at submultiples of the nominal power-line (system) frequency. Required rates for 50 Hz and 60 Hz systems are listed in Table 1.

Table 1—Required PMU reporting rates

System frequency	50 Hz		60 Hz				
Reporting rates (F _s —frames per second)	10	25	10	12	15	20	30

The actual rate to be used shall be user selectable. Inclusion of more rates, particularly up to system frequency is encouraged.

5.1.2 Reporting times

For a reporting rate N frames per second, the reporting times shall be evenly spaced through each second with frame number 0 (numbered 0 through N–1) coincident with the UTC second rollover (usually the 1 PPS provided by GPS). These reporting times (timetags) are to be used for determining the instantaneous values of the synchrophasor as defined in 4.2. This is illustrated in Figure 1, where the reporting times are at 0, T₀, 2T₀, 3T₀, 4T₀, etc.

5.1.3 Example results

Table 2 gives the synchrophasor values as defined in Equation (1) for the waveforms shown in Figure 2. The values are derived for a 10 frame-per-second reporting rate with a system frequency of 60 Hz. Synchrophasor values are shown for base phase angles of 0° and –90° at the 1 PPS time mark as shown in Figure 2 for both 60 Hz and 61 Hz signals. The synchrophasor values at 50 Hz and 51 Hz for a 50 Hz system frequency are identical.

5.1.4 PMU response time

The PMU response time will be measured by applying a positive or negative 10% step in magnitude with the input signal at nominal magnitude and rated frequency. The response time is the interval of time between the instant the step change is applied and the timetag of the first phasor measurement for which the TVE enters and stays in the specified accuracy zone corresponding to the compliance level (1%).

5.2 Accuracy limits

Under the conditions where X_m, ω, and φ are fixed, and for the influence conditions shown in Table 3, the TVE shall not exceed the TVE limit given in Table 3 for the given compliance level.

TVE is defined as shown in Equation (2):

$$TVE = \sqrt{\frac{(X_r(n) - X_r)^2 + (X_i(n) - X_i)^2}{X_r^2 + X_i^2}} \quad (2)$$

where X_r(n) and X_i(n) are the measured values, given by the measuring device, and X_r and X_i are the theoretical values of the input signal at the instant of time of measurement, determined from Equation (1) and the known conditions of X_m, ω, and φ.

Table 2—Table of synchrophasor values for 60 Hz system at a 10 frame-per-second reporting rate

Time	Fractional time		Synchrophasor—60 Hz		Synchrophasor—61 Hz	
Second	Frame number	Fractional second	Synchrophasor (0°)	Synchrophasor (−90°)	Synchrophasor (0°)	Synchrophasor (−90°)
k−1	9	0.900000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle -36^\circ$	$X_m/\sqrt{2}, \angle -126^\circ$
k	0	0.000000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$
k	1	0.100000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle 36^\circ$	$X_m/\sqrt{2}, \angle -54^\circ$
k	2	0.200000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle 72^\circ$	$X_m/\sqrt{2}, \angle -18^\circ$
k	3	0.300000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle 108^\circ$	$X_m/\sqrt{2}, \angle 18^\circ$
k	4	0.400000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle 144^\circ$	$X_m/\sqrt{2}, \angle 54^\circ$
k	5	0.500000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle 180^\circ$	$X_m/\sqrt{2}, \angle 90^\circ$
k	6	0.600000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle -144^\circ$	$X_m/\sqrt{2}, \angle 126^\circ$
k	7	0.700000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle -108^\circ$	$X_m/\sqrt{2}, \angle 162^\circ$
k	8	0.800000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle -72^\circ$	$X_m/\sqrt{2}, \angle -162^\circ$
k	9	0.900000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle -36^\circ$	$X_m/\sqrt{2}, \angle -126^\circ$
k+1	0	0.000000	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$	$X_m/\sqrt{2}, \angle 0^\circ$	$X_m/\sqrt{2}, \angle -90^\circ$

When the input signal frequency is exactly equal to rated, the phasor will be time-invariant and its coordinates will be fixed and determined by the signal phase. When the input signal frequency is not equal to rated, the phasor will undergo a rotation in the complex plane as illustrated in Table 2. TVE is the magnitude of the vector difference between the theoretical phasor defined in Equation (1) and the phasor estimate given by the measuring device, expressed as a fraction of the magnitude of the theoretical phasor as shown in Equation (2).

5.3 Compliance verification

Compliance tests shall be performed by comparing the phasor estimates obtained under steady-state conditions to the corresponding theoretical values of X_r and X_i and calculating TVE, as defined in Equation (2). *Steady-state conditions* are where X_m , ω , and ϕ of the test signal, and all other influence quantities are fixed for the period of the measurement. (Note that for off-nominal frequencies, the measured phase angle will change even though the test signal phase ϕ is constant.)

A calibration device used to verify performance in accordance with this subclause shall be traceable to national standards and have a “test accuracy ratio” of at least four compared with these test requirements (for example, provide a TVE measurement within 0.25% where TVE is 1%). In cases where there is no national standard available for establishing traceability, a detailed error analysis shall be performed to demonstrate compliance with these requirements.

All compliance tests are to be performed under steady-state conditions, with reference conditions and influence quantities as defined in Table 3. Effects of the influence quantities shall be considered cumulative, and the TVE shall not exceed the error listed for the given compliance level under any combination of influence quantities shown in Table 3. To evaluate compliance with this requirement, the effects of the influence quantities may be separately evaluated.

Documentation shall be provided by any vendor claiming compliance with this standard that shall include a statement of the compliance level being achieved and demonstrating this performance. In addition, if the verification system is based on an error analysis as called for previously, this analysis shall be provided as well.

Table 3—Influence quantities and allowable error limits for compliance levels 0–1

Influence quantity	Reference condition	Range of influence quantity change with respect to reference and maximum allowable TVE in percent (%) for each compliance level			
		Level 0		Level 1	
		Range	TVE (%)	Range	TVE (%)
Signal frequency	F_{nominal}	± 0.5 Hz	1	± 5 Hz	1
Signal magnitude	100% rated	80% to 120% rated	1	10% to 120% rated	1
Phase angle	0 radians	$\pm \pi$ radians	1	$\pm \pi$ radians	1
Harmonic distortion	<0.2% (THD)	1%, any harmonic up to 50th	1	10%, any harmonic up to 50th	1
Out-of-band interfering signal, at frequency f_i where $ f_i - f_0 > F_s/2$, F_s = phasor reporting rate, $f_0 = F_{\text{nominal}}$	<0.2% of input signal magnitude	1.0% of input signal magnitude	1	10% of input signal magnitude	1

NOTE 1—The required level of compliance shall be determined by the user. Level 1 is intended as the “standard” compliance level; level 0 is provided for applications with requirements that cannot be served with level 1.⁶

NOTE 2—The reference condition specifies the condition for that quantity when not being varied. For example, when testing signal magnitude, the magnitude will be varied but the frequency will be nominal, the phase-angle 0 radians, the harmonic distortion <0.2%, and all out-of-band interfering signals < 0.2%. The TVE must stay within the specified error range during all tests.

NOTE 3—An out-of-band interfering signal is any signal with frequency outside the frequency range determined as shown from the nominal system frequency and the phasor reporting rate. The test specified in 5.3 demonstrates the effectiveness of the PMU anti-aliasing filter. The test signal should include those frequencies outside of the bandwidth specified above which cause the greatest TVE.

NOTE 4—PMUs that are not compensated for group delay or other deficiencies are not likely to meet TVE compliance requirements (see Annex C).

NOTE 5—This standard does not impose any limitations to the use of PMUs under any conditions. PMUs are actually very good for making measurements under many transient conditions, and there have been many publications documenting this. The standard does not address the accuracy and response time under transient conditions, and so all testing is

⁶Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

restricted to steady-state conditions. The problem with including transient performance requirements comes in stating requirements that are measurable, can be uniformly applied, and are not unduly restrictive on implementations. This is still an emerging technology and applying anticipated performance requirements could hamper development. Harmonizing a common set of dynamic performance requirements should be undertaken once the range of implementations and measurement applications has been more fully explored. At this time, dynamic performance under transient conditions should be specified and verified by the users to meet their application needs.

6. Synchrophasor message format

6.1 Message application

This subclause describes the format of messages to and from a PMU for use in real-time communication of phasor data. *Real-time data transmission* is defined here as taking place concurrently with the measurement process. If the PMU device is to be used with other systems where the phasor data information is to be transmitted in real time, implementation of this protocol is required for conformance with this standard. If the PMU device is used only for phasor data archiving or recording, then this protocol is not required. Implementation of additional protocols for phasor data communication is not restricted.

Any communication system or media may be used for data transmission. The message frames shall be transmitted in their entirety as they are specified. When used with a stacked protocol such as fieldbus message specification (FMS) or Internet protocol (IP), the entire frame including sync and CRC-CCITT shall be written into and read from the application layer interface. When used with more direct systems like raw Ethernet or RS-232, the entire frame will also be sent with the CRC-CCITT assuring data integrity.

This message protocol may be used for communication with a single PMU or a secondary system that receives data from several PMUs. The secondary system, here referred to as a data concentrator (DC, also called a *phasor data concentrator* or PDC in some references), shall have its own user assigned ID code. The protocol allows for necessary identifying information, such as the PMU IDCODE and status, to be imbedded in the data frame for proper interpretation of the measured data.

6.2 Message framework

Four message types are defined here: data, configuration, header, and command. The first three message types are transmitted from the PMU/DC and the last (command) is received by the PMU/DC. Data messages are the measurements made by a PMU. Configuration is a machine-readable message describing the data the PMU/DC sends and providing calibration factors. Header information is human-readable descriptive information sent from the PMU/DC but provided by the user. Commands are machine-readable codes sent to the PMU/DC for control or configuration. Information may be stored in any convenient form in the PMU/DC itself, but when transmitted it shall be formatted as frames described in the following subclauses.

Only data, configuration, header, and command frames are defined in this standard. Other types may be designated in the future. In normal operation, the PMU only sends data frames. Annex D contains examples of data, configuration, and command frames.

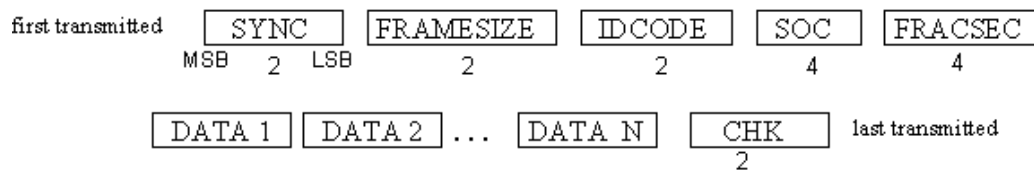


Figure 3—Example of frame transmission order

6.2.1 Overall message

All message frames start with a 2-byte SYNC word followed by a 2-byte FRAMESIZE word, a 2-byte IDCODE, and a time stamp consisting of a 4-byte SOC and 4-byte fraction of second (FRACSEC), which includes a 24-bit fraction-of-second integer and an 8-bit Time Quality flag described in 6.2.2. The SYNC word provides synchronization and frame identification. IDCODE positively identifies the unit sending or receiving the message. Bits 4–6 in the SYNC word designate the frame type. This word is detailed Table 4. All frames terminate in check word (CHK), which is a CRC-CCITT. This CRC-CCITT uses the generating polynomial $X^{16} + X^{12} + X^5 + 1$ with an initial value of -1 (hex FFFF) and no final mask. All frames are transmitted exactly as described with no delimiters. Figure 3 illustrates frame transmission order. The SYNC word is transmitted first and check word last. Two- and 4-byte words are transmitted most significant byte first (network or “big endian” order). All frame types use this same order and format. This first published edition of this standard shall be designated version 1 (binary 0001).

6.2.2 Time and Time Quality

The 32-bit (4-byte) FRACSEC is divided into two components: a 24-bit integer that is the actual Fraction-of-Second count and an 8-bit Time Quality flag. The time of measurement or data transmission for non-data frames is the SOC time stamp that fixes the integer second plus the fractional time. The fractional time is determined by dividing the 24-bit integer fraction of second by the TIME_BASE integer given in configuration frame, as shown in Equation (3):

$$\text{Time} = \text{SOC} + \text{Fraction-of-Second} / \text{TIME_BASE} \quad (3)$$

The bits of the Time Quality flag indicate the “quality” of the time being reported as well as indication of Leap Second status. Table 5 details these assignments. Bit 7 is reserved for future use. Bit 4 is the Leap Second Pending bit and shall be set as soon as it is known but no less than 1 s or more than 59 s before a leap second occurs. It shall be cleared in the first second after the leap second occurs. Bit 5 is the Leap Second Occurred bit and shall be set in the first second after the missing second and remains set for 24 h afterward. Bit 6 is the Leap Second Direction bit that is 0 for adding a leap second and 1 for deleting a leap second. It shall be set (to 0 or 1 as required) at the same time or before the leap second pending bit is set and remain the same for at least 24 h afterward. This will allow analysis programs to factor in a $\pm$ Leap Second in any analysis or time difference calculation.

Table 4—Word definitions common to all frame types

Field	Size (bytes)	Comments
SYNC	2	Frame synchronization word. Leading byte: AA hex Second byte: Frame type and Version, divided as follows: Bit 7: Reserved for future definition Bits 6–4: 000: Data Frame 001: Header Frame 010: Configuration Frame 1 011: Configuration Frame 2 100: Command Frame (received message) Bits 3–0: Version number, in binary (1–15), version 1 for this initial publication.
FRAMESIZE	2	Total number of bytes in the frame, including CHK. 16-bit unsigned number. Range = maximum 65535.
IDCODE	2	PMU/DC ID number, 16-bit integer, assigned by user, 1 to 65 534 (0 and 65 535 are reserved). Identifies device sending and receiving messages.
SOC	4	Time stamp, 32-bit unsigned number, SOC count starting at midnight 01-Jan-1970 (UNIX time base). Ranges 136 yr, rolls over 2106 AD. Leap seconds are not included in count, so each year has the same number of seconds except leap years, which have an extra day (86 400 s).
FRACSEC	4	Fraction of Second and Time Quality, time of measurement for data frames or time of frame transmission for non-data frames. Bits 31–24: Time Quality as defined in 6.2.2. Bits 23–00: Fraction-of-second, 24-bit integer number. When divided by TIME_BASE yields the actual fractional second. FRACSEC used in all messages to and from a given PMU shall use the same TIME_BASE that is provided in the configuration message from that PMU.
CHK	2	CRC-CCITT, 16-bit unsigned integer.

Table 5—Time Quality flag bit definitions

Bit #	Description
7	Reserved.
6	Leap second direction—0 for add, 1 for delete.
5	Leap second occurred—Set in the first second after the leap second occurs and remains set for 24 h.
4	Leap Second Pending—Set before a leap second occurs and cleared in the second after the leap second occurs.
3–0	Time Quality indicator code—See Table 6.