IEC/IEEE 60255-118-1

Edition 1.0 2018-12

INTERNATIONAL STANDARD

colour inside

Measuring relays and protection equipment –
Part 118-1: Synchrophasor for power systems – Measurements

IEC/IEEE 60255-118-1:2018-12(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.120.70 ISBN 978-2-8322-6172-9

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This publication is published as an IEC/IEEE Dual Logo standard.

The text of this document is based on the following documents:

FDIS	Report on voting
95/395/FDIS	95/396/RVD

Full information on the voting for the approval of this document can be found in the report on voting indicated in the above table.

International standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

A list of all parts in the 60255 International Standard, published under the general title *Measuring relays and protection equipment*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,
- replaced by a revised edition, or
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[1] A list of IEEE participants can be found at the following URL:
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INTRODUCTION

This document provides continuation and further development of previous synchrophasor standards, notably the IEEE C37.118 series. It defines synchrophasor, frequency, and rate of change of frequency (ROCOF) measurements as used in this technology. These definitions are in agreement with most research on and analysis of dynamic electric power system measurements, but may differ from those given in other contexts. Function and performance requirements are given for synchrophasor measurements. Tests, evaluation criteria, and error limits are provided to determine compliance with the requirements.

Informative Annexes A, B, C, F, and H provide details about timing aspects, definition application and derivations, PMU measurements, generator power angle, and environmental tests. Informative Annex D details the M and P class reference models used to ensure the requirements can be met; these models are for limit qualification only, as it is expected that most real implementations will perform better than these models. Informative Annex E proposes revised performance requirements for synchrophasors produced from sampled values. These may be used as a basis for normative requirements in a future standard revision. Normative Annexes G and I provide optional qualification of extended steady-state accuracy and measurement bandwidth determination.

A phasor measurement unit (PMU) estimates the parameters magnitude, phase angle, frequency, and rate of change of frequency from the signals appearing at its input terminals or interface. Input signals may be corrupted by harmonics, noise, and changes in state caused by load changes and control and protective actions which complicate parameter estimation. Some examples are harmonics introduced by non-linear loads, step changes in phase introduced by switched reactive elements, and random noise from arc furnaces. These artefacts complicate the process of measuring the generation and load characteristics at or near the system fundamental frequency. The intent of this document is to describe and quantify the performance of a PMU so that it provides a reliable and accurate measurement under real power system conditions.

Synchrophasors are estimated from samples of the voltage and current AC waveforms. Since these signals are alternating current, the estimate uses an interval or "window" over which the samples are taken and used to make the estimate. There could be changes in the waveform parameters during the estimation interval, so the estimate will represent some kind of "average" value for the sinusoid over that window. The length and weighting of the window directly impacts the estimate. A longer window reduces interference but averages out more dynamic changes. In conditions of rapid dynamic changes, such as during a fault, the phasor values can be very inaccurate. The user needs to evaluate their applications and employ appropriate filtering if such conditions could cause a problem.

Frequency and ROCOF are defined as the first and second derivatives of phase angle. They are often computed using finite differencing of the measured angle. Any interference in the angle adversely affects these measurements. Consequently, these measurements are less precise and can produce misleading values. This document 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 should be aware that, in the presence of real system interference, 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, though they are difficult to implement in a real-time environment. Alternatives are neither described nor evaluated in this document.

Specific environmental requirements are out of scope for this document, which specifies functional requirements. Testing required by this document will be performed under standard laboratory conditions which do not include environmental conditions that may be specified for some deployments. Devices implementing the functions described in this document may also follow environmental standards such as IEEE Std 1613™ and IEC 60255-1. Vendors are encouraged to provide information regarding the effect of environmental influences on device performance, perhaps including the pass/fail criteria used when determining environmental compliance. Guidance regarding suggested test profiles is included in Annex F.

MEASURING RELAYS AND PROTECTION EQUIPMENT –

Part 118-1: Synchrophasor for power systems – Measurements

1 Scope

This part of IEC 60255 is for synchronized phasor measurement systems in power systems. It defines a synchronized phasor (synchrophasor), frequency, and rate of change of frequency 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 document does not specify hardware, software or a method for computing phasors, frequency, or rate of change of frequency.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60255-1, *Measuring relays and protection equipment – Part 1: Common requirements*

IEEE Std C37.90™, *IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus*

3 Terms, definitions, and abbreviated terms

For the purpose of this document, the following terms and definitions apply.

ISO, IEC and IEEE maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp
- *IEEE Standards Dictionary Online:* available at http://dictionary.ieee.org

3.1 Terms and definitions

3.1.1
frequency error
FE
difference between the measured frequency and the reference frequency, both at the same time

3.1.2
leap second
positive or negative one-second adjustment to the coordinated universal time (UTC) that keeps it close to mean solar time

3.1.3
measurand
physical or electrical quantity, property, or condition that is to be measured

3.1.4
Nyquist frequency
frequency that is one-half the sampling frequency of a discrete signal processing system

3.1.5
phasor
complex equivalent of a sinusoidal 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

3.1.6
phasor data concentrator
data concentrator (DC) used in phasor measurement systems

3.1.7
phasor measurement unit
PMU
device or function in a multifunction device that produces synchronized phasor, frequency, and rate of change of frequency (ROCOF) estimates from voltage and/or current signals and a time synchronizing signal

3.1.8
rate of change of frequency error
RFE
difference between the measured rate-of-change of frequency and the reference rate-of-change of frequency, both at the same time

3.1.9
reference
<of or pertaining to> a time, level, waveform feature, or waveform that is used for comparison with, or evaluation of, other times, levels, waveform features, or waveforms

Note 1 to entry: This type of entity may or may not be an ideal entity.

3.1.10
synchrophasor
synchronized phasor
phasor representing the fundamental of an AC signal whose magnitude is the RMS value of the fundamental amplitude and angle is the difference between the signal fundamental angle and the phase angle of a cosine at the nominal signal frequency that is synchronized to UTC time

3.1.11
total vector error
TVE
normalized value of the difference between the measured synchrophasor and the reference synchrophasor, both at the same time

3.2 Abbreviated terms

BCD	binary coded decimal
f_0	system nominal frequency, either 50 Hz or 60 Hz
ω_0	system nominal frequency ($2\pi f_0$), in radians/s
f_{in}	input frequency of the fundamental; this is the frequency of the measurement input which is normally at or very close to nominal (50 Hz or 60 Hz) but may vary considerably during major disturbances or testing
fps	frames per second; the rate that frames of synchrophasor data are transmitted
F_s	frequency of measurement data reporting, in frames per second (fps) that have the same units as Hz (1/s)

GNSS global navigation satellite system
GPS global positioning system
IRIG-B: inter-range instrumentation group time code format B
PPS pulse per second
ROCOF rate of change of frequency
SCADA supervisory control and data acquisition
SOC second of century
THD total harmonic distortion
THD+N total harmonic distortion plus noise
UTC coordinated universal time

4 Synchrophasor measurement

4.1 Input and output quantities

As shown in Figure 1, the input quantities are the time and the power system voltage and current signals. The time signal shall provide UTC time with sufficient accuracy that the PMU can meet the specified performance requirements. The time signal shall meet the input requirements specified by the PMU manufacturer. Annex A reviews common formats.

Voltage and current signals shall be supplied to the PMU as analog quantities over wire or as data packets over communication circuits as specified by the manufacturer. These signals represent the AC power system signals.

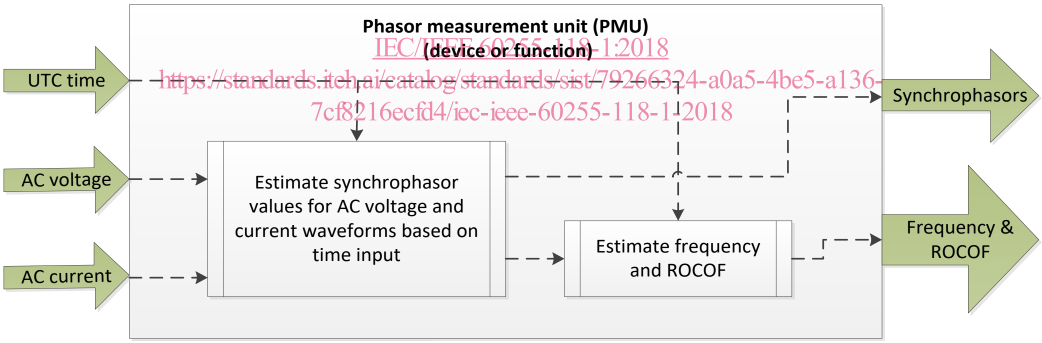

Figure 1 – Input and output quantities

Outputs are the synchrophasor, frequency, and ROCOF estimates made by the PMU. These are normally supplied with a timestamp that is the time of measurement. Additional analog and digital inputs and output may be included by the PMU manufacturer, but are not in the scope of this document so are not considered here.

4.2 Power system signal

The voltage or current in an AC power grid is modelled with the following equation:

$$x(t) = X_{\mathrm{m}}(t)\cos[\theta(t)] + D(t) \tag{1}$$

where

t is time in seconds, where t = 0 is coincident with a UTC second rollover;

X_{m} is the peak magnitude of the sinusoidal AC signal;

θ is the angular position of the sinusoidal AC signal in radians;

D is a disturbance signal that contains additive contributions to the signal, including, but not limited to harmonics, noise, DC offset and out-of-band interference.

NOTE 1 The disturbance signal, D, does not appear in the measurand definitions because it includes additive interference that is attenuated or rejected by the synchrophasor estimation process.

NOTE 2 X_m, θ, and D are continuous functions of time, as indicated by the (t) notation.

4.3 Measurand definitions

4.3.1 Synchrophasor phase angle

The synchrophasor phase angle $\phi(t)$ is defined as the phase difference between the angular position $\theta(t)$ and phase due to the nominal frequency f_0:

$$\phi(t) = \theta(t) - 2\pi f_0 t \tag{2}$$

NOTE The angular velocity of θ is typically close to angular velocity resulting from the nominal power system frequency, f_0, of 50 Hz or 60 Hz. The synchrophasor is often provided in the form of digital samples, or reports, at a rate substantially lower than the power system nominal frequency (e.g., 10 reports per second for either of a 50 Hz or 60 Hz power system). Sampling theory depends on a sampling rate greater than 120 samples/s to reconstruct a 60 Hz signal without aliasing. Subtracting $2\pi f_0 t$ from θ causes the angular velocity of the synchrophasor phase angle $\phi(t)$ to go to zero as the frequency approaches nominal. This allows synchrophasors to be reported at relatively low rates without aliasing. For example, for an f_0 of 60 Hz, power system signals whose fundamental frequency is between 55 Hz and 65 Hz, exclusive, can be represented by synchrophasors reported at 10 frames/s without aliasing.

4.3.2 Synchrophasor measurand

The synchrophasor measurand is a complex number that can be represented in polar coordinates as:

$$X(t) = \left(\frac{X_m(t)}{\sqrt{2}}, \phi(t)\right) \tag{3}$$

Alternatively, the synchrophasor measurand can be represented in rectangular coordinates as:

$$X(t) = \left(X_r(t), X_i(t)\right) \tag{4}$$

where the real (X_r) and imaginary (X_i) components are:

$$X_r(t) = \frac{X_m(t)}{\sqrt{2}} \cos[\phi(t)] \tag{5}$$

$$X_i(t) = \frac{X_m(t)}{\sqrt{2}} \sin[\phi(t)] \tag{6}$$

NOTE 1 Definition of $X_m(t)$, $\theta(t)$ and $D(t)$ *is* sufficient to define the time domain signal and expected value of all measurands. The discrete time expected measurand can be extracted from continuous time measurand by letting $t = nT$, where n is an integer and T is a measurement reporting period in units of seconds (i.e., the inverse of the reporting rate).

NOTE 2 Examples of the application of the measurand definitions are given in Annex B.

4.4 Frequency measurand definition

The frequency measurand is the angular velocity of the AC power system signal in units of Hz. It relates to the angular position of the fundamental power system signal as shown in Equation (7):

$$f(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt} = f_0 + \frac{1}{2\pi}\frac{d[\phi(t)]}{dt} \tag{7}$$