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Communication networks and systems for power utility automation – Part 9-3: Precision time protocol profile for power utility automation

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue
New York, NY 10016-5997
United States of America
stds.ipr@ieee.org
www.ieee.org

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COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

Part 9-3: Precision time protocol profile for power utility automation

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This standard cancels and replaces IEC/PAS 61850-9-3 published in 2015.

The text of this standard is based on the following IEC documents:

FDIS	Report on voting
57/1679/FDIS	57/1713/RVD

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

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A list of all parts in the IEC 61850 series, published under the general title *Communication networks and systems for power utility automation*, can be found on the IEC website.

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A bilingual version of this publication may be issued at a later date.

1 A list of IEEE participants can be found at the following URL: http://standards.ieee.org/downloads/61850-9-3/61850-9-3-2016/61850-9-3-2016_wg-participants.pdf

INTRODUCTION

General

This part of IEC 61850 specifies a precision time protocol (PTP) profile of IEC 61588:2009 ¦ IEEE Std 1588-2008 applicable to power utility automation, which allows compliance with the highest synchronization classes of IEC 61850-5 and IEC 61869-9.

This part of IEC 61850 applies Layer 2 communication according to IEC 61588:2009 ¦ IEEE Std 1588-2008, Annex F, and uses peer-to-peer delay measurement according to the default profile of IEC 61588:2009 ¦ IEEE Std 1588-2008, Annex J.4, with restricted range of values.

When clocks are singly attached, this profile is a subset of IEC 61588:2009 ¦ IEEE Std 1588-2008 with above restrictions.

When clocks are doubly attached, this profile extends the BMCA of IEC 61588:2009 ¦ IEEE Std 1588-2008 as IEC 62439-3:2016, Annex A, specifies.

NOTE IEC 62439-3:2016, Annex B is identical to this part of IEC 61850, except that doubly attached clocks are mandatory, while this part of IEC 61850 leaves them optional.

COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

Part 9-3: Precision time protocol profile for power utility automation

1 Scope

This part of IEC 61850 specifies a precision time protocol (PTP) profile of IEC 61588:2009 ¦ IEEE Std 1588-2008 applicable to power utility automation, which allows compliance with the highest synchronization classes of IEC 61850-5 and IEC 61869-9.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61588:2009, *Precision clock synchronization protocol for networked measurement and control systems* ¦ IEEE Std 1588-2008, *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*[2]

IEC TR 61850-90-4:2013, *Communication networks and systems for power utility automation – Part 90-4: Network engineering guidelines*

IEC 62439-3:2016, *Industrial communication networks – High availability automation networks – Part 3: Parallel Redundancy Protocol (PRP) and High availability Seamless Redundancy (HSR)*

ISO/IEC 9646-7, *Open systems interconnection – Conformance testing methodology and framework – Part 7: Implementation conformance statements*

3 Terms, definitions, abbreviations, acronyms, and conventions

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61588:2009 ¦ IEEE Std 1588-2008 and IEC 62439-3:2016, as well as the following, apply:

3.1.1
device time inaccuracy
time inaccuracy evaluated or measured between the time signal at the input of a device and the time signal that this device generates

Note 1 to entry: This definition applies to TCs, BCs and media converters.

Note 2 to entry: Device time inaccuracy includes the uncertainties in the computation of the path delay assuming an ideal Pdelay_Resp from an upstream neighbour, and the uncertainty introduced in responding to an ideal Pdelay_Req from a downstream neighbour.

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2 IEEE Std 1588-2008 was adopted as IEC 61588:2009.

3.1.2
grandmaster-capable
ordinary clock or boundary clock that is able to take the role of a grandmaster

Note 1 to entry: A grandmaster-capable clock is not necessarily connected to a recognized standard time source.

3.1.3
grandmaster time inaccuracy
time inaccuracy evaluated or measured between the reference time signal at the input of a grandmaster clock and the time signal(s) that the grandmaster generates

Note 1 to entry: Grandmaster time inaccuracy includes the uncertainty introduced in responding to an ideal Pdelay_Req from a downstream neighbour.

3.1.4
network time inaccuracy
time inaccuracy evaluated or measured between the reference time signal at the input of a grandmaster clock and the time signal at the input of a given slave clock, considering the worst path between the grandmaster(s) and the slave

Note 1 to entry: Network time inaccuracy varies depending on the path the time signals take.

3.1.5
reference time inaccuracy
time inaccuracy evaluated or measured between the time maintained by the international standards laboratories that form the basis for the International Atomic Time (TAI) and Coordinated Universal Time (UTC) timescales and the reference time signal at the input of a grandmaster

Note 1 to entry: Reference time inaccuracy considers e.g. the GPS or the DCF77 time inaccuracy as received at a particular geographical location, at the output of the receiver.

3.1.6
subdomain
region of a time domain delimited by Boundary Clocks, each subdomain having exactly one selected master (Boundary Clock or grandmaster)

3.1.7
time error
deviation from the time reference used for measurement or synchronization caused by a network element, evaluated over a short time span (a few Sync intervals)

3.1.8
time inaccuracy
time error not exceeded by 99,7 % of the measurements, evaluated over a series of 1 000 measurements (about 20 minutes) in steady state

Note 1 to entry: Assuming a Gaussian distribution, this corresponds to three sigma ($3\,\sigma$ = 99,7 %) or no more than 3 points outside the specified interval, out of 1 000 total points evaluated.

3.1.9
total time inaccuracy
time inaccuracy evaluated or measured between the time maintained by the international standards laboratories that form the basis for the International Atomic Time (TAI) and Universal Coordinated Time (UTC) timescales and the time signal at the input of a slave clock

Note 1 to entry: The TimeAccuracy attribute of IEC 61850-7-2 sums the total time inaccuracy and the time inaccuracy of the sampling. Therefore, the mapping from total time inaccuracy to TimeAccuracy is implementation-dependent.

3.2 Abbreviations and acronyms

For the purposes of this document, the abbreviations and acronyms given in IEC 61588:2009 ¦ IEEE Std 1588-2008 and IEC 62439-3:2016, as well as the following, apply:

ATOI Alternate Time Offset Indicator (IEC 61588:2009 ¦ IEEE Std 1588-2008, 16.3)

MIB Management Information Base (RFC 1157)

PICS Protocol Implementation Conformance Statement (ISO/IEC 9646-7)

SNMP Simple Network Management Protocol (RFC 1157)

4 Identification

The identification values for this profile according to IEC 61588:2009 ¦ IEEE Std 1588-2008, 19.3.3 are:

profileName: IEC/IEEE 61850-9-3 "Precision time protocol profile for power utility automation"

profileVersion: 1.0

profileIdentifier: 00-0C-CD-00-01-xy

Whereas the first nibble of the sixth octet is a bitfield:

– x = 0 for a singly-attached clock
– x = 1 for PRP redundancy
– x = 2 for HSR redundancy
– x = 3 for both PRP and HSR (configurable) redundancy
– y = 0 (minor revision: profileVersion 1.0)

organizationName: IEC Technical Committee 57 Working Group 10

sourceIdentification: A copy of IEC/IEEE 61850-9-3 can either be obtained from the International Electrotechnical Commission (http://www.iec.ch) or from the Institute of Electrical and Electronics Engineers (http://standards.ieee.org).

NOTE The OUI defined in IEC 61588:2009 ¦ IEEE Std 1588-2008, Annex J.4, does not apply.

5 Clock types

This specification distinguishes clocks by their capabilities:

- Ordinary Clocks (OCs) implement one of the following capabilities:
  – Slave-only (defaultDS.slaveOnly = true)
    no port can be in the MASTER state.
  – Grandmaster-capable (defaultDS.slaveOnly = false)
    the port (or the port pair in redundancy) can be in the MASTER state.
  – Grandmaster-only (defaultDS.slaveOnly = false and clockClass = 6 or 7)
    no port can be in the SLAVE state.
- Transparent Clocks (TCs) correct and forward PTP messages:
  their ports do not have states in IEC 61588:2009 ¦ IEEE Std 1588-2008.
- Boundary Clocks (BCs) are never slave-only and can have either:
  – exactly one port in the SLAVE state and all other in the MASTER or PASSIVE state;
  – all ports in the MASTER state, in which case the BC is the grandmaster.

NOTE 1 Within a time domain, a BC has a port in the SLAVE state in the upper subdomain and one or several ports in the MASTER state in the lower subdomain(s) (see IEC TR 61850-90-4).

NOTE 2 A BC filters the messages that are forwarded from one subdomain to the other(s). A BC does not propagate event messages, but does propagate management messages. A BC propagates selected TLVs such as ALTERNATE_TIME_OFFSET_INDICATOR (ATOI) from one subdomain to the next, but these TLVs are attached to different Announce messages.

6 Protocol specifications

All clocks shall transmit PTP messages according to IEC 61588:2009 ¦ IEEE Std 1588-2008, Annex F (Transport of PTP over IEEE 802.3 /Ethernet).

All clocks shall support the delay measurement defined in IEC 61588:2009 ¦ IEEE Std 1588-2008, 10.3 and 11.4 (Peer delay mechanism).

All clocks shall support the PTP timescale defined in IEC 61588:2009 ¦ IEEE Std 1588-2008, 7.2.2 (based on TAI).

All singly attached clocks shall support the default best master clock algorithm in IEC 61588:2009 ¦ IEEE Std 1588-2008, 9.3.2, 9.3.3 and 9.3.4.

All doubly attached clocks according to IEC 62439-3:2016 shall support in addition the extension to the best master clock algorithm defined in IEC 62439-3:2016, Annex A.

All clocks shall support both 1-step and 2-step synchronization on ingress, they may use 1-step or 2-step synchronization on egress.

All clocks shall support at least one of the three management mechanisms, as stated in IEC 61588:2009 ¦ IEEE Std 1588-2008, 15.1.1:

1) the alternate management mechanism using the SNMP MIB specified in IEC 62439-3:2016, Annex E, and/or
2) the alternate management mechanism using the management objects defined in IEC TR 61850-90-4:2013, 19.3 and 19.4, and/or
3) the manufacturer-defined fixed values and/or the manufacturer-specific implementation means to address all configurable values.

For testing purposes, it is recommended to equip clocks with a 1 PPS output, see 7.9.

7 Requirements

7.1 Measurement conditions

Steady state is defined as 30 s after a single master starts to send synchronization messages and 16 s after a change of master, with no change to the environment temperature.

This definition applies only to clocks that have been energized for 30 minutes to accommodate, for instance, temperature-controlled oscillators.

7.2 Network time inaccuracy

The following requirements on the network elements aim at achieving a network time inaccuracy better than ±1 µs after crossing approximately 15 TCs or 3 BCs.

7.3 Network elements

All network elements shall be clocks according to this part of IEC 61850, conformant media converters and/or conformant links.

7.4 Requirements for grandmasters

7.4.1 Grandmaster time inaccuracy

A grandmaster-capable clock shall have a time inaccuracy measured between its applied time reference signal and the produced synchronization messages that is smaller than 250 ns.

NOTE This value corresponds to an IEC 61588:2009 ¦ IEEE Std 1588-2008 clockAccuracy of 22 hex.

In case the grandmaster-capable clock has no time reference signal, IEC 61588:2009 ¦ IEEE Std 1588-2008, J.4.4.1 shall apply.

7.4.2 Grandmaster holdover

A grandmaster shall remain within the time inaccuracy of 7.4.1 for a holdover time of at least 5 s after losing its time reference signal, given that it was in steady state.

7.4.3 Grandmaster clockQuality in start-up, holdover and recovery

A grandmaster clock shall adjust its clockClass according to IEC 61588:2009 ¦ IEEE Std 1588-2008, Table 5 with the values:

6 while synchronized to its time reference signal and in steady state;

7 after loss of its time reference signal, while in holdover;

52 after loss of its time reference signal, when its time error exceeds 7.4.1;

187 after loss of its time reference signal, when its time error exceeds 1 μs;

6 after recovering the time reference signal and in steady state.

NOTE 1 This modifies IEC 61588:2009 ¦ IEEE Std 1588-2008, Table 5 with the timing requirements of this profile.

NOTE 2 The clockClass 6 appears twice in this list, once before loss of time reference signal, and once after recovery thereof.

NOTE 3 A grandmaster clock adjusts its clockAccuracy and offsetScaledLogVariance according to IEC 61588:2009 ¦ IEEE Std 1588-2008, 7.6.2.5 and 7.6.3.

7.4.4 Grandmaster traceable flags

PTP messages carry a timeTraceable and a frequencyTraceable flag. A grandmaster that receives its reference signal e.g. through a GPS receiver would set the timeTraceable flag, while a grandmaster that e.g. only receives a 1PPS signal would set the frequencyTraceable flag. These flags are however not considered in the BMCA, so other means allow prioritizing a time source over a frequency source, when both exist in the same time domain, for instance configuring Priority1, see 7.9.

7.5 Requirements for TCs

The TC time inaccuracy cumulates the time errors in measuring the residence delay, measuring the peer delay in the ingress port and responding to the peer delay measurement from the downstream clocks in the egress port(s). It does not include time error due to asymmetry in either link, nor introduced by the upstream or downstream peer devices involved in the peer delay measurements.

A TC shall introduce less than 50 ns of device time inaccuracy, measured between the applied synchronization messages at any ingress port and the produced synchronization messages at any egress port, given it is in steady state.

A TC should forward Sync messages even if it is not yet in steady state.

NOTE 1 The TC's contribution to time inaccuracy is measurable using peer clocks with known contribution to time error in the peer delay measurement and using links with known or negligible asymmetry, and subtracting those amounts from the observed TC time error.

7.6 Requirements for BCs

7.6.1 BC time inaccuracy

The BC time inaccuracy cumulates the time errors in local clock adjustment, measuring the peer delay in the port in the SLAVE state and responding to the peer delay measurement from the downstream clocks in the port(s) in the MASTER state. It does not include time errors due to asymmetry in either link, nor introduced by the upstream or downstream peer devices involved in the peer delay measurements.

A BC shall introduce less than 200 ns of device time inaccuracy between the port in the SLAVE state and any port in the MASTER state, given it is in steady state.

A BC should send Announce and Sync messages even if it is not yet in steady state.

NOTE 1 The BC's contribution to time inaccuracy is measurable using peer clocks with known contribution to time error of the peer delay measurement and using links with known or negligible asymmetry, and subtracting those amounts from the observed BC time error.

7.6.2 BC as free-running grandmaster

In case the BC has no port in the SLAVE state and no time reference signal, IEC 61588:2009 ¦ IEEE Std 1588-2008, J.4.4.1 shall apply.

7.6.3 BC as master in holdover

A BC shall remain within the time inaccuracy of 7.4.1 for a holdover time of at least 5 s after losing its time reference signal or PTP synchronization, given that it was in steady state.

7.7 Requirements for media converters

Media converters (e.g. fibre to copper) introduce a delay, considered in the peer-to-peer delay measurement. This delay suffers from a significant jitter and could be different in both directions.

Media converters that support IEC 61588 are considered as TCs or BCs and are subject to the requirements of 7.5 and 7.6, respectively.

Media converters that do not support IEC 61588 shall present a jitter of less than 50 ns and an asymmetry of less than 25 ns.

7.8 Requirements for links

Links present a predictable and nearly constant link propagation delay (about 5 µs/km for fibre or copper), whose average value is regularly calculated by peer-to-peer delay measurement.

NOTE Radio links are not considered.

Since delay asymmetry is not measurable, network engineering must know it to compensate for it.

Links shall present a propagation asymmetry of less than 25 ns or shall have a known propagation asymmetry with an asymmetry variation of less than 25 ns.

7.9 Network engineering

To achieve the required network time inaccuracy, careful network design is required, considering the placement of masters and redundant masters and possible network topology changes because of reconfigurations, so as not to exceed the number of allowed TCs and BCs.

The network designer should only select network elements knowing their contribution to network time inaccuracy and dependencies on the operating conditions. The network designer should estimate the network time inaccuracy for all slave clocks.

The network designer should use network elements with stricter specifications in more demanding applications or larger networks.

The total time inaccuracy ε_T of the time signal available at the input of a given clock is computed at engineering time as:

$$\varepsilon_T = \varepsilon_{RF} + \varepsilon_{GM} + (N_{TC} \times \varepsilon_{TC}) + (N_{BC} \times \varepsilon_{BC}) + (N_{MC} \times \varepsilon_{MC})$$

The network time inaccuracy ε_N of the time signal available at the input of a given clock is computed at engineering time as:

$$\varepsilon_N = \varepsilon_{GM} + (N_{TC} \times \varepsilon_{TC}) + (N_{BC} \times \varepsilon_{BC}) + (N_{MC} \times \varepsilon_{MC})$$

where:

ε_T = total time inaccuracy;

ε_N = network time inaccuracy;

ε_{RF} = reference time inaccuracy;

ε_{GM} = grandmaster time inaccuracy (see 7.4);

ε_{TC} = TC time inaccuracy (see 7.5);

ε_{BC} = BC time inaccuracy (see 7.6);

ε_{MC} = media converter time inaccuracy (see 7.7);

N_{TC} = number of TCs in series on the longest path to this clock;

N_{BC} = number of BCs in the path on the longest path to this clock;

N_{MC} = number of media converters in the path on the longest path to this clock.

NOTE 1 Medium asymmetry is considered negligible in a properly engineered substation.

NOTE 2 The fields in the Announce message, especially timeSource, clockQuality and stepsRemoved provide an estimation of the actual time inaccuracy.

The network commissioner should check the time inaccuracy of the installed network components and verify the topology (e.g. using the management mechanism, if such is provided) and then perform a calibration for the network time inaccuracy of all slave clocks, e.g. using their 1 PPS output.

Network engineers should configure the Priority1 field to give preference to grandmasters that are time-traceable over grandmasters that are frequency-traceable in the same time domain, see 7.4.4.

The network engineer should ensure that all clocks participating in the PTP time distribution are set to the same time domain. To avoid conflict with another PTP time distribution that occupies time domain 0 on the same network, time domain 93 is recommended as an alternative to time domain 0. This also applies to the primary domain of TCs.