



BSI Standards Publication

Communication networks and systems for power utility automation

Part 90-5: Use of IEC 61850 to transmit
synchrophasor information according to
IEEE C37.118

National foreword

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TECHNICAL REPORT



**Communication networks and systems for power utility automation –
Part 90-5: Use of IEC 61850 to transmit synchrophasor information according to
IEEE C37.118**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

Part 90-5: Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118

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The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 61850-90-5, which is a technical report, has been prepared by IEC technical committee 57: Power systems management and associated information exchange.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
57/1144/DTR	57/1207/RVC

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

This technical report has been prepared in a joint effort between IEC and IEEE. A task force consisting of members from the IEC TC 57 WG 10 as well as the IEEE Power and Energy Society/IEEE Power System Relay Committee has prepared that report with task force meetings both at the regular meetings of IEC TC 57 WG 10 as well as at the regular meetings of the IEEE Power and Energy Society/IEEE Power System Relay Committee. Once the technical report is approved and published, the results will be integrated as amendments into the relevant parts of IEC 61850.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

INTRODUCTION

Synchrophasor data as measured and calculated by PMUs are considered to be useful information to assess the condition of the electrical power network.

The synchrophasors and related message formats to transmit synchrophasor data over long distances are defined in IEEE C37.118.

Even though the communication according to IEEE C37.118 has proven to be usable and work well, there is a desire to have a communication mechanism that is compliant to the concept of IEC 61850. This document lays out how this shall be done.

COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

Part 90-5: Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118

1 Scope

This part of IEC 61850 provides a way of exchanging synchrophasor data between PMUs, PDCs WAMPAC (Wide Area Monitoring, Protection, and Control), and between control center applications. The data, to the extent covered in IEEE C37.118-2005, are transported in a way that is compliant to the concepts of IEC 61850.

However, given the primary scope and use cases, this document also provides routable profiles for IEC 61850-8-1 GOOSE and IEC 61850-9-2 SV packets. These routable packets can be utilized to transport general IEC 61850 data as well as synchrophasor data.

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 61850-2:2003, *Communication networks and systems in substations – Part 2: Glossary*

IEC 61850-6:2009, *Communication networks and systems in substations – Part 6: Configuration description language for communication in electrical substations related to IEDs*

IEC 61850-7-1, *Communication networks and systems for power utility automation – Part 7-1: Basic communication structure – Principles and models*

IEC 61850-7-2, *Communication networks and systems in substations – Part 7-2: Basic information and communication structure – Abstract communication service interface (ACSI)*

IEC 61850-7-3, *Communication networks and systems for power utility automation – Part 7-3: Basic communication structure – Common data classes*

IEC 61850-7-4:2010, *Communication networks and systems for power utility automation – Part 7-4: Basic communication structure – Compatible logical node classes and data object classes*

IEC 61850-8-1:2011, *Communication networks and systems for power utility automation – Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3*

IEC 61850-9-2:2010, *Communication networks and systems for power utility automation – Part 9-2: Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3*

IEC/TR 61850-90-1, *Communication networks and systems for power utility automation – Part 90-1: Use of IEC 61850 for the communication between substations*



IEC/TS 62351-1, *Power systems management and associated information exchange – Data and communications security – Part 1: Communication network and system security – Introduction to security issues*

IEC/TS 62351-6:2007, *Power systems management and associated information exchange – Data and communications security – Part 6: Security for IEC 61850*

ISO/IEC 8802-3:2000, *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*

ISO/IEC 19772, *Information technology – Security techniques – Authenticated encryption*
Also available as: NIST SP 800-38D

ITU-T X.234, *Information technology – Protocol for Providing the OSI connectionless-mode transport service*
Amendment 1: *Addition of connectionless-mode multicast capability*

IEEE 802.1Q, *Virtual Bridged Local Area Networks*

IEEE C37.118.1, *Standard for Synchrophasor Measurements for Power Systems*

IEEE C37.118.2:2011, *Standard for Synchrophasor Data Transfer for Power Systems*

NIST Special Publication 800-38D, *Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC*

RFC 768, *User Datagram Protocol*

RFC 791, *Internet Protocol DARPA Internet Program Protocol Specification*

RFC 793, *Transmission Control Protocol*

RFC 826, *An Ethernet Address Resolution Protocol*

RFC 894, *A Standard for the Transmission of IP Datagrams over Ethernet Networks*

RFC 1108, *U.S. Department of Defense Security Options for the Internet Protocol*

RFC 1240, *OSI Connectionless Transport Services on top of UDP Version:1*

RFC 2104, *HMAC: Keyed-Hashing for Message Authentication*

RFC 2406, *IP Encapsulating Security Payload (ESP)*

RFC 2407, *Internet Key Exchange (IKEv1) Protocol*

RFC 2474, *Definition of Differentiated Services Field (DS Field) in IPv4 and IPv6 Headers*

RFC 2991, *Multipath Issues in Unicast and Multicast Next-Hop Selection*

RFC 3168, *The Addition of Explicit Congestion Notification (ECN) to IP*

RFC 3246, *An Expedited Forwarding PHB (Per-Hop Behavior)*

RFC 3376, Internet Group Management Protocol, Version 3

RFC 3547, The Group Domain of Interpretation

RFC 5771, IANA Guidelines for IPv4 Multicast Address Assignments

UCA User's Group 61850-9-2LE- Implementation Guideline for Digital Interface to Instrument Transformers using IEC 61850-9-2

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61850-2, IEC 61850-7-2 and IEEE C37.118.1 as well as the following apply.

3.1

IED tool

short for IED configuration tool or IED configurator in the sense of IEC 61850-6

3.2

nonce

number used once

Note 1 to entry: A nonce is some value that varies with time, although a very large random number is sometimes used.

3.3

part(ial) system

part of a complete system, with a defined, self-consistent part functionality

3.4

project

system part with ownership of a set of IEDs, typically those located in one substation, and handled by one system configuration tool

3.5

gateway

internetworking system capable of allowing communications/information exchange between two networks that use different communication protocols

3.6

system

union of all communicating application-functions performing some overall task like "management of a substation", via logical nodes

Note 1 to entry: The physical system is composed of all devices hosting these functions and the interconnecting physical communication network.

4 Abbreviated terms

The following abbreviations apply to this document.

APDU	Application Protocol Data Unit
A-Profile	Application Profile
CDC	Common Data Class
CID	Configured IED Description
CT	Current Transformer
DA	Data archiver
DNS	Domain Name Service
DSCP	Differentiated Services Code Point
ECN	Explicit Congestion Notification
EF	Expedited Forwarding
ESP	Electronic Security Perimeter
ET	Event Trigger
FACTS	Flexible Alternating Current Transmission Systems
FC	Functional constraint
FCD	Functionally Constrained Data
FCDA	Functionally Constrained Data Attribute
FSS	Functional Software Specification
GCM	Galois Counter Mode
GDOI	Group Domain of Interpretation
GMAC	Galois Message Authentication Code
GoCB	GOOSE Control Block
GOOSE	Generic Object Oriented Substation Event
GW	Gateway
HMI	Human Machine Interface
HW	Hardware
IANA	Internet Assigned Numbers Authority
ID	Identification
IED	Intelligent Electronic Device – any programmable or configurable device in the system
IGMP	Internet Group Management Protocol
IID	IED Instance Description. Describes an IED instance in a project.
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
KDC	Key Distribution Center
LAN	Local area network
LD	Logical Device (IEC 61850)
LI	Length Identifier. This value contains the length of the SI or PI with which it is associated.
LN	Logical Node (IEC 61850)
m	Mandatory – shall be implemented
MAC	Media Access Control
MSV	Multicast Sampled Value
MSVCB	Multicast Sampled Values Control Block
o	Optional – may be implemented

OOS	Out-of-step
ORG	Originator
OSI	Open System Interconnect
PDC	Phasor Data Concentrator
PI	Parameter Identifier. This identifier is used to identify a specific session protocol parameter.
PICS	Protocol Conformance Implementation Statement
PMU	Phasor Measurement Unit
POP	Proof of Possession
PSP	Physical Security Perimeter
r	Readable
RAS	Remedial Action Scheme
SA	Substation Automation
SCD	System Configuration Description in the sense of 61850-6. Output of a system tool of a project to configure the IEDs belonging to the project (imported by IED tools).
SCL	Substation Configuration description Language according to IEC 61850
SDH	Synchronous Digital Hierarchy
SED	System Exchange Description: an SCL file containing a part of a system for exchange of interfacing and responsibility data between projects
SEQ	Sequence
SI	Session Identifier. This identifier is used to identify the session protocol that is in use.
SIPS	System Integrity Protection Scheme
SONET	Synchronous Optical NETwork
SP	Synchrophasor
ssPDC	Substation Phasor Data Concentrator
SPDU	Session Protocol Data Unit
SPS	Special Protection Scheme
SS	Substation System
SSDU	Session Service Data Unit
SV	Sampled Values
SVCB	Sampled Value control block; here used to send synchrophasor data periodically
R-SV	Routable Sampled Value service via UDP
R-GOOSE	Routable GOOSE via UDP
SW	Software
TAI	International Atomic Time (TAI, from the French name Temps Atomique International).
TCI	Tag Control Information
TCP	Transmission Control Protocol
TOS	Type of Service
TPDU	Transport Protocol Data Unit
TPID	Tag Protocol Identifier (for IEEE 802.1Q networks)
T-Profile	Transport Profile
TSAP	Transport Service Access Point
TSDU	Transport Service Data Unit
TSEL	Transport Selector
UDP	User Datagram Protocol
VT	Voltage Transformer. Also known as a Potential Transformer (PT).
w	Writeable
WAMPAC	Wide Area Monitoring, Protection, and Control

WAN	Wide area network
XML	eXtensible Markup Language
XSD	eXtensible Markup Language (XML) Schema Definition
R-MSVCB	Routable Multicast Sampled Value Control Block
R-GoCB	Routable GOOSE Control Block

NOTE Abbreviations used for the identification of the common data classes and as names of the attributes are specified in the specific clauses of this document and are not repeated here.

5 Use cases

5.1 General

Synchrophasor communication can be used within a substation such as for synchrocheck or substation level state estimation, or from several substations to a center which performs regional or network level alarms and stability calculations. Both areas of use are described and delineated in the following subclauses.

In the following use cases, the arrows indicate data flow from one device to another. The solid-like arrows are the basic data flow for all illustrated applications, and the dashed arrows are optional data flow from additional locations. The dashed boxes around groups of objects are co-located equipment as labelled.

5.2 Wide area applications utilizing synchrophasors

In the majority of the applications, the sources and sinks for the synchrophasor data are separated by large distances. In this context, "large" means distances which extend essentially further than a typical local area network (LAN).

One of the options to transmit data over arbitrary large distances is using the Internet Protocol (IP). The IP allows the routing of data packets (IP packets) between different networks over any distance. This document focuses on options that utilize IP.

The use of UDP for the streaming of the synchrophasor data is a proven and functional method. The many working applications of the IEEE C37.118 protocol confirm this. Thus, a method utilizing UDP for streaming the SV data is again required. TCP can also be and has been used but with the reservations outlined in 6.4.

In all use cases, the latency requirement refers to end-to-end communications delay. This is the interval of time from when the message is sent from the measurement device to when it is received by the application. It includes all communication delays including LAN, WAN, and router delays as well as delays in intermediate processing units such as ssPDC and PDC units. It does not include measurement delays from the signal input to synchrophasor calculation. It is specified for each use case as a general guideline for communication planning for the described application. Individual application needs will vary and those particular requirements need to be assessed at the time of implementation.

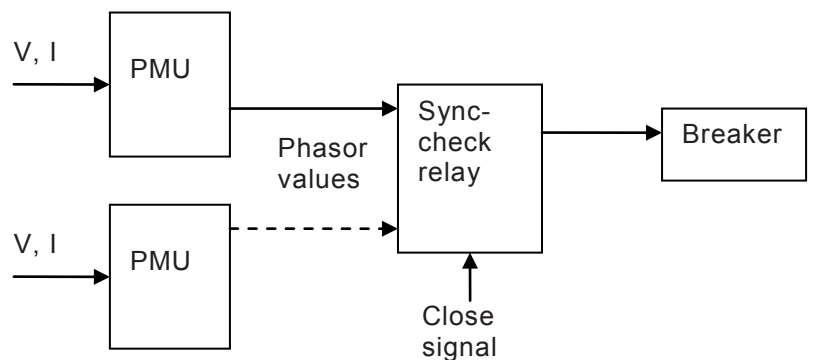
For an application which takes an action based on data it receives, lost packets effectively increase delay in response. A single lost packet will cause a delay equivalent to the interval between packets set by the data reporting rate. The application can tolerate lost packets up to the allowable delay for response. It can therefore tolerate greater numbers of successive lost packets by using higher data rates. Some applications may be able to estimate values for lost data from previous ones, but even this will result in a delayed action. In all cases, applications dependent on transmitted data require a time out to detect excessive packet loss and a fall back operating mode and/or alarm when this occurs.

Applications that record data or build response curves for calculation or visualisation will usually tolerate some data loss with little problem. They can approximate missing values with various patching techniques. The problem is more in the pattern of loss rather than simply loss. Short loss intervals are much easier to patch with reasonable accuracy than long ones. Loss consisting of short dropouts of a few successive samples is more tolerable than less frequent longer dropouts. Any response will be delayed as previously described. A data loss detection timeout and fall-back operating mode and/or alarms are also required.

Jitter, or variation in delay, will cause a variation in action time of any application that uses the data. As long as the jitter is considerably lower than the data rate interval, it should not have much effect on the application. If it approaches the allowable delay time which could be larger or smaller than the interval between successive data samples, it will have an effect on the response and can be the limiting factor. Data concentration will be delayed by jitter as the process must wait for all data to arrive before assembling a complete packet and forwarding it. In all cases, jitter needs to be included in the worst case delay calculations.

5.3 Synchro-check

In this application, data are sent from one or more PMU devices to a sync check relay. The general information flow is shown in Figure 1. The relay uses this information to assure the phase angles of the voltage on two sides of a breaker are close enough that the breaker can be closed without harm.



IEC 843/12

Figure 1 – Use case diagram for Synchro-check

Actors:

Name	Role description
PMU	Computes synchrophasors & frequency
Relay	Checks phase angle between selected inputs
Breaker	Connects/disconnects power line

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU estimates synchrophasor and frequency values from voltages and currents
Data sending & receiving	PMU sends values that are received by relay
Relay decision	Checks phase angle between selected inputs and issues a signal to breaker if included angle is within limits

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors & system frequency
Step 2	PMU selects phasors and frequency at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to relay

Data receiving & action

Use case step	Description
Step 1	Relay receives synchrophasor data
Step 2	Relay extracts appropriate phase angle data and checks status flags
Step 3	Relay checks phase angle between selected inputs
Step 4	Relay makes decision & issues command if needed

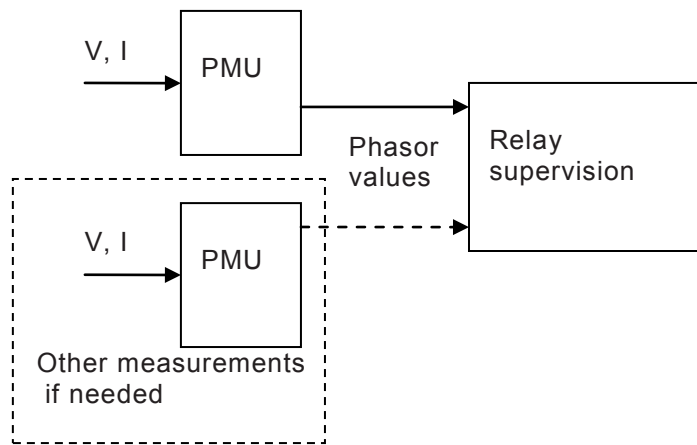
Constraints:

Synchrophasor measurements can be communicated at a variety of rates and may conform to other standards such as IEEE C37.118.1. The following table summarizes a minimum measurement transmission rate, maximum delay in data transmission, and maximum measurement time error. The measurement timing error contributes directly to error in phase angle measurement which is critical for this application. Such measurement errors are governed by IEEE C37.118.1.

Minimum rate	Maximum communication delay (latency) time	Maximum measurement timing error
4/second	0,1 s	0,05 ms

5.4 Adaptive relaying

In this application, data is sent from one or more PMU devices to a relay supervision function. The general information flow is shown in Figure 2. The receiving device uses this information to adjust relaying parameters or settings so the relay is making optimal decisions based on the actual system configuration. This type of application as currently envisioned is a low-speed application that takes advantage of the precision and wider observability of the phasor measurement system.



IEC 844/12

Figure 2 – Use case diagram for adaptive relaying

Actors:

Name	Role description
PMU	Computes synchrophasors & frequency
Relay supervisor	Receives data & makes setting adjustments based on pre-determined algorithm and tables using synchrophasor measurements

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU estimates synchrophasor and frequency values from voltages and currents
Data sending & receiving	PMU sends values that are received by relay supervisor
Relay supervisor decision	Compares measurements with reference values using given algorithms; changes relay parameters as needed.

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors & system frequency
Step 2	PMU selects phasors and frequency at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to relay

Data receiving & action

Use case step	Description
Step 1	Relay supervisor receives synchrophasor data
Step 2	Relay supervisor extracts voltage/current angle and magnitude and frequency information as needed
Step 3	Relay supervisor computes settings based on algorithms and measurements
Step 4	Relay supervisor makes changes in relay settings as required

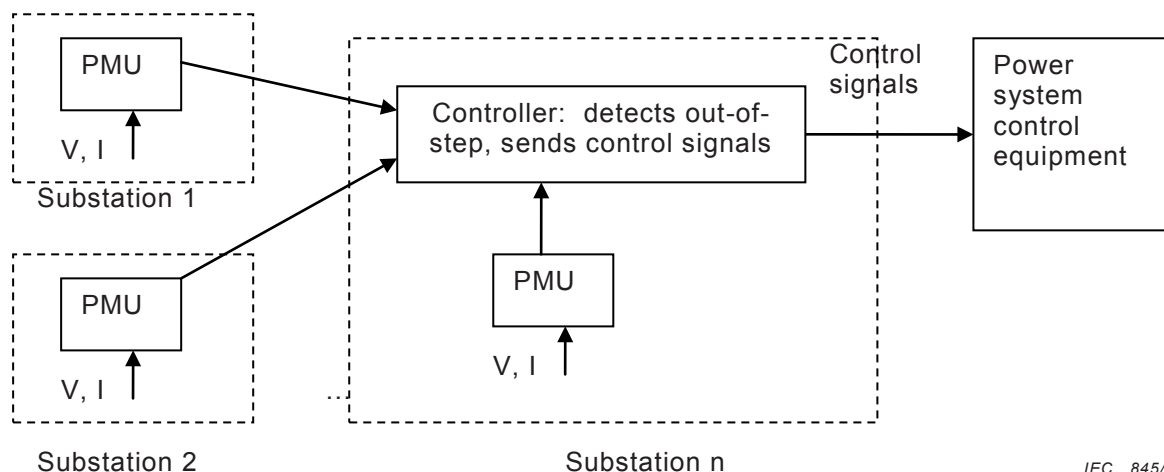
Constraints:

Synchrophasor measurements can be communicated at a variety of rates and may conform to other standards, such as IEEE C37.118.1. Since adaptive relaying is not an established function, actual times and rates may vary considerably from this guideline. These values are estimated to represent the highest data rate, the maximum communication delay, and maximum measurement timing error that will be required by this application.

Minimum rate	Transfer time class	Time synchronization accuracy class
4/second	TT3 0,1 s	T3 0,025 ms

5.5 Out-of-step (OOS) protection

In this application, data is sent from two (or more) PMU devices to a controller that detects out-of-step conditions between substations or system areas. It uses the phase angle and frequency measurements to detect excessive and increasing phase angle, and takes action to reduce the angle or island the system. The general information flow is shown in Figure 3.



IEC 845/12

Figure 3 – Use case diagram for out-of-step (OOS) protection

Actors:

Name	Role description
PMU	Computes synchrophasor & frequency
Out-of-step controller	Receive data from the local PDC & perform various processing, alarming, and visualization functions
Power system control equipment	Controls the power system through switching, FACTS power controllers, DC controls, etc.

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU estimates synchrophasor and frequency values from voltages and currents
Data sending & receiving	PMU sends values that are received by the controller
Out-of-step protection	The controller compares the data from all PMUs to detect if the protected areas are going out-of-step with each other. If it detects conditions that indicate the areas are going OOS, it initiates control actions

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors & system frequency
Step 2	PMU selects phasors and frequency at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to the controller

Data receiving & action

Use case step	Description
Step 1	Controller receives synchrophasor data
Step 2	Controller selects appropriate data for processing
Step 3	OOS Application compares measurements from indicated PMUs and takes action according to indicated conditions

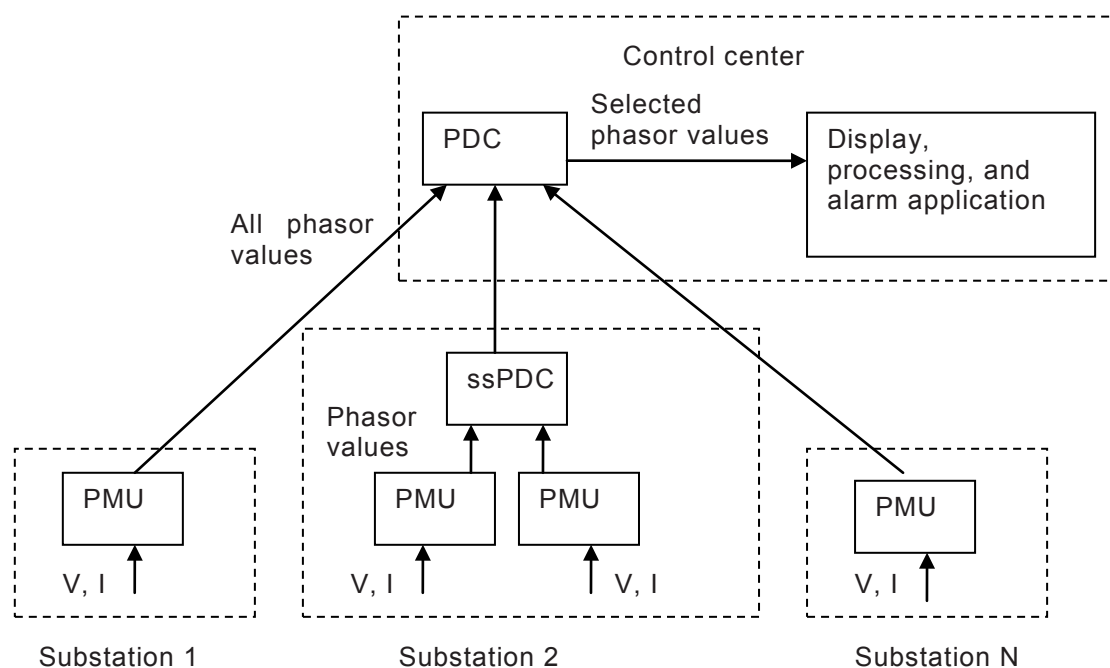
Constraints:

OOS control actions must take place within a limited time. The measurements must be validated within a short period of time. The data rate has to be rapid enough to support the allowed latency between samples. The following table summarizes the minimum measurement transmission rate, allowable latency range, and maximum measurement timing error that can be tolerated in this application.

Minimum rate	Transfer time class	Time synchronization accuracy class
10/second	TT2 0,5 s	T3 0,025 ms

5.6 Situational awareness

In this application, data is sent from one or more PMU devices to alarm and display applications in a control center. These applications may include processing and alarm functions such as oscillation detection and path loading limits. These applications provide alarms to operations personnel based on information derived from the data and compared with pre-programmed criteria. The general information flow is shown in Figure 4.



IEC 846/12

Figure 4 – Use case diagram for situational awareness

Actors:

Name	Role description
PMU	Computes synchrophasors & frequency
ssPDC	Substation Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs in the substation
PDC	Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs or other PDCs
User applications	Receive data from the local PDC & perform various processing, alarming, and visualization functions

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU estimates synchrophasor and frequency values from voltages and currents
Data sending	PMU sends synchrophasor & frequency values
Data receiving/sending	If there is an ssPDC, the data is received in the substation, combined with data from other PMUs, and forwarded to the destination PDC
Data receiving	PDC receives data from PMU or ssPDC, combines with data from other measuring units, and sends on to applications
Situational awareness applications	Applications provide displays of information and process data for more advanced alarms and displays

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors & system frequency
Step 1	PMU selects phasors and frequency at given output rate
Step 2	PMU packages data with appropriate status and time stamp
Step 3	PMU sends data to the ssPDC or PDC

Data receiving intermediate (alternate path)

Use case step	Description
Step 1	ssPDC receives synchrophasor data
Step 2	ssPDC correlates and selects output data
Step 3	ssPDC resends output data to PDC

Data receiving

Use case step	Description
Step 1	PDC receives synchrophasor data
Step 2	PDC correlates and selects output data
Step 3	PDC resends output data to applications

Applications process data and alert operators

Use case step	Description
Step 1a	Application 1 searches data for system oscillations, sends an alarm to operators when one is located
Step 1b	Application 2 computes system phase angles, computes limit violations, and sends alarm to operators if there are exceptions
Step 1c	Application 3 computes flows (MW & MVAR) at strategic points (flow gates) and reports violations to operators
Step 1d	Application 4 computes system voltages and sends alarms to operators for deteriorating conditions or limit violations
Step 2	Additional displays of processed data results and alarm violation details are made available to operators

Constraints:

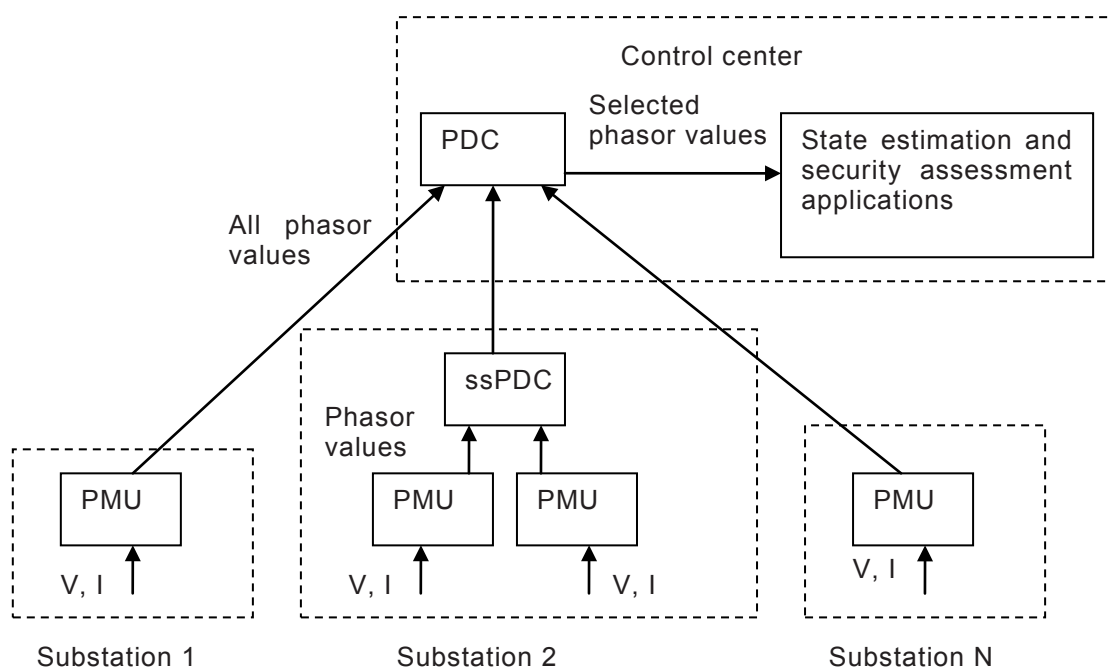
Synchrophasor measurements can be communicated under a variety of rates. The measurement may conform to other standards such as IEEE C37.118.1. The following table summarizes the range of required measurement transmission rates, time delays for data delivery, and maximum measurement time errors for the listed applications.

Application type	Minimum rate	Transfer time class	Time synchronization accuracy class
Inter-area oscillation detection	10/second	TT0 >1 s	T3 0,025 ms
Local oscillation detection (up to 10 Hz)	50/second	TT0 >1 s	T3 0,025 ms

Application type	Minimum rate	Transfer time class	Time synchronization accuracy class
Series resonance detection (frequencies $< f_0$)	Rate $> 3 \times$ (maximum frequency observed)	TT0 > 1 s	T3 0,025 ms
System phase angles	1/second	TT0 > 1 s	T3 0,025 ms
Power flow	1/second	TT0 > 1 s	T3 0,025 ms
Voltage profiles	1/second	TT0 > 1 s	T0 10 ms

5.7 State estimation and on-line security assessment

In this application, data is sent from one or more PMU devices to state estimator and security assessment applications in a control center. The state estimator determines all the voltages and power flows in the grid. Security assessment determines the failure risks by applying various criteria to the state estimate. State estimation will initially use synchrophasor data to supplement traditional SCADA data for added functionality and improved performance since phasor measurements will initially be too sparse to fully support its requirements. Once sufficient measurements are available, state estimation can operate exclusively with phasor data. The general information flow is shown in Figure 5.



IEC 847/12

Figure 5 – Use case diagram for state estimation

Actors:

Name	Role description
PMU	Computes synchrophasor & frequency
ssPDC	Substation Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs in the substation
PDC	Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs or other PDCs
User applications	Receive data from the local PDC, merge with SCADA measurements & perform estimation and assessment functions

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU estimates synchrophasor and frequency values from voltages and currents
Data sending	PMU sends synchrophasor & frequency values in continuous data stream
Data receiving/sending	If there is an ssPDC, the data is received in the substation, combined with data from other PMUs, and resent on to the destination PDC
Data receiving	PDC receives data from PMU or ssPDC, combines with data from other measuring units, and sends to state estimator and security assessment functions
State estimation	State estimator combines synchrophasor and SCADA data to create a state estimate
Security assessment	Security assessment uses state estimate and other data as required to perform assessment function

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors & system frequency
Step 2	PMU selects phasors and frequency at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to the ssPDC or PDC

Data receiving intermediate (alternate path)

Use case step	Description
Step 1	ssPDC receives synchrophasor data
Step 2	ssPDC correlates and selects output data
Step 3	ssPDC resends output data to PDC

Data receiving

Use case step	Description
Step 1	PDC receives synchrophasor data
Step 2	PDC correlates and selects output data
Step 3	PDC resends output data to applications

Applications process data and alert operators

Use case step	Description
Step 1	State estimator receives synchrophasor and SCADA data which is used to produce an estimate of the system state
Step 2	Security assessment functions use the state estimate and other data (synchrophasor and other) to assess system security and report violations to operators

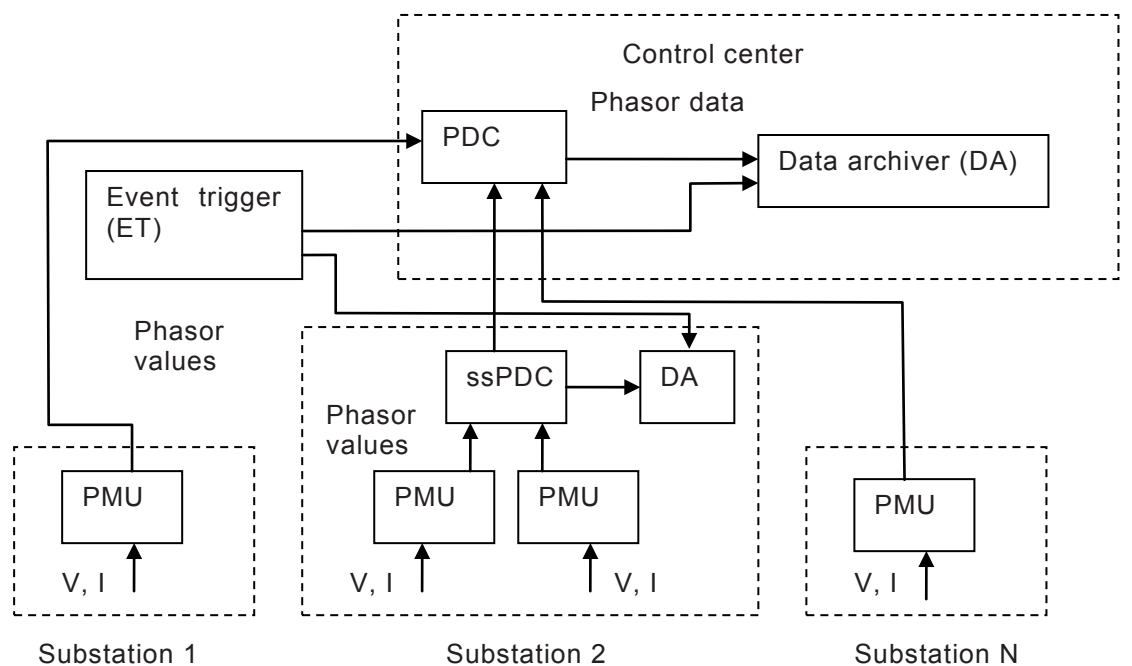
Constraints:

Synchrophasor measurements can be communicated at a rate suitable for the application it serves. Traditional state estimation operates at a rate of seconds to minutes. State estimation using phasor data can operate at sub-second intervals. There is some interest in using high rate state estimation as a filter to provide corrected data for real-time controls, but here it is being considered in the more traditional use for reporting and security assessment. A key point is obtaining measurements that are taken at the same time regardless of the rate. Measurements that conform to IEEE C37.118.1 will have this property. The following table summarizes the required data transmission rates, data transmission delay, and acceptable measurement time error.

Application type	Range of rates	Transfer time class	Time synchronization accuracy class
State estimation	1/(5 min) to 10/second	TT0 >1 s	T3 0,025 ms

5.8 Archive data (event & continuous)

Measurements from PMUs should be archived for system analysis. Archived data should include both continuous measurements and snapshots triggered by anomalous events. These data need to be accessible for later retrieval and analysis. Continuous archiving is accomplished by applications that either have sufficient storage space that they will not run out between scheduled changes, or which utilize size limiting features that delete the oldest data within a time limit. Triggered archive functionality is initiated by an event trigger (ET), here treated as a black box, which sends to one or more data archivers (DAs) an event notification which indicates a need to archive the event data. Data archiving may be a function within PDCs and ssPDCs or may be a stand-alone application. The general information flow is shown in Figure 6.



IEC 848/12

Figure 6 – Use case diagram for archiving data

Actors:

Name	Role description
PMU	Computes synchrophasors & frequency
ssPDC	Substation Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs in the substation
PDC	Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs or other PDCs
ET	Event trigger – notifies PDCs and ssPDCs to archive data within a particular time frame for later retrieval / analysis
DA	Data archiver – a functional unit with the ability to store continuous or event data from a PDC or ssPDC in non-volatile media for later retrieval and analysis

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU estimates synchrophasor and frequency values from voltages and currents
Data sending	PMU sends synchrophasor & frequency values
Data receiving/sending	If there is an ssPDC, the data is received in the substation, combined with data from other PMUs, and forwarded to the destination PDC
Data receiving	PDC receives data from PMU or ssPDC, combines with data from other measuring units, and sends on to applications
Event trigger detection & sending	The ET determines when an event has occurred and sends a trigger that has sufficient information for the Data Archiver to correctly record the event
Event trigger receiving	A DA receives a message from an ET specifying an event to be archived for later retrieval or analysis.
Event data sending	A PDC or ssPDC sends data for the event to a DA.

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors & system frequency
Step 1	PMU selects phasors and frequency at given output rate
Step 2	PMU packages data with appropriate status and time stamp
Step 3	PMU sends data to the ssPDC or PDC

Data receiving intermediate (alternate path)

Use case step	Description
Step 1	ssPDC receives synchrophasor data
Step 2	ssPDC correlates and selects output data
Step 3	ssPDC resends output data to PDC

Data receiving

Use case step	Description
Step 1	PDC receives synchrophasor data
Step 2	PDC correlates and selects output data
Step 3	PDC resends output data to applications

Event trigger sending & receiving

Use case step	Description
Step 1	ET detects event & sends trigger information to DA
Step 2	DA stores data according to requirements for the specified event

Constraints:

Latency and bandwidth are unlikely to be constraints in the archival process, since it is not a real-time or near-real-time application. The main constraint is that the archival process be lossless, i.e., the measurements generated at the PMUs on the system should be the same measurements stored within the data archive.

Activity	Minimum rate	Maximum communication delay (latency) time	Measurement and timetag accuracy
Event data sending	N/A	N/A	Maximum accuracy of the PMUs used to generate the event data

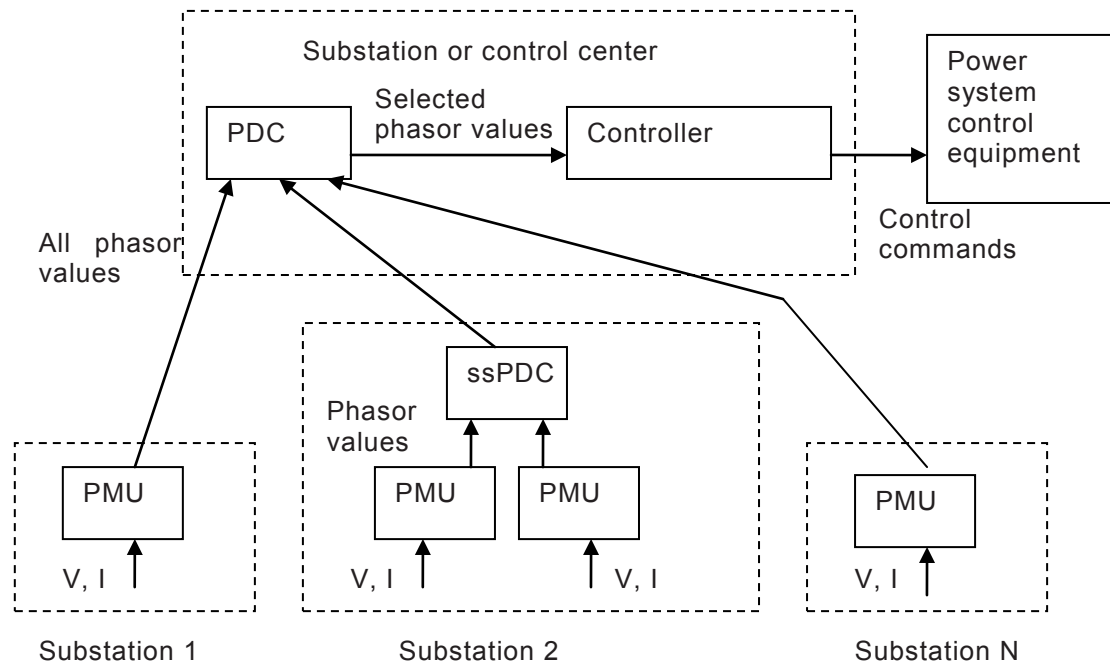
5.9 Wide area controls

5.9.1 General

There are several different use cases for using synchrophasors in the context of wide area controls. The following subclauses document the related use cases.

5.9.2 Special protection schemes

In this application, data are sent from one or more PMU devices to a controller located at a substation, control center, or other appropriate facility. The data may go directly to the controller or may go through ssPDC or PDC data gathering devices. Using programmed algorithms, the controller will take action based on these measurements. Control functions can include switching capacitors, reactors or lines, generator dropping, SVC damping, and any other action that can be implemented. This action can include both traditional special protection schemes (SPS, SIPS, RAS, etc.) and more sophisticated schemes that are based on measured system responses rather than pre-programmed responses. Synchrophasors provide accurate high speed measurements useful for this purpose. The general information flow is shown in Figure 7.



IEC 849/12

Figure 7 – Use case diagram for wide area controls

Actors:

Name	Role description
PMU	Computes synchrophasors & frequency
ssPDC	Substation Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs in the substation
PDC	Phasor Data Concentrator – collects, aligns, selects & possibly decimates data from several PMUs or other PDCs
Controller	Receive data from the local PDC & execute algorithms that implement control functions
System control equipment	Power system control elements including breakers, switches, FACTS power controllers, DC controls, and similar equipment

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU samples current and voltage and estimates synchrophasor and frequency values
Data sending	PMU sends synchrophasor & frequency values in continuous data stream or event reporting methods
Data receiving/sending	If there is an ssPDC, the data is received in the substation, combined with data from other PMUs, and forwarded to the destination PDC
Data receiving	PDC receives data from PMU or ssPDC, combines with data from other measuring units, and sends on to a controller
Power system controls	Controllers receive data and determine actions based on data and control algorithms

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors & system frequency
Step 2	PMU selects phasors and frequency at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to the ssPDC or PDC or controller

Data receiving intermediate (alternate path)

Use case step	Description
Step 1	ssPDC receives synchrophasor data
Step 2	ssPDC correlates and selects output data
Step 3	ssPDC resends output data to PDC or controller

Data receiving

Use case step	Description
Step 1	PDC receives synchrophasor data
Step 2	PDC correlates and selects output data
Step 3	PDC resends output data to controller

Controller actions

Use case step	Description
Step 1	Controller receives and validates the data
Step 2	Controller executes control algorithms searching for conditions that require executing control functions
Step 3	If a situation is found that requires a control function, controller sends control command to indicated control equipment

Constraints:

Control actions must take place within a limited time. Some may need to be executed within milliseconds, and some only within seconds. The data rate and latency must support requirements of the particular control action. Control action speed will be limited by how frequently data are sent (data rate) and the time it takes to receive the data after it has been sent (latency). A wide variety of control actions can be implemented using a synchrophasor based wide area system. The following table is only an example for some control actions but by no means covers all situations. It should be used as a guideline for the higher-speed applications regarding measurement transmission rate, timetag error, latency range, and measurement timing error.

Minimum rate	Transfer time class	Time synchronization accuracy class
10/second	TT2 0,5 s	T3 0,025 ms

5.9.3 Predictive dynamic stability maintaining system

When a severe fault occurs in a loop or mesh network connecting two major power systems, an out-of-step condition can occur between the two systems. By checking for a suitable indicator that would denote the occurrence of a disturbance having a gradual onset of between 5 s to 10 s, an out-of-step condition can be detected and by subsequently splitting the system at a specific point it is possible to prevent the out-of-step occurring. The system is composed of PMUs which are used to gather information and are located at each major point of the power system; the IED enables the splitting of the power system. The IED and PMU are connected within a communication network.

Each PMU sends the voltage angle for its own part of the power system to the IED. The IED compares the angles between the PMUs and predicts the future angle. If the predicted angles between the PMUs in system A and the PMUs in system B exceed pre-determined values, the IED determines that an out-of-step condition will occur and trips the CB.

Alternative method: The IED measures the angular difference between PMUs under normal conditions. When a disturbance occurs, the change in angular difference is calculated from the generator rotor angle (speed) or from frequency deviation.

The general information flow is shown in Figure 8.

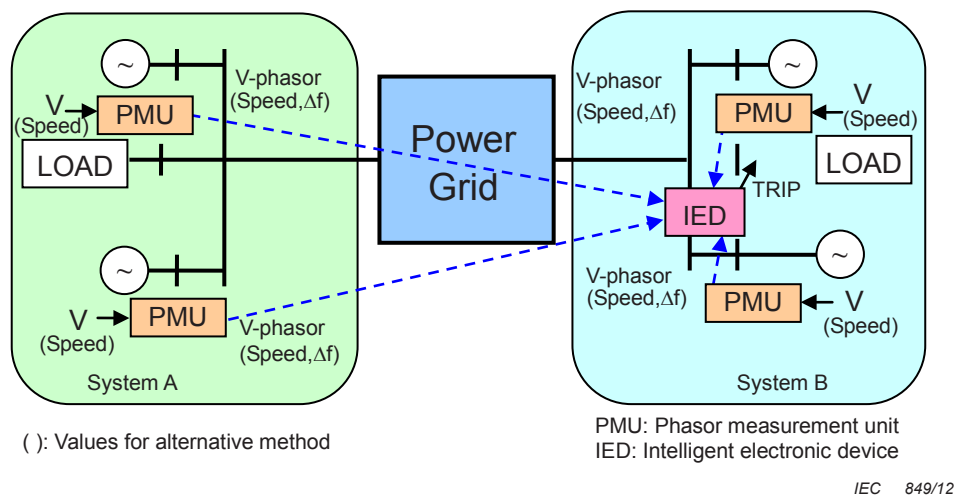


Figure 8 – Use case diagram for predictive dynamic stability

The communication requirements can be summarized as follows:

Actors:

Name	Role description
PMU	Computes synchrophasors
IED	Receives data from PMUs, predicts dynamic stability & power system control

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU samples current and voltage and estimates synchrophasor values
Data sending & receiving	PMU sends values that are received by the IED
Power system control	The IED compares the data from all PMUs The IED is able to predict an out of step between two systems, System A and B. When an out of step is predicted, the IED determines to split a part of either system A or B in order to prevent an out of step occurring between System A and B.

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors
Step 2	PMU selects phasors at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to the IED

IED actions

Use case step	Description
Step 1	IED receives synchrophasor data and validates the data
Step 2	IED computes the voltage angular difference between two systems
Step 3	IED predicts the voltage angular difference between two systems 150 ms – 200 ms ahead
Step 4	If the predicted angles exceed the pre-determined values, then the IED judges that an out-of-step between two systems will occur and splits part of either system

Constraints:

Control actions must take place within a limited time. This application predicts the voltage angular difference 150 ms to 200 ms in the future. When the predicted angles exceed pre-determined values, control is executed to split part of the systems.

The requirement for communication delay (latency) time is shown in the following table with consideration being given to the output time of the IED and operation time of CBs; high reliability data communication is also required. Furthermore, high accuracy measurement is required with the maximum timing error permissible shown in the following table so that the IED compares the angles among plural PMUs

Minimum rate	Allowable communication delay (latency) time	Maximum measurement timing error
25/second @ 50 Hz 30/second @ 60 Hz	20 ms	0,05 ms

5.9.4 Under voltage load shedding

Major blackouts such as those that occurred in Tokyo and France in 1987 and those in the North American Eastern interconnections and Southern Europe in 2003 were related to voltage instability.

Since transmission reinforcements are hard to justify as solutions to voltage instability and cascading outages experienced under extreme conditions, under voltage load shedding would seem to be a suitable alternative contingency.

The example system is composed of PMUs installed at four 500 kV substations and IEDs installed at several 275 or 154/66 kV substations. The IEDs are connected to all PMUs.

One of the purposes of the IED is to detect long-term voltage collapse; this is executed at the 500 kV network level as opposed to the 275 kV or lower voltage networks which are automatically regulated by tap changing on the 500/275 kV or 154 kV transformers.

The IED affords high reliability by use of the following procedure. The IEDs detect slow types of voltage collapse, in the range of eight seconds to two minutes, by detecting unusual continuous $\Delta V/\Delta t$ values. Fast voltage collapse can also be detected using a $\Delta V/\Delta t$ calculation with a one second data window. Each IED can trip more than one line. When the IED detects a voltage collapse, it trips each line CB following expiration of an on-delay timer which can be set independently for each line. (Independent time settings are applied for each line.)

The general information flow is shown in Figure 9.

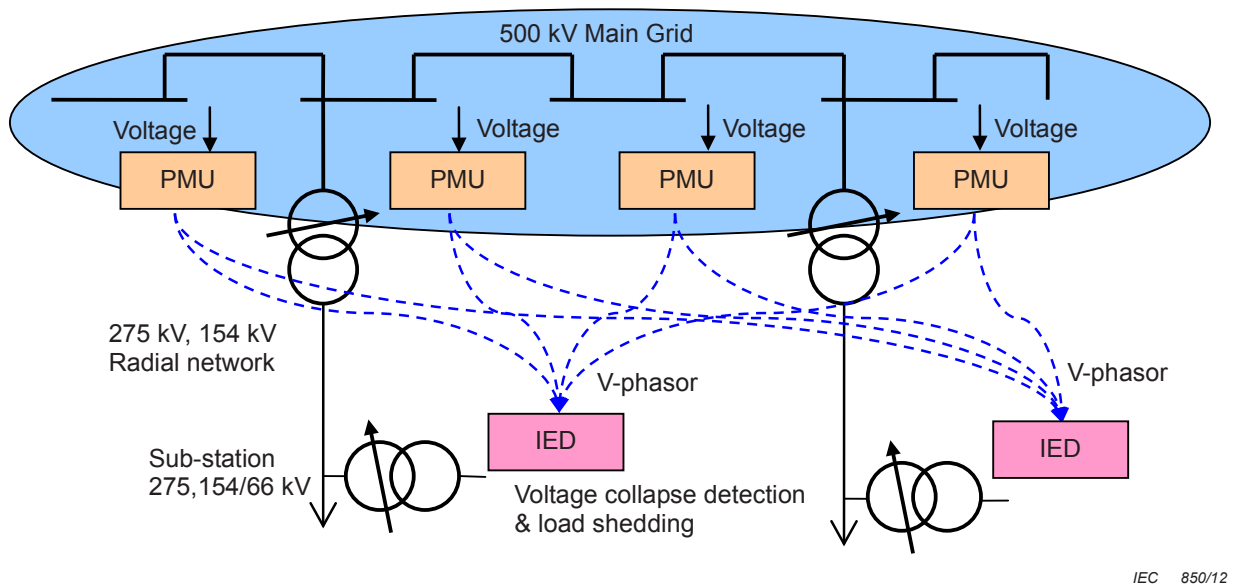


Figure 9 – Use case diagram for under voltage load shedding

The communication requirements can be summarized as follows:

Actors:

Name	Role description
PMU	Computes synchrophasors
IED	Receives data from the PMU, detects voltage collapse & power system control

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU samples current and voltage and estimates synchrophasor values
Data sending & receiving	PMU sends values that are received by the IED
Power system control	The IED detects a voltage collapse using data from all PMUs. If the IED detects a voltage collapse, load is shed until the voltage recovers its normal state.

Basic flow:

PMU actions

Use case step	Description
Step 1	PMU computes V & I synchrophasors
Step 2	PMU selects phasors at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to the IED

IED actions

Use case step	Description
Step 1	IED receives synchrophasor data and validates the data
Step 2	IED calculates the ratio of the voltage drop using data from each PMU
Step 3	IED will determine that a voltage collapse has occurred, if almost all PMU ratios of voltage drop exceed the pre-determined normal voltage value
Step 4	If the IED detects a voltage collapse, load will be shed by the IED until the pre-determined normal voltage level has been recovered

Constraints:

Control actions must take place within a limited time. This application detects the trend that voltage drops are occurring simultaneously in plural substations, and sheds load successively until the pre-determined normal voltage level has been recovered. The following performance requirements have been determined by considering the period from an initial voltage drop to a volt.

Minimum rate	Allowable communication delay (latency) time	Maximum measurement timing error
25/second @ 50 Hz 30/second @ 60 Hz	100 ms	10 ms

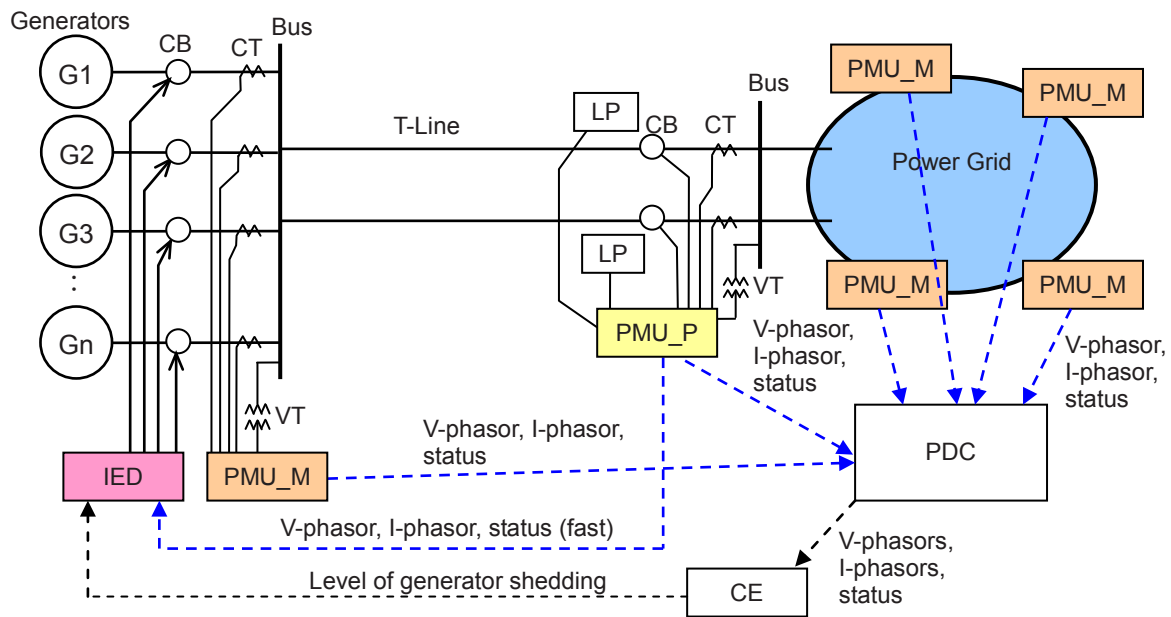
5.9.5 Phenomenon assumption type WAMPAC

When a very severe fault occurs, such as the complete loss of an important power corridor, generators may lose synchronisation with the power network. It may also cause overload of transmission lines or transformers. Imbalance between generation and consumption can occur when a power system network is separated resulting in abnormal frequency conditions.

Phenomenon assumption type WAMPAC (Wide Area Monitoring, Protection and Control) executes generator shedding or load shedding in order to avoid these types of unstable conditions on the power system network based on a pre-fault calculation using on-line power system information.

Phenomenon assumption type WAMPAC is composed of data collecting Terminal Equipment (PMU_M: PMU class M), collecting and Triggering Terminal Equipment (PMU_P: PMU class P), Controller Terminal Unit (IED) and Central Equipment (CE). PMU_M is located at the main substation and the power station. PMU_P is located at the substation in which the detection of the faults predicted (such as line faults) is possible. IED units are located at power stations in which the generators to be shed are located. PDC and CE are typically located in a central control centre where on-line power system information from PMU_M and PMU_P can be obtained.

The general information flow is shown in Figure 10.



LP: Line protection relay, PDC: Phasor data concentrator, CE: Center equipment

IEC 851/12

Figure 10 – Use case diagram for WAMPAC

The operating procedure for each equipment type is described as follows:

CE retrieves the operational status of the power system, i.e. connections and topology, etc. and V and I from PMU_M and PMU_P via the PDC in the form of on-line power system information. A power system model representing the current status and the distribution of the flow of power on the grid is generated in CE for analysis from the on-line power system information and stored as system facility data. A transient stability calculation is undertaken for the assumed fault cases using the power system model, and the transient stability is checked for each case. The level of generator shedding required to maintain stability is then calculated. The result is summarised in a tabular format and sent to the IED. CE repeats this process every few tens of seconds. PMU_P detects faults within the power system from information gathered from the operation of protection relays, change of CB status and sends the information to the IED.

Under normal conditions, PMU_P and PMU_M measure V and I and obtain the status of the circuit breakers and line disconnectors, and this information is sent to the PDC. Periodically, the IED detects changes in the information measured by PMU_P which is stored in a tabular format in CE. It contains information identifying which generators are to be tripped to maintain stability for the severe faults predicted.

The communication requirements can be summarized as follows:

Actors:

Name	Role description
PMU	Computes synchrophasors & frequency
PDC	Phasor Data Concentrator collects the computed data from PMUs, and sends power system data to CE
CE	CE estimates the power system state, and selects the target power system primary equipment to be controlled in order to maintain stability for a specific fault, the result of the calculation is transmitted to the IED.
IED	IED receives a list of the power equipment to be controlled for potential specific faults. IED receives notification of a fault occurrence from PMU class P and compares the fault information and the list, the IED transmits a control command to the power equipment to be controlled.

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU samples current and voltage and estimates synchrophasor values
Data sending & receiving	Data in PMU is transmitted to PDC Data in PMU class P is transmitted to IED
State estimation	State estimator combines Synchrophasor and SCADA data which are utilized for an estimation of the system status
Creating a list for control table	Based upon the estimation of power system conditions, a list of the power system equipment to be controlled is created that will be used to stabilize the power system in response to specific faults
Power system control	IED compares the list with the actual fault and executes power system control

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU computes V & I synchrophasors
Step 2	PMU selects phasors at given output rate
Step 3	PMU packages data with appropriate status and time stamp
Step 4	PMU sends data to the PDC or IED

PDC actions

Use case step	Description
Step 1	PDC receives synchrophasor data
Step 2	PDC correlates and selects output data
Step 3	PDC resends output data to CE

CE actions

Use case step	Description
Step 1	State estimator receives Synchrophasor and SCADA data which are utilized for an estimation of the system status
Step 2	CE calculates the power equipment to be controlled in order to stabilize the power system in respect to t possible specific faults
Step 3	The specific faults and the power equipment to be controlled are listed and transmitted to the IED

IED actions

Use case step	Description
Step 1	IED normally receives and updates a list of the power system equipment to be controlled
Step 2	IED receives fault information from PMUs class P
Step 3	The actual fault information and the list are compared and the relevant power equipment is controlled accordingly

Constraints:

Control actions must take place within a limited time. This application consists of two stages. One is a state estimation and security assessment (PMU to PDC/CE), and the other is a system control as typified in SPS/RAS (PMU to IED). The requirement for “PMU to PDC/CE” and “PMU to IED” is almost the same as those in Subclauses 5.6 and 5.8 respectively. The time constraints for the communication between the IED and PMUs, which have the capability of detecting faults and controlling power equipment, are severe as shown in the following table.

Objects	Minimum rate	Allowable communication delay (latency) time	Maximum measurement timing error
PMU to PDC/CE	1/second to 10/second	5 s	0,05 ms
PMU to IED	50/second @ 50 Hz 60/second @ 60 Hz	20 ms	0,05 ms

5.9.6 Phasor Data Concentrator (PDC)

The Phasor Data Concentrator (PDC) function receives or subscribes to phasor data streams from one or more PMUs and/or other PDCs. The primary purpose of the PDC is to assemble one or more new output data streams from these input data streams. By combining phasor data from many sources into one or a few merged streams, the PDC enables transport of data from many individual PMU sources using a limited number of communications paths and/or paths of limited data capacity. A PDC can also publish a single phasor data stream for subscription by client functions described in use cases below, including situational awareness, state estimation, on-line security assessment, display, data processing, alarming, archiving, and wide area control. With this PDC function at the input, these subscribing application functions do not require communications connections or management for a long list of individual PMU sources.

The functions within the PDC function that are needed to accomplish this merging are:

- selection of particular values from input streams;
- validation of input values, including data presence, test mode, and quality;
- aggregation of values from input streams to create one or more output streams;
- decimation or interpolation of input value streams to allow aggregation of data with different sampling rates;
- time alignment of input values from different streams;
- protocol conversion in either direction between the IEC 61850-90-5 protocol as specified in other clauses of this document, and the communications protocol formats of IEEE C37.118-2005, C37.118.2-2011, IEEE 1344, or other specified transport protocols;
- security implementation – authentication and/or encryption for input or output streams;
- calculation or scaling of derived values from input values, for insertion in an output stream (e.g. insert phase shift, or compute phase angle between input locations).

Functions a) to c) in this list are essential for any PDC. Functions d) and e) are core functions within the PDC function, but may not be needed in every application, and thus may be configured as ‘off’ in a particular case. Functions f) to h) are functions that need not be present in every PDC application; if included, these functions may also be configured as ‘off’.

While the PDC function list is typically provided in one physical equipment unit, some of the functions it performs might also be carried out in other units elsewhere in the system configuration – especially functions f) to h).

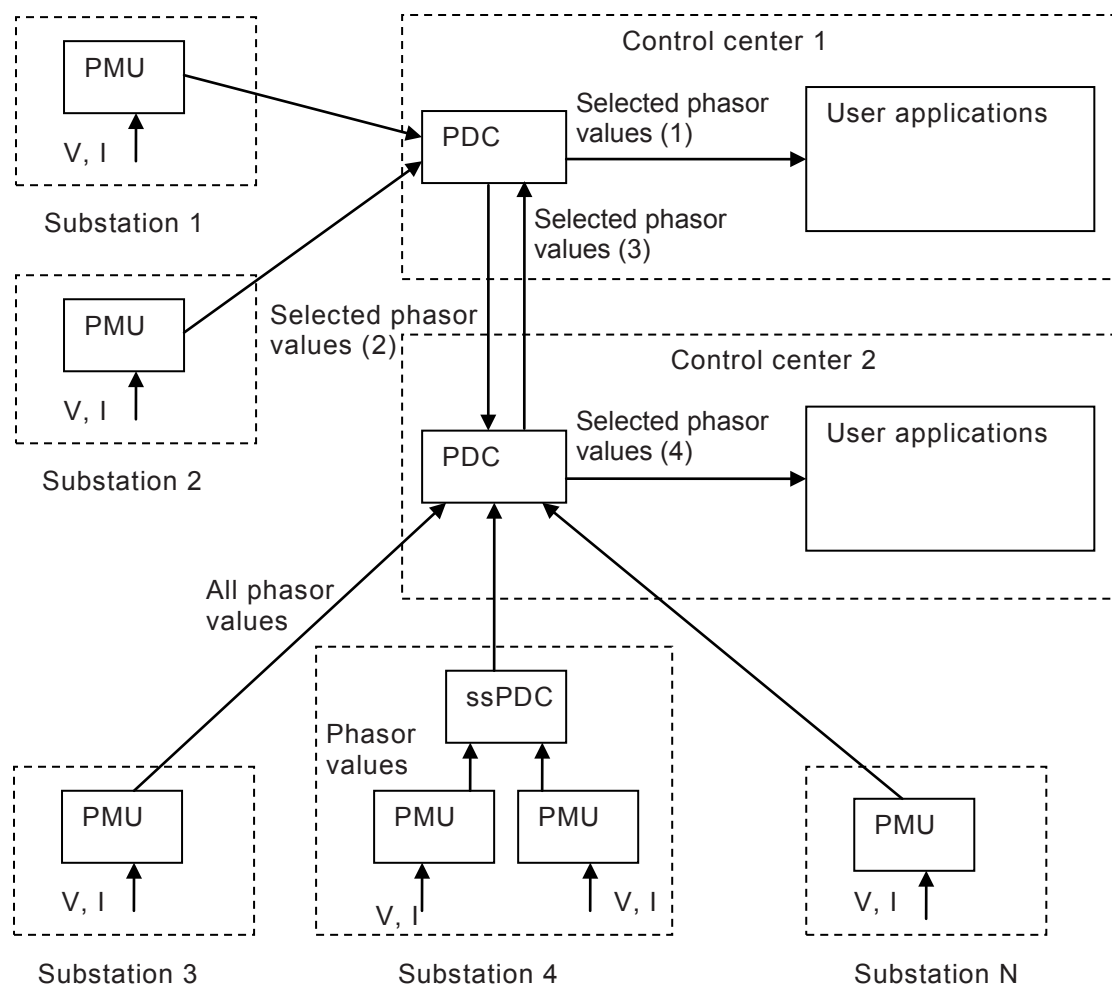
By performing communications protocol conversions per f), the PDC enables the integration of legacy data sources or user applications with communications systems based on IEC/TR 61850-90-5 or on other protocols, such as IEEE C37.118-2005. This conversion function thus supports migration towards exclusive use of IEC/TR 61850-90-5.

The use case diagram below shows how a PDC may publish more than one output stream. Furthermore, each output stream may have unique identification, synchrophasor data points listing, sampling rate, communications protocol, or security features configuration.

In the use case diagram and following description, as well as other use cases, show a Substation Phasor Data Concentrator (ssPDC) as a distinct functional entity. ssPDC is described in 6.4.2, as opposed to a PDC at a higher level of the hierarchy as described in 6.4.3. However, the ssPDC is just a specific instance of a PDC and may have any of the eight functions listed above included and enabled.

The general information flow is shown in Figure 11.

Use case diagram



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Figure 11 – Use case diagram for phasor data concentrator

Actors:

Name	Role description
PMU	Computes synchrophasor values, frequency, rate of change of frequency, and attaches related measurement and status points in a repetitive stream of output data messages in IEC/TR 61850-90-5 format as specified below, IEEE C37.118.2 format, or other message packet format.
ssPDC	Substation Phasor Data Concentrator - selects, validates, aggregates, and optionally decimates, interpolates, or time aligns data from multiple PMUs in the substation. Optionally converts data to and from IEC/TR 61850-90-5 as required by communications connections, secures data transfer, and calculates or scales derived data values. Special instance of PDC
PDC	Phasor Data Concentrator - selects, validates, aggregates, and optionally decimates, interpolates, or time aligns data from multiple PMUs or PDCs. Optionally converts data to and from IEC/TR 61850-90-5 as required by communications connections, secures data transfer, and calculates or scales derived data values
User applications	Receive collected data from the local PDC & perform various client functions listed in use cases below

Operations:

Name	Service or information provided
Data sampling & phasor estimate	PMU samples input values and computes synchrophasor values, frequency, and rate of change of frequency. PMU attaches related measurement and status points
Data origination & sending	PMU sends a repetitive stream of output data messages in IEC/TR 61850-90-5 format as specified below, IEEE C37.118.2 format, or other message packet format
Data receiving/sending	An ssPDC receives data from within the substation, combines it with data from other PMUs, and forwards merged output stream to the next destination PDC. A PDC receives data from PMUs, ssPDCs, or other PDCs. It selects, validates, aggregates, and optionally decimates, interpolates, or time aligns data from multiple PMUs or PDCs. Optionally it converts data to and from IEC/TR 61850-90-5 as required by communications connections, secures data transfer, and calculates or scales derived data values
Data receiving	A PDC receives data from PMUs, ssPDCs, or other PDCs. It selects, validates, aggregates, and optionally decimates, interpolates, time aligns data, or calculates or scales derived values from multiple PMUs or PDCs. PDC sends output streams to user applications
Data receiving – test mode	One or more input data streams are indicating test mode
Data sending – test mode	One or more output data streams are to be set to indicate test mode
Commissioning	PDC is turned on for the first time, or for the first time with a new configuration
Input change	The configuration of an input stream changes in a way that requires reconfiguration of an output stream
Input failure	PDC stops receiving one or more connected or subscribed data streams completely, or values of input stream have bad quality
Deenergization/energization or fail/replace	PDC is turned off for an arbitrary period and turned back on. Replacement of failed PDC by identically configured unit may occur during time off line. Consider effect of 1 min change flag in IEEE C37.118.2
Data receiving - user applications	Applications provide situational awareness, state estimation, on-line security assessment, display, data processing, alarming, archiving, wide area control, and specific protection or control functions

Basic flow:

Data origination & sending

Use case step	Description
Step 1	PMU measures V & I synchrophasors, power flows, frequency, rate of change of frequency, and other measurement and status points
Step 2	PMU computes data set at configured output rate
Step 3	PMU packages data set with appropriate status flags and time stamp
Step 4	PMU sends data sets to the ssPDC or PDC in a continuous stream and configured data communications protocol

Data receiving/sending – ssPDC

Use case step	Description
Step 1	ssPDC receives synchrophasor data streams from multiple PMU sources
Step 2	ssPDC converts communications protocol of each data input
Step 3	ssPDC validates, selects, combines, and merges data points into output stream
Step 4	ssPDC formats, secures, and sends output data to PDC

Data receiving/sending – PDC

Use case step	Description
Step 1	PDC receives synchrophasor data from multiple PMU, ssPDC, or PDC sources
Step 2	PDC converts communications protocol of each data input
Step 3	PDC validates, aligns, decimates or interpolates data inputs, computes or scales data values, and selects output data for each of multiple output streams
Step 4	PDC formats, secures, and publishes or sends one or more output data streams

Data receiving – test mode

Use case step	Description
Step 1	PDC or ssPDC receives synchrophasor data from multiple PMU, ssPDC, or PDC sources
Step 2	PDC converts communications protocol of each data input
Step 3	PDC determines test mode value for each dataset in each input stream
Step 4	PDC validates, aligns, decimates or interpolates data inputs, calculates or scales values in consideration of test modes, and selects output data for each of multiple output streams
Step 5	PDC maps test mode values as configured to each dataset in each output stream.
Step 6	PDC formats, secures, and publishes or sends one or more output data streams

Data sending – test mode

Use case step	Description
Step 1	PDC receives synchrophasor data from multiple PMU, ssPDC, or PDC sources
Step 2	ssPDC converts communications protocol of each data input
Step 3	ssPDC validates, aligns, decimates or interpolates data inputs, calculates or scales values, and selects output data for each of multiple output streams
Step 4	PDC maps local test mode value to each dataset in each output stream
Step 5	PDC formats, secures, and publishes or sends one or more output data streams

Commissioning

Use case step	Description
Step 1	PDC is configured while off line
Step 2	PDC is energized and applies current input configuration
Step 3	PDC converts communications protocol of each data input
Step 4	PDC validates configuration and ConfRev of each input
Step 5	PDC commences receiving/sending with test modes as selected in PDC or inputs, and with appropriate ConfRev

Input change

Use case step	Description
Step 1	PDC detects change of configuration and ConfRev of each input. A change may be an expected event in an intentional local or wide area updating process, or may be due to a configuration error
Step 2	PDC marks bad quality for changed output data, and inserts null data if source data cannot be identified
Step 3	PDC generates local alarm output until its configuration is updated to recognize new ConfRev of inputs

Input failure

Use case step	Description
Step 1	One or multiple received or subscribed input streams ceases
Step 2	PDC maps bad quality indications to appropriate output message status objects
Step 3	PDC inserts null values as required in output streams
Step 4	PDC generates local alarm output until input stream is restored

Deenergization/reenergization or fail/replace

Use case step	Description
Step 1	PDC is deenergized
Step 2	PDC is reenergized.
Step 3	PDC validates that its own configuration has not changed
Step 4	PDC converts communications protocol of each data input
Step 5	PDC validates configuration and ConfRev of each input
Step 6	PDC commences receiving/sending with test modes as selected in PDC or inputs, and with appropriate ConfRev. Consider effect of one minute change flag in IEEE C37.118.2

Data receiving – user applications

Use case step	Description
Step 1	User application receives or subscribes to data stream from PDC
Step 2	User application processes synchrophasor data according to specific use cases for respective applications
Step 3	User application processes test modes and quality values in data stream from PDC to yield appropriate outputs or constrained behavior

Constraints:

Synchrophasor measurements can be communicated to and from PDCs at a variety of sampling rates from once every number of minutes to 100 or 120 measurements per second. The measurements may conform to standards such as IEEE C37.118-2005, C37.118.1-2011, or IEC/IEEE 60255-118-1. PDCs are connected in hierarchical architectures in which transfer time delays may accumulate as values pass to applications. The following table presents minimum requirements. The user application installer must ensure that individual PMU delays and errors, as well as the accumulated delays and errors for a sequence of PDCs, are compatible with the requirements of the application. Note that PDCs should be designed not to degrade the accuracy of time stamps applied at the PMU, or the time synchronization accuracy class.

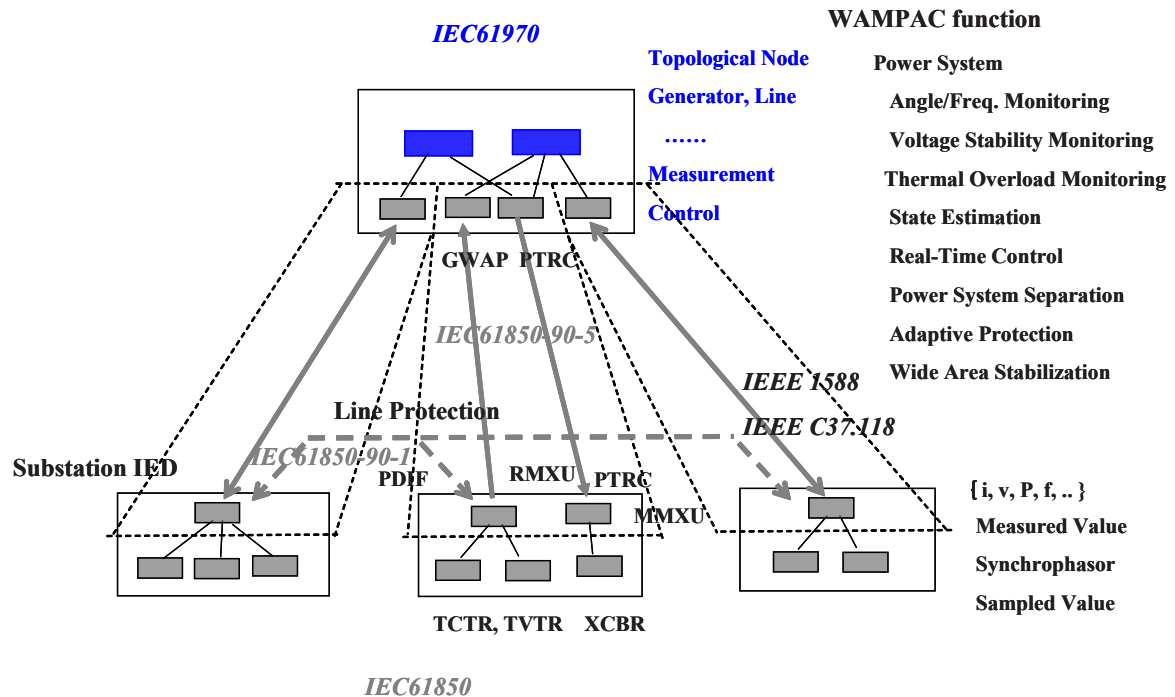
Requirement	Performance class	Transfer time class	Time synchronization accuracy class
Delay acceptable for protection functions	P13	TT6 < 3 ms	T3 < 0,025 ms
Delay acceptable for other functions	P14	TT5 < 10 ms	T3 < 0,025 ms

6 Modelling considerations

6.1 General

To describe a system in IEC 61850, each client and server needs to be modelled as a logical node on some IED. In the case of substation internal synchrophasor applications, probably existing logical nodes can be used, like RSYN for the synchrocheck function and PPAM for generator out-of-step protection. In case that the application itself is outside the IEC 61850 scope, e.g. for pure monitoring and archiving purpose, the ITMI, IHMI or IARC logical nodes can be used. In case any controls are done with classical client server services like Operate, the ITCI logical node can be used as for a network control center. However, there are some wide area control and frequency stability applications, where controls must be given in a time scale for which the classical Operate method might be too slow, so that UDP based GOOSE needs to be used. In this case, a logical node is needed which is able to produce data which can be packed into a GOOSE (command) message. The current IEC 61850-7-4 foresees for this purpose the GAPC logical node. However, to support a better semantic description, e.g. for automated engineering, it might be worthwhile to introduce e.g. generic WAC logical node (e.g. GWAC or CWAN) and a generic WAP logical node (e.g. GWAP or PWAN). In special cases, even the definition of application specific logical nodes might be worthwhile. This needs a more detailed analysis of function implementation and needs to be decided later on a per application base.

A basic logical node based architecture is illustrated in Figure 12.



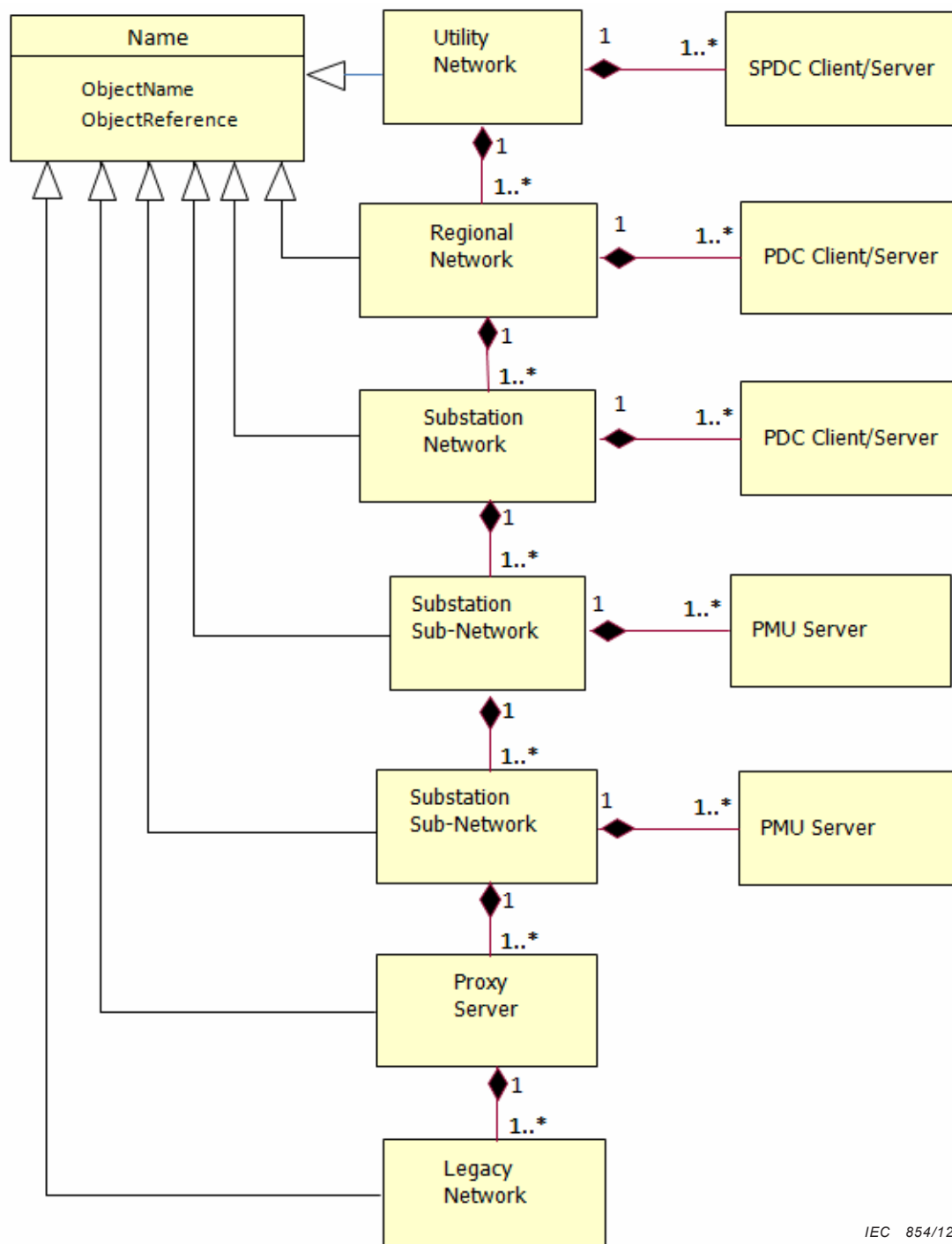
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Figure 12 – Basic IEC 61850 model of WAMPAC functions

The following subclauses provide modelling guidance for synchrophasor based devices including PMUs and PDCs.

6.2 System hierarchy

Protection, monitoring and control systems that use synchrophasors are complex hierarchical systems with PMUs at the bottom of the hierarchy and PDCs at the different levels of the hierarchy as shown in Figure 13.



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Figure 13 – System hierarchy

6.3 PMU model

The PMU is a function within an IED which is responsible for the calculation and publishing of synchrophasor measurements as defined in IEEE C37.118.1.

These calculations are based on sampled values produced by the analog input module within the IED containing the PMU function or based on streaming sampled values produced by one or more merging units in the substation that the IED containing the PMU function is subscribing to.

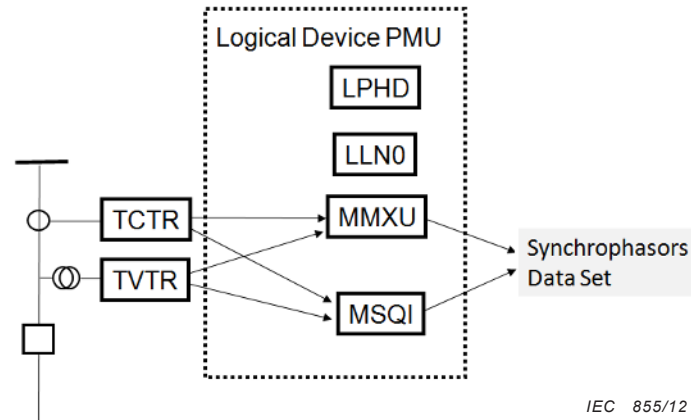


Figure 14 – PMU object model

If the PMU is publishing phase currents and voltages, one or more instances of MMXU will be used as shown in Figure 14.

If the PMU is publishing sequence currents and voltages, one or more instances of MSQI will be used.

6.4 Phasor Data Concentrators (PDCs)

6.4.1 General

There are several recognized deployment options for PDCs: Substation and Regional. The following subclauses give guidance of the modelling of these entities.

6.4.2 Substation PDC model

The substation Phasor Data Concentrator (PDC) is a function that receives over the substation LAN data from multiple PMUs in the substation. The received data are sorted by their time-tags and provided to other applications to use them. If necessary, the PDC may need to perform re-sampling in order to align measurements from devices using different publishing rates.

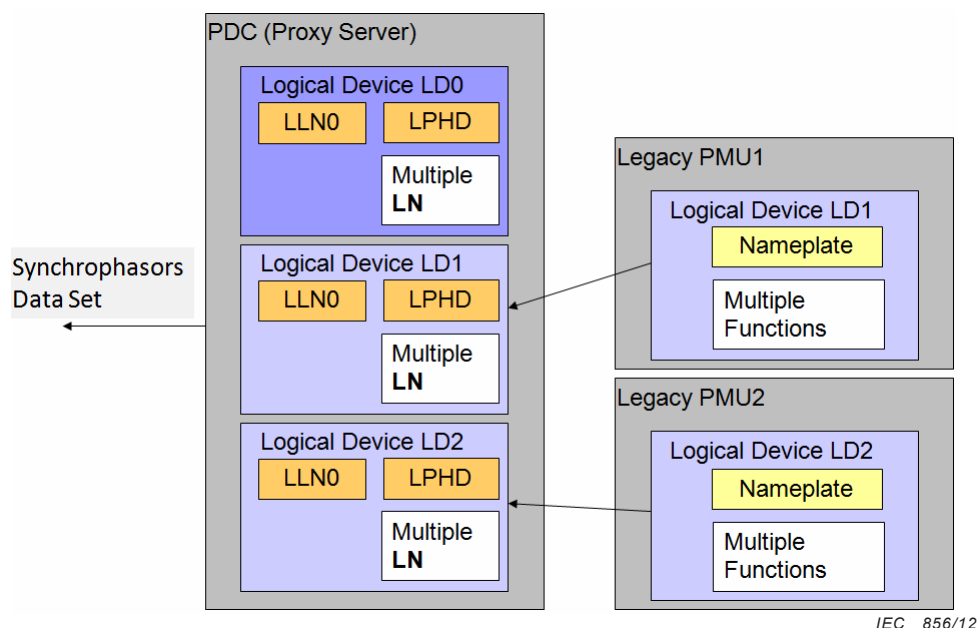


Figure 15 – Substation PDC model with legacy PMUs

A data set containing a representative set of data as required by the upper levels of the system hierarchy is created and published over a wide area interface using UDP multicast.

It is recommended to model the PDC function as a PDC logical device with the Proxy data object in logical node LPHD *Proxy* set to *True*.

The PDC model is based on the nesting of logical devices as defined in IEC 61850-7-1. An example of a possible hierarchy is shown in Figure 15.

6.4.3 Regional or system level PDC

The Regional level Phasor Data Concentrator (PDC) is a function that receives over the wide area network data from multiple PDCs in different substations. The received data are sorted by their time-tags and provided to other applications to use them. If necessary, the PDC may need to perform re-sampling in order to align measurements from devices using different publishing rates.

A data set containing a representative set of data as required by the upper levels of the system hierarchy is created and published over a wide area interface using UDP multicast.

It is recommended to model the PDC function as a PDC logical device with the Proxy data object in logical node LPHD *Proxy* set to *True*.

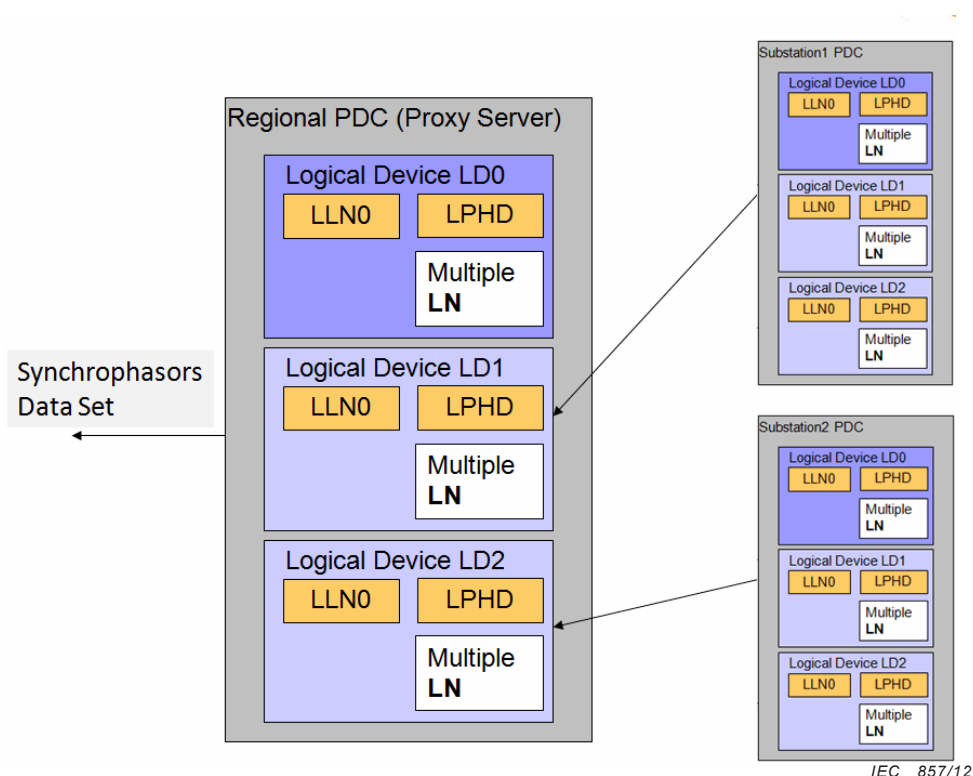


Figure 16 – Regional PDC object model

The Regional PDC model, shown in Figure 16, is based on the nesting of logical devices defined in IEC 61850-7-1.

6.4.4 Quality

Data that have been re-sampled or interpolated shall set their “substituted” quality bit set.