

Communication networks and systems in substations —

Part 5: Communication requirements for functions and device models

The European Standard EN 61850-5:2003 has the status of a
British Standard

ICS 33.200

National foreword

This British Standard is the official English language version of EN 61850-5:2003. It is identical with IEC 61850-5:2003.

The UK participation in its preparation was entrusted to Technical Committee PEL/57, Power system control and associated communications, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 131, and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 28 November 2003

© BSI 28 November 2003

ISBN 0 580 42988 1

Amendments issued since publication

Amd. No.	Date	Comments

Communication networks and systems in substations
Part 5: Communication requirements for functions and device models
(IEC 61850-5:2003)

Réseaux et systèmes de communication
dans les postes
Partie 5 : Prescriptions relatives
à la communication pour les fonctions
et les modèles de dispositifs
(CEI 61850-5:2003)

Kommunikationsnetze und -systeme
in Stationen
Teil 5: Kommunikationsanforderungen
für Funktionen und Gerätemodelle
(IEC 61850-5:2003)

This European Standard was approved by CENELEC on 2003-10-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Lithuania, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

The text of document 57/641/FDIS, future edition 1 of IEC 61850-5, prepared by IEC TC 57, Power system control and associated communications, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61850-5 on 2003-10-01.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2004-07-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2006-10-01

Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, annex ZA is normative and annexes A to J are informative.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61850-5:2003 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INTRODUCTION.....	7
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	9
4 Abbreviations	12
5 Substation automation system functions	13
5.1 Introduction	13
5.2 Logical allocation of functions and interfaces.....	13
5.3 The physical allocation of functions and interfaces	15
5.4 The role of interfaces	15
6 Goal and requirements	16
6.1 Interoperability	16
6.2 Static design requirements	16
6.3 Dynamic interaction requirements	16
6.4 Response behavior requirements	17
6.5 Approach to interoperability.....	17
6.6 Conformance test requirements.....	17
7 Rules for function definition	17
7.1 Function description	18
7.2 Logical Node description	18
7.3 PICOM description	18
8 Categories of functions.....	18
8.1 System support functions	18
8.2 System configuration or maintenance functions.....	18
8.3 Operational or control functions.....	19
8.4 Local process automation functions.....	19
8.5 Distributed automatic support functions	19
8.6 Distributed process automation functions	19
9 The logical node concept.....	19
9.1 Logical nodes and logical connections.....	19
9.2 The need for a formal system description	20
9.3 Requirements for logical node behavior.....	21
9.4 Examples for decomposition of common functions into logical nodes.....	21
10 The PICOM concept	22
10.1 Attributes of PICOMS	23
10.2 PICOMs and data models.....	24
11 List of logical nodes.....	24
11.1 Logical Nodes for protection functions	25
11.2 Logical Nodes for control.....	30
11.3 Physical device	33
11.4 System and device security	33
11.5 LNs related to primary equipment.....	33
11.6 LNs related to system services	33

12	The application of LN (informative)	36
12.1	Basic principles	36
12.2	Basic examples	37
12.3	Additional examples	38
12.4	Remarks on modeling	41
13	Message performance requirements	42
13.1	Introduction	42
13.2	Basic time requirements	42
13.3	Event time definition	43
13.4	Transfer time definition	43
13.5	The introduction and use of message types	44
13.6	The introduction and use of performance classes	44
13.7	Message types and performance classes	45
14	Requirements for data integrity	48
15	System performance requirements	48
15.1	Introduction	48
15.2	Calculation methods	49
15.3	Calculation results	50
15.4	Summary	50
16	Additional requirements for the data model	51
16.1	Requirements for the addressing of logical nodes	51
16.2	Requirements for the data model	51
	Annex A (informative) Logical nodes and related PICOMs	52
	Annex B (informative) PICOM identification and message classification	66
	Annex C (informative) Communication optimization	73
	Annex D (informative) Rules for function definition	74
	Annex E (informative) Interaction of functions and logical nodes	76
	Annex F (informative) Categories of functions	77
	Annex G (informative) Functions	79
	Annex H (informative) Results from the function description	104
	Annex I (informative) Performance calculations	110
	Annex J (informative) Examples for protection functions in compensated networks	128
	Annex ZA (normative) Normative references to international publications with their corresponding European publications	130
	Bibliography	131
	Figure 1 – Relative position of this part of the IEC 61850 series	7
	Figure 2 – Levels and logical interfaces in substation automation systems	14
	Figure 3 – The logical node and link concept	20
	Figure 4 – Examples of the application of the logical node concept	22
	Figure 5 – Protection function consisting of 3 logical nodes	24
	Figure 6 – The basic communication links of a logical node of main protection type	28

Figure 7 – Decomposition of functions into interacting LNs on different levels: examples for generic automatic function, breaker control function and voltage control function	37
Figure 8 – Decomposition of functions into interacting LN on different levels: examples for generic function with telecontrol interface, protection function and measuring/metering function	37
Figure 9 – Example for control and protection LNs of a transformer bay combined in one physical device (some kind of maximum allocation).....	38
Figure 10 – Example for interaction of LNs for switchgear control, interlocking, synchrocheck, autoreclosure and protection	38
Figure 11 – Example for sequential interacting of LNs (local and remote) for a complex function such as point-on-wave switching – Sequence view	39
Figure 12 – Example for functional interacting of LNs (local and remote) for a complex function such as point-on-wave switching – Architecture view	39
Figure 13 – Example for automatic tap changer control for voltage regulation	40
Figure 14 – Circuit breaker controllable per phase (one instance of XCBR per phase) and instrument transformers with measuring units per phase (one instance of TCTR or TVTR per phase)	40
Figure 15 – Distributed busbar protection (LN instances of PBDF for central unit and for units per bay - left) and interlocking (LN instance of CILO) on bay level per switch/circuit breaker (right).....	41
Figure 16 – Definition of overall transfer time.....	44
Figure I.1 – T1-1 small size transmission substation/ D2-1 medium size distribution substation.....	110
Figure I.2 – T1-2 small size transmission substation with one and a half breaker scheme/T2-2 large size transmission substation with ring bus.....	111
Figure I.3 – Substation of type T1-1 with allocation functions	113
Figure I.4 – Substation of type D2-1 with allocated functions	114
Figure I.5 – Substation of type T1-2 (functions allocated in the same way as for T2-2 in Figure I.6)	115
Figure I.6 – Substation of type T2-2 with allocated functions.....	116
Figure I.7 – Large transmission substation with a ring similar to type T2-2 (function allocation described in Clause I.2)	117
Figure I.8 – Large transmission substation with a ring similar to T2-2 (function allocation see text below)	118
Figure I.9 – Ethernet configuration with shared hub	127
Figure I.10 – Ethernet configuration with switched hubs.....	127
Figure J.1 – The transient earth fault in a compensated network.....	128
Figure J.2 – Short term bypass for single earth fault in compensated networks.....	129
Figure J.3 – The double earth fault in compensated networks	129
Table 1 – Raw data for protection and control.....	46
Table 2 – Raw data for metering	47
Table A.1 – PICOM groups	52
Table A.2 – Logical node list.....	52
Table B.1 – Identification and type allocation of PICOMs – Part 1	67
Table B.2 – Identification and type allocation of PICOMs – Part 2	68
Table B.3 – Identification and type allocation of PICOMs – Part 3	69
Table B.4 – Identification and type allocation of PICOMs – Part 4	70

Table B.5 – PICOM types – Part 1	71
Table B.6 – PICOM types – Part 2	72
Table H.1 – Function-function interaction – Part 1	104
Table H.2 – Function-function interaction – Part 2	105
Table H.3 – Function decomposition into Logical Nodes – Part 1	106
Table H.4 – Function decomposition into Logical Nodes – Part 2	107
Table H.5 – Function decomposition into Logical Nodes – Part 3	108
Table H.6 – Function decomposition into Logical Nodes – Part 4	109
Table I.1 – Definition of the configuration of all substations evaluated	111
Table I.2 – Overview of the main results of the performed calculations based on one common bus system covering all interfaces excluding interface 2 and 9	112
Table I.3 – Results for the substation T1-1	113
Table I.4 – Results for the substation D2-1	114
Table I.5 – Results for the substation T1-2	115
Table I.6 – Results for the substation T1-2	116
Table I.7 – Results for the substation according to Figure I.7 (function allocation described in Clause I.2)	117
Table I.8 – 138 kV affected (faulted) lines and related messages	120
Table I.9 – Message delays of 38 – 256 byte multicast messages on a shared hub network	121
Table I.10 – Message delays of 38 messages on a switched hub network	121
Table I.11 – Message delays of a variable number of messages on a shared hub network	122
Table I.12 – Message delays of a variable number of messages on a switched hub network	122
Table I.13 – Summary table	123
Table I.14 – 138 kV affected lines	124
Table I.15 – 138 kV unaffected lines (per line)	124
Table I.16 – Total 138 kV lines	124
Table I.17 – 345 kV affected lines/per line/per relay system – Relay 1	125
Table I.18 – 345 kV affected lines/per line/per relay system – Relay 2	125
Table I.19 – 345 kV affected lines/per line/system communications	125
Table I.20 – 345 kV affected lines	126
Table I.21 – 345 kV unaffected lines/per line	126
Table I.22 – Total 345 kV lines	126
Table I.23 – Total LAN	126

INTRODUCTION

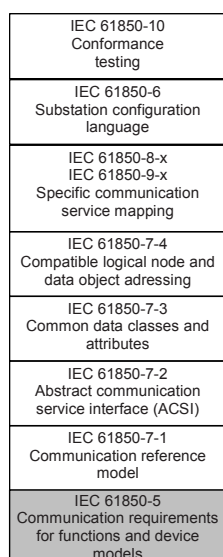
The IEC 61850 series is intended to provide interoperability between all devices in substations. Communication between these devices has to fulfil a lot of requirements imposed by all the functions to be performed in substations. Depending on the philosophy both of the vendor and of the user and on the state-of-the-art in technology, the allocation of functions to devices and control levels is not commonly fixed. This results in different requirements for the different communication interfaces within the substation. The IEC 61850 series shall support any allocation of functions.

The IEC 61850 series should have a long lifetime but be able to follow the fast changes in communication technology by both its technical approach and its document structure. Figure 1 shows the relationship of this part of the IEC 61850 series to subsequent parts of the IEC 61850 series. The IEC 61850 series has been organized so that changes to one part do not require a significant rewriting of another part, i.e. the parts are based on the communication requirements in this part of the IEC 61850 series; the derived modelling requirements in subsequent parts will not change the requirements of this part of the IEC 61850 series. The general parts, the requirement specification and the modelling parts are independent from any implementation. The implementation needed for the use of the IEC 61850 series is defined in some dedicated parts.

This part of the IEC 61850 series defines the communication requirements for functions and device models for substations.

The modelling of communication requires the definition of objects (for example, data objects, data sets, report control, log control) and services provided by objects (for example, get, set, report, create, delete). This is defined in IEC 61850-7-x with a clear interface to implementation. To use the benefits of communication technology, in the IEC 61850 series, no new OSI stacks are defined but a standardized mapping on existing stacks is given in IEC 61850-8-x and IEC 61850-9-x. A substation configuration language (IEC 61850-6) and a standardized conformance testing complement the IEC 61850 series. Figure 1 shows the general structure of the documents of the IEC 61850 series, as well as the relative position of IEC 61850-5 within this series.

NOTE To keep the layered approach of the IEC 61850 series which does not mix application and implementation requirements, terms such as client, server, data objects, etc. are normally not used in this part of the IEC 61850 series (requirements). In IEC 61850-7-x (modeling), IEC 61850-8-x and IEC 61850-9-x (specific communication service mapping) terms belonging to application requirements such as PICOMs are normally not used.



IEC 1903/03

Figure 1 – Relative position of this part of the IEC 61850 series

COMMUNICATION NETWORKS AND SYSTEMS IN SUBSTATIONS –

Part 5: Communication requirements for functions and device models

1 Scope

This part of IEC 61850 applies to Substation Automation Systems (SAS). It standardizes the communication between intelligent electronic devices (IEDs) and the related system requirements.

The specifications of this part refer to the communication requirements of the functions being performed in the substation automation system and to device models. All known functions and their communication requirements are identified.

The description of the functions is not used to standardize the functions, but to identify communication requirements between technical services and the substation, and communication requirements between Intelligent Electronic Devices within the substation. The basic goal is interoperability for all interactions.

Standardizing functions and their implementation is completely outside the scope of this part of IEC 61850. Therefore, a single philosophy for allocating functions to devices cannot be assumed in the IEC 61850 series. To support the resulting request for free allocation of functions, a proper breakdown of functions into parts relevant for communication is defined. The exchanged data and their required performance are defined. These definitions are supplemented by informative data flow calculations for typical substation configurations.

Intelligent electronic devices from substations such as protective devices are also found in other installations such as power plants. Using this part of IEC 61850 for such devices in these plants also would facilitate the system integration but this is beyond the scope of this part of IEC 61850.

2 Normative references

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

IEC 60044-8, *Instrument transformers – Part 8: Electronic current transformers*

IEC 60870-4, *Telecontrol equipment and systems – Part 4: Performance requirements*

IEC 61346 (all parts), *Industrial systems, installations and equipment and industrial products – Structuring principles and reference designations*

IEC 61850-2, *Communication networks and system in substations – Part 2: Glossary*¹

IEC 62053-22, *Electricity metering equipment (a.c.) – Particular Requirements – Part 22: Static meters for active energy (classes 0,2 S and 0,5 S)*

¹ To be published.

IEEE Std C37.2:1996, *IEEE Standard Electrical Power System Device Function Numbers and Contact Designations*

NOTE Informative references are found in the Bibliography.

3 Terms and definitions

For the purpose of this part of IEC 61850, the following terms and definitions as well as those given in IEC 61850-22, apply.

3.1 function

task which is performed by the substation automation system. Generally, a function consists of subparts called logical nodes, which exchange data with each other. By definition, only logical nodes exchange data and, therefore, a function that exchanges data with other functions must have at least one logical node. As a consequence, only data contained in logical nodes can be exchanged in the context of the IEC 61850 series.

3.2 distributed function

function which is performed in two or more logical nodes that are located in different physical devices. Since all functions communicate in some way, the definition of a local or a distributed function is not unique but depends on the definition of the functional steps to be performed until the function is completed. In case of the loss of one LN or one related communication link, the function may be blocked completely or show a graceful degradation, if applicable.

3.3 system

set of interacting entities which perform a common functionality. Its backbone is some communication mechanism.

3.3.1 logical system

communicating (via its logical nodes) set of all application functions performing some overall task such as “management of a substation” in the context of IEC 61850

3.3.2 physical system

interaction set of all devices hosting these functions and the interconnecting physical communication network. The boundary of a system is given by its logical or physical interfaces. Examples are industrial systems, management systems, information systems, and within the scope of the IEC 61850 series, substation automation systems. The backbone of physical system is its communication system.

3.3.3 substation automation system

system which operates, protects, monitors, etc. the substation, i.e. the primary system. For this purpose, it uses fully numerical technology and serial communication links (communication system).

3.3.4 primary system

common term for all power system equipment and switchgear

² To be published.

3.3.5

secondary system

interaction set of all components and systems in the substation for operation, protection, monitoring, etc, i.e. the primary system. In case of full application of numerical technology, the secondary system is synonymous with the substation automation system.

3.3.6

communication system

interconnected set of all communication links

3.4

device

mechanism or piece of equipment designed to serve a purpose or perform a function, for example a breaker, relay, or substation computer. Communication relevant properties are described in a proper device related model.

3.4.1

intelligent electronic device

is any device incorporating one or more processors with the capability to receive or send data/control from or to an external source, for example electronic multifunction meters, digital relays, controllers. An entity capable of executing the behavior of one or more specified logical nodes in a particular context and delimited by its interfaces. If not stated otherwise intelligent electronic devices have an internal clock by definition providing for example time tags. This adds the requirement of a system wide time synchronization of all these clocks if applicable.

3.4.2

physical device

equivalent to an intelligent electronic device as used in the context of the IEC 61850 series

3.5

Logical Node

LN

smallest part of a function that exchanges data. A Logical Node (LN) represents the function within a physical device; it performs some operations for that function. A LN is an object defined by its data and methods. Logical nodes related to primary equipment are not the primary equipment itself but its intelligent part or image in the secondary system, i.e. local or remote I/Os, intelligent sensors and actuators, etc.

3.6

connection

the links between entities

3.6.1

logical connection

communication link between logical nodes

3.6.2

physical connection

communication link between physical devices

3.7

interchangeability

the possibility to replace a device from the same vendor, or from different vendors, utilizing the same communication interface and as a minimum, providing the same functionality, and with no impact on the rest of the system. If differences in functionality are accepted, the exchange may also require some changes somewhere in the system. Interchangeability requires standardization of functions and, in a strong sense, of devices also. Both such requirements are outside the scope of the IEC 61850 series.

3.8 interoperability

ability of two or more intelligent electronic devices from the same vendor, or different vendors, to exchange information and use that information for correct co-operation. Interoperability is a prerequisite of interchangeability.

3.9 PICOM

Piece of Information for COMmunication describing an information transfer on a given logical connection with given communication attributes between two logical nodes. It also contains the information to be transmitted and, in addition, requirement attributes such as performance. It does not represent the actual structure and format for data that is exchanged over the communication network. This information is found in the parts IEC 61850-8 and IEC 61850-9. The assumed logical point-to-point connection describes the source and sink of this information transfer but does not prescribe the communication procedures. Therefore, multicast and broadcast procedures are not excluded.

NOTE The PICOM approach was adopted from CIGRE working group 34.03 (according to CIGRE – Technical Report, Ref.No.180) and allows for performance requirements also.

3.10 bay

closely connected subparts of the substation with some common functionality. Examples are the switchgear between an incoming or outgoing line and the busbar, the buscoupler with its circuit breaker and related isolators and earthing switches, the transformer with its related switchgear between the two busbars representing the two voltage levels, the diameter (see definition) in a 1½ breaker arrangement, virtual bays in ring arrangements (breaker and adjacent isolators), etc. These subparts very often comprise a device to be protected such as a transformer or a line end. The control of the switchgear in such a subpart has some common restrictions like mutual interlocking or well-defined operation sequences. The identification of such subparts is important for maintenance purposes (what parts may be switched off at the same time with a minimum impact on the rest of the substation) or for extension plans (what has to be added if a new line is linked in). These subparts are called “bays” and are managed by devices with the generic names “bay controller” and “bay protection”. The functionality of these devices represents an additional logical control level below the overall station level that is called “bay level”. Physically, this level must not exist in any substation; i.e. there may be no physical device “bay controller” at all.

3.11 diameter

applies to a 1½-breaker arrangement and comprises the complete switchgear between the two busbars, i.e. the 2 lines and the 3 circuit breakers with all related isolators, earthing switches, CTs and VTs. The diameter has some common functional relationship both for operation, maintenance and extensions.

3.12 level functions

functions related to some control levels of the substation automation system

3.12.1 bay level functions

functions using mainly the data of one bay and acting mainly on the primary equipment of one bay. The definition of bay level functions considers some kind of a meaningful substructure in the primary substation (see 3.10) configuration and, related to this substructure, some local functionality or autonomy in the secondary system (substation automation). Examples for such functions are line protection or bay control. These functions communicate via the logical interface 3 within the bay level and via the logical interfaces 4 and 5 to the process level, i.e. with any kind of remote I/Os or intelligent sensors and actuators. Interfaces 4 and 5 may be hardwired also but hardwired interfaces are beyond the scope of the IEC 61850 series.

3.12.2**process level functions**

all functions interfacing to the process, i.e. basically binary and analogue I/O functions such as data acquisition (including sampling) and issuing of commands. These functions communicate via the logical interfaces 4 and 5 to the bay level.

3.12.3**station level functions**

refer to the substation as a whole. There are two classes of station level functions; i.e. process related station level functions and Interface related station level functions

3.12.4**process related station level functions**

functions using the data of more than one bay or of the complete substation and acting on the primary equipment of more than one bay or of the complete substation. Examples of such functions are station-wide interlocking, automatic sequencers or busbar protection. These functions communicate mainly via the logical interface 8.

3.12.5**interface related station level functions**

functions representing the interface of the SAS to the local station operator HMI (Human Machine Interface), to a remote control center TCI (telecontrol interface) or to the remote engineering workplace for monitoring and maintenance TMI (telemonitoring interface). These functions communicate via the logical interfaces 1 and 6 with the bay level and via the logical interface 7 and the remote control interface to the outside world. Logically, there is no difference if the HMI is local or remote. In the context of the substation at least a virtual interface for the SAS at the boundary of the substation exists. The same applies both for the TCI and TMI. These virtual interfaces may be realised in some implementations as proxy servers.

4 Abbreviations

GPS	Global Positioning System (time source)
HMI	Human Machine Interface
I/O	Input and Output contacts or channels (depending on context)
IED	Intelligent Electronic Device
IF	(Serial) Interface
LAN	Local Area Network
LC	Logical Connection
LN	Logical Node
MMS	Manufacturing Message Specification
NCC	Network Control Center
OSI	Open System Interconnection
PC	Physical Connection
PD	Physical Device
PICOM	Piece of Information for COMmunication
SAS	Substation Automation System
TCI	TeleControl Interface (for example, to NCC)
TMI	TeleMonitoring Interface (for example, to engineers workplace)

5 Substation automation system functions

5.1 Introduction

The functions of a substation automation system (SAS) refer to tasks, which have to be performed in the substation. These are functions to control, monitor and protect the equipment of the substation and its feeders. In addition, there exist functions, which are needed to maintain the SAS, i.e. for system configuration, communication management or software management.

5.2 Logical allocation of functions and interfaces

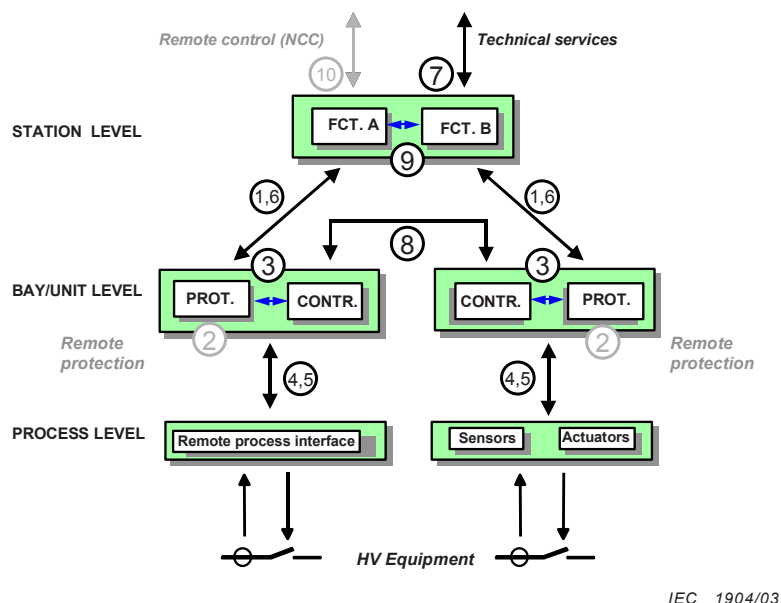
The functions of a substation automation system may be logically allocated on three different levels (station, bay/unit, or process). These levels are shown by the logical interpretation of Figure 2 together with the logical interfaces 1 to 10.

- a) *Process level functions* are all functions interfacing to the process. These functions communicate via the logical interfaces 4 and 5 to the bay level.
- b) *Bay level functions* (see bay definition in Clause 3) are functions using mainly the data of one bay and acting mainly on the primary equipment of one bay. These functions communicate via the logical interface 3 within the bay level and via the logical interfaces 4 and 5 to the process level, i.e. with any kind of remote I/Os or intelligent sensors and actuators. Interfaces 4 and 5 may also be hardwired, but hardwired interfaces are beyond the scope of the IEC 61850 series.
- c) There are two classes of *station level functions*:
 - 1) *Process related station level functions* are functions using the data of more than one bay or of the complete substation and acting on the primary equipment of more than one bay or of the complete substation. These functions communicate mainly via the logical interface 8.
 - 2) *Interface related station level functions* are functions representing the interface of the SAS to the local station operator HMI (Human Machine Interface), to a remote control center TCI (TeleControl Interface) or to the remote engineering for monitoring and maintenance TMI (TeleMonitoring Interface). These functions communicate via the logical interfaces 1 and 6 with the bay level and via the logical interface 7 and the remote control interface to the outside world.

NOTE 1 Interface 2 regarding remote protection (teleprotection) is outside the scope of this part of IEC 61850. Since the same kind of data is exchanged over this interface as within the substation, the future use of the IEC 61850 series is recommended.

NOTE 2 The remote control interface to the network control center (IF10) is outside the scope of this part of IEC 61850. The related IEC standards are IEC 60570-5-101 and IEC 60570-5-104. To reduce the efforts for the gateway to the NCC, a future alignment would be very convenient. Since partly the same data are exchanged between the control centers as between the substation and the NCC, a coordination with the related standard IEC 60870-6 (TASE2) is recommended. The standard should be used for a future seamless communication structure from the process level to the network control center. Since the use of interface 7 and the interface 10 may be overlapping, a co-ordination of the standards for both interfaces is recommended.

NOTE 3 Process level and bay level functions in particular may be found integrated in a single device without a physical separation. This does not change the logical structure but the physical implementation (see 5.3).



IEC 1904/03

Figure 2 – Levels and logical interfaces in substation automation systems

The meaning of the interfaces

- IF1: protection-data exchange between bay and station level
- IF2: protection-data exchange between bay level and remote protection (outside the scope of this part of IEC 61850)
- IF3: data exchange within bay level
- IF4: CT and VT instantaneous data exchange (especially samples) between process and bay level
- IF5: control-data exchange between process and bay level
- IF6: control-data exchange between bay and station level
- IF7: data exchange between substation (level) and a remote engineer's workplace
- IF8: direct data exchange between the bays especially for fast functions such as interlocking
- IF9: data exchange within station level
- IF10: control-data exchange between substation (devices) and a remote control center (outside the scope of this part of IEC 61850)

The devices of a substation automation system may be installed **physically** on different functional levels (station, bay, and process). This refers to the physical interpretation of Figure 2.

NOTE 4 The distribution of the functions in a communication environment may occur through the use of wide area network, local area network, and process bus technologies. The functions are not constrained to be deployed within/over any single communication technology.

- 1) *Process level devices* are typically remote process interfaces such as I/Os, intelligent sensors and actuators connected by a process bus as indicated in Figure 2.
- 2) *Bay level devices* consist of control, protection or monitoring units per bay.
- 3) *Station level devices* consist of the station computer with a database, the operator's workplace, interfaces for remote communication, etc.

5.3 The physical allocation of functions and interfaces

Despite of the similarity of logical and physical levels there is no unique way for mapping the logical function structure to the physical device structure. The mapping is dependent on availability and performance requirements, cost constraints, the state of the art in technology, etc.

The *station computer* may act as a client only with the basic HMI, TCI and TMI functions. All other station level functions may be distributed completely over the bay level devices. In this case, the interface 8 is the backbone of the system. On the other side, all station wide functions such as interlocking etc. may reside in the station computer acting now both as client and server. In this case, the interface 1 and 6 take over the complete functionality of interface 8. Many other solutions are possible.

The bay level functions may be implemented in dedicated *bay level devices* (protection unit, control unit, without or with redundancy) or in combined protection and control units. Some may be moved physically down to the process level supported by the free allocation of functions.

If there are no serial interfaces 4 and 5, the process level functions are implemented in the bay level devices. The realization of the serial interfaces 4 and 5 may include remote I/O devices only or intelligent sensors and actuators, which provide some bay level functionality on process level already.

The logical interfaces may be implemented as dedicated physical interfaces (plugs). Two or more may also be combined into a single common physical interface. In addition, these interfaces may be combined and implemented into one or more physical LANs. The requirements for these physical interfaces depend upon the allocation of functions to levels and devices.

5.4 The role of interfaces

Not all interfaces have to be present in a substation. This flexible approach covers both the retrofit of existing substations and the installation in new substations, at present and in the future.

The numbering of interfaces according to Figure 2 is helpful for the identification of the type of interfaces needed in substations and for data flow calculations.

The interface numbers allow the easy definition of the two important LANs or bus systems: Often, interfaces 1, 6, 3, 9, 8 are combined with the **station/interbay bus** since it connects both the station level with the bay level and the different bay level IEDs with each other. Interfaces 4 and 5 are combined with the **process bus**, which connects the bay level with the process level and the different process level IEDs with each other. Very often, the process bus is restricted to one single bay only. If the process bus is extended to other bays, it may also take over the role of interface 8, at least for raw data.

Interface 7 is dedicated for external communication with a remote monitoring center. It could also be realized by a direct interface to the station/interbay bus. Interface 2, dedicated to communication with a remote protection device and interface 10, dedicated to remote control are outside the scope of this part of IEC 61850 (see also NOTE 1 and NOTE 2 of 5.2).

According to the function allocation, the message types of Clause 13 based on communication performance requirements may be assigned to the different interfaces. The free allocation of functions means that such an assignment may not be common for all substation automation systems.

6 Goal and requirements

6.1 Interoperability

The goal of the IEC 61850 series is to provide interoperability between the IEDs from different suppliers or, more precisely, between functions to be performed in a substation but residing in equipment (physical devices) from different suppliers. Interchangeability is outside the scope of IEC 61850. Interchangeability needs in addition to the interoperability according to IEC 61850 also standardized functionality (see 3.1).

Interoperability for devices from different suppliers has the following aspects:

- a) the devices shall be connectable to a common bus with a common protocol (syntax);
- b) the devices shall understand the information provided by other devices (semantics);
- c) the devices shall together perform a common or joint function if applicable (distributed functions).

Since there are no constraints regarding system structure and data exchange, some static and dynamic requirements shall be fulfilled to provide interoperability.

6.2 Static design requirements

The goal of interoperability for any configuration results in the following requirements, which are not completely independent from each other:

- a) The free allocation of functions to devices shall be supported by the communication; i.e. communications must be able to permit any function to take place in any device. It does not mean that all devices must support all functions.
- b) The functions of the substation automation system (SAS) and their communication behavior shall be described device independent, i.e. with no reference to any implementation in IEDs.
- c) The functions shall be described only as far as necessary for the identification of the information to be exchanged.
- d) The interaction of device independent distributed functions shall be described by the logical interfaces in between. These logical interfaces may be freely allocated to physical interfaces or LANs for implementation.
- e) The functions used today and their communication requirements are well known but the IEC 61850 series shall be open also for communication requirements arising from future functions.

6.3 Dynamic interaction requirements

The goal of interoperability for any data exchange results in the following requirements, which are not completely independent from each other:

- a) The IEC 61850 series shall define generic information to be communicated and generic communication behavior of the functions to support planned and future functional extensions of the substation automation system. Extension rules shall be given.
- b) The information transfer data shall be defined with all related attributes (see PICOMs).
- c) The exchanged data shall carry all attributes for an unambiguous understanding of the receiver.
- d) The acceptable overall transfer time of exchanged data shall be defined and guaranteed in any situation.

6.4 Response behavior requirements

Since interoperability is also claimed for a proper running of functions, the reaction of the application in the receiving node has to be considered.

- a) The reaction of the receiving node has to fit into the overall requirement of the distributed function to be performed.
- b) The basic behavior of the functions in any degraded case, i.e. in case of erroneous messages, lost data by communication interrupts, resource limitations, out of range data, etc. has to be specified. This is important if the overall task cannot be closed successfully, for example if the remote node does not respond or react in a proper way.

These requirements are function related local issues and, therefore, outside the scope of the IEC 61850 series. But the requirement left for the IEC 61850 series is the provision of proper quality attributes to be transferred with the data under consideration.

6.5 Approach to interoperability

To approach interoperability, the functions to be performed in substations are identified and categorized according to their different communication requirements in the rest of this document. The requirements for its data exchange shall be clearly defined. The interoperability for freely allocated and distributed functions implies a proper decomposition of functions in communicating entities. The requested mutual understanding of devices from different suppliers results in a proper data and communication service model (IEC 61850-7-x). The mapping of this model to state-of-the-art communication stacks shall be defined unambiguously (IEC 61850-8-x and IEC 61850-9-x).

6.6 Conformance test requirements

Interoperability depends both on the device properties and the system design and engineering. Conformance tests shall be performed to verify that the communication behavior of a device as system component is compliant with the interoperability specification of IEC 61850. These tests specify what shall be applied on a device to check that the communication function is correctly performed with a complementary device. Also the pass criteria have to be well defined. Conformance tests may involve the use of various simulators to represent the context of the substation and of the communication network.

Definitions of the conformance tests will be given in IEC 61850-10.³

7 Rules for function definition

To get the communication requirements in a substation, an identification of all functions is necessary. The function description considers the LN and PICOM approach and consists of three steps:

- a) Function description including the decomposition into LNs.
- b) Logical node description including the exchanged PICOMs.
- c) PICOM description including the attributes.

Any identification of functions in substations will be incomplete, but the assumption is made that the identified functions cover in a very representative way all communication requirements in substations.

³ Under consideration.

7.1 Function description

The function description, given in Annex G, provides the following information

- a) Task of the function.
- b) Starting criteria for the function.
- c) Result or impact of the function.
- d) Performance of the function.
- e) Function decomposition.

NOTE This point describes how functions are decomposed using LNs and how many decomposition sets typically exist. This information is very important since the communication is based on interacting LNs.

- f) Interaction with other functions.

7.2 Logical Node description

The Logical Node description – given later in the body of this part of the IEC 61850 series – provides the following information:

- a) grouping according to their most common application area;
- b) short textual description of the functionality;
- c) IEEE device function number if applicable (for protection and some protection related logical nodes only);
- d) abbreviation/acronym used within the documents of the IEC 61850 series;
- e) relation between functions and logical nodes in tables (see Annex H) and in the function description (see Annex G);
- f) exchanged PICOMs described in tables (see Annex A).

7.3 PICOM description

The PICOM description – as given in Clause 10 – provides the following information:

- a) semantics;
- b) logical point-to-point connection;
- c) performance requirements;
- d) type of data.

8 Categories of functions

Different categories of functions are identified. Some functions may belong not only to the given category and its category allocation is only a convention. Only the functions are listed in the following Subclauses; the function description is given in Annex G.

8.1 System support functions

- a) Network management.
- b) Time synchronization.
- c) Physical device self-checking.

8.2 System configuration or maintenance functions

- a) Node identification.
- b) Software management.
- c) Configuration management.

- d) Operative mode control of Logical Nodes.
- e) Setting.
- f) Test mode.
- g) System security management.

8.3 Operational or control functions

- a) Access security management.
- b) Control.
- c) Operational use of spontaneous change of indications.
- d) Synchronous switching (point-on-wave switching).
- e) Parameter set switching.
- f) Alarm management.
- g) Event (management and) recording.
- h) Data retrieval.
- i) Disturbance/fault record retrieval.

8.4 Local process automation functions

- a) Protection function (generic).
- b) Distance protection (example of protection function).
- c) Bay interlocking.
- d) Measuring, metering and power quality monitoring.

8.5 Distributed automatic support functions

- a) Station-wide interlocking.
- b) Distributed synchrocheck.

8.6 Distributed process automation functions

- a) Breaker failure.
- b) Automatic protection adaptation (generic).
- c) Reverse blocking (For example, for automatic protection adaptation).
- d) Load shedding.
- e) Load restoration.
- f) Voltage and reactive power control.
- g) Infeed switchover and transformer change.
- h) Automatic switching sequences.

9 The logical node concept

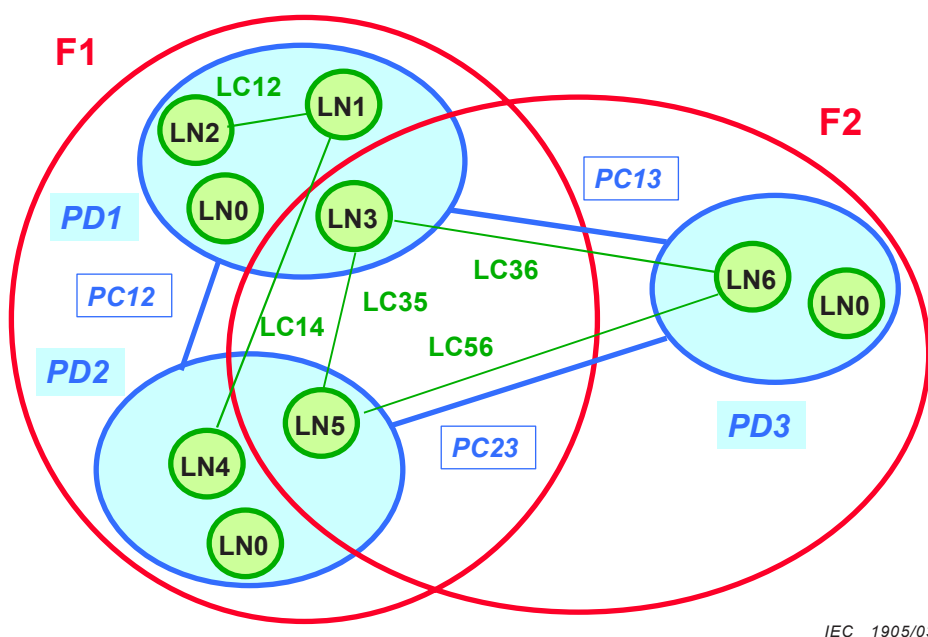
9.1 Logical nodes and logical connections

To fulfill all the requirements stated above, especially the free distribution and allocation of functions, all functions are decomposed into logical nodes (LN) that may reside in one or more physical devices. There are some data to be communicated which refer not to any function but to the physical device itself such as nameplate information or the result of device self-supervision. Therefore, a logical node “device” is needed and will be introduced as LN0.

The LNs are linked by logical connections (LC) for a dedicated exchange of data in between. Therefore, the IEC 61850 series shall define the communication between these LNs.

This approach is shown in Figure 3. The logical nodes (LN) are both allocated to functions (F) and physical devices (PD). The logical nodes are linked by logical connections (LC), the devices by physical connections (PC). Any logical node is part of a physical device; any logical connection is part of a physical connection. The logical node “device” dedicated for any physical device is displayed as LN0 (in the four letter code introduced in Figure 3 for all logical nodes, LLN0).

Since it is impossible to define all functions for present and future use, or their distribution and interaction, it is very important to specify and standardize the interaction between the logical nodes in a generic way.



See 9.1 for an explanation.

Figure 3 – The logical node and link concept

9.2 The need for a formal system description

The static structure of the communication system describes where the data are potentially coming from (sending LN) and going to (receiving LN). This structure has to be engineered or negotiated during the set-up phase of the system. Opening and closing communication channels dynamically at run time will always refer to the given static structure. To control the free allocation and to create interoperable systems, a strong formal device and system description for communication engineering shall be provided. Such a formal description (substation configuration language) is defined in IEC 61850-6⁴.

⁴ Under consideration.

9.3 Requirements for logical node behavior

Each receiving LN shall know what data are needed for performing its task; i.e. it shall be able to check if the delivered data are complete and valid and of the proper quality. In real-time systems such as substation automation, the most important validity criterion is the age of the data. The sending LN may set most quality attributes. The decision that data are “old” is the genuine task of the receiving LN. Missing or incomplete information is covered since in this case, no data with an acceptable age are available. Therefore, the requirements for communication providing interoperability between distributed LNs are reduced to the standardization of the data to be available or needed and the assignment of validity (quality) attributes in an appropriate data model as defined in IEC 61850-7-x.

The requirements mentioned above imply that the sending LN is also the source of the primary data, i.e. it keeps the most up-to-date values of these data, and that the receiving LN is processing these data for some related functionality. In case of mirrored data (data base image of the process, proxy server, etc.) these mirrored data shall be kept as up-to-date (“valid”) as needed by the function using these data.

In case of corrupted or lost data, the receiving LN cannot operate in a normal way, but may be in a degraded mode. Therefore, the behavior of the LN both in the normal and degraded mode has to be well defined, but the degradation behavior of the function has to be designed individually depending on the function and is beyond the scope of this part of IEC 61850. The other LNs of the distributed function and the system supervision shall also be informed about this degradation by a standardized message or proper data quality attributes, so that necessary actions are taken. If there is for example enough time, a request for sending valid data could also be sent out (retry). The detailed sequential behavior of the distributed functions cannot be standardized at all.

Examples of data based complex interoperability are the different interlocking algorithms (for example Boolean or topology based interlocking) which can be performed with the same data set (the position indications of the switchgear).

Since the Logical Node concept covers essential requirements in a consistent and comprehensive way, this concept itself is seen as a requirement, which shall be used in the detailed modeling given in IEC 61850-7-x.

9.4 Examples for decomposition of common functions into logical nodes

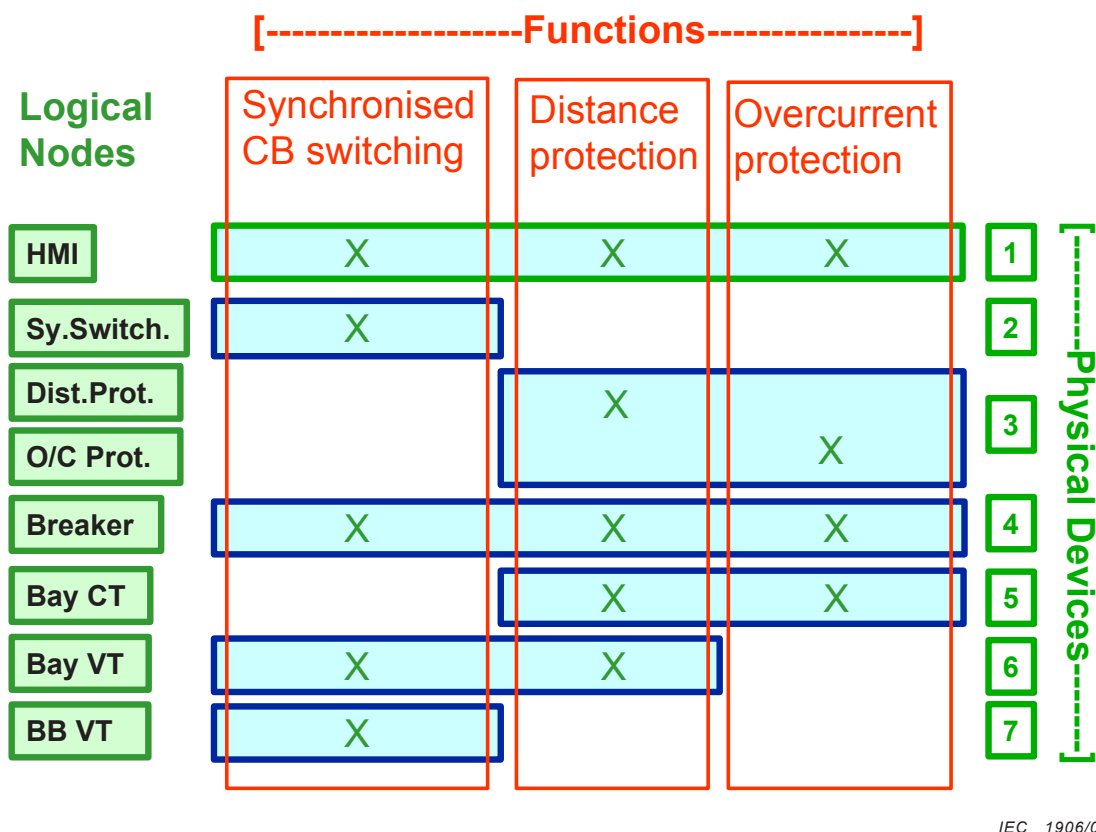
In Figure 4, there are examples of common functions given

- a) synchronized circuit breaker switching;
- b) distance protection;
- c) overcurrent protection.

The functions are decomposed into logical nodes listed in Figure 4, the allocated physical devices are described by numbers

- 1) Station computer.
- 2) Synchronized switching device.
- 3) Distance protection unit with integrated overcurrent function.
- 4) Bay control unit.
- 5) Current instrument transformer.
- 6) Voltage instrument transformer.
- 7) Busbar voltage instrument transformer.

The logical node “device” (LLN0) as contained in any physical device is not shown.



See 9.4 for explanations.

Figure 4 – Examples of the application of the logical node concept

10 The PICOM concept

PICOMs introduced by CIGRE WG34.03 (according to **CIGRE Technical Report, Ref.No.180**) are used to describe the information exchanged between LNs. The components or attributes of a PICOM are:

- a) Data, meaning the content of the information and its identification as needed by the functions (semantics).
- b) Type, describing the structure of the data, i.e. if it is an analog or a binary value, if it is a single value or a set of data, etc.
- c) Performance meaning the permissible transmission time (defined by performance class), the data integrity and the method or cause of transmission (for example periodic, event driven, on request).
- d) Logical connection, containing the logical source (sending logical node) and the logical sink (destination or receiving logical node).

NOTE PICOMs describe exchanged information (“content”) and communication requirements (“attributes”). The “bits on the wire” are found in the mappings, i.e. in IEC 61850-8-x and IEC 61850-9-x.

10.1 Attributes of PICOMS

There are three types of attributes defined by their purpose.

10.1.1 PICOM attributes to be covered by any message

- Value: value of the information itself if applicable.
- Name: for identification of the data.
- Source: the LN where the signal comes from.
- Sink: the LN where the signal goes to.
- Time tag: absolute time to identify the age of the data if applicable.
- Priority of transmission: to be used for:
 - LN input queues (if more than one);
 - LN input and output (re-transmission order) in case of intermediate LNs.
- Time requirements: cycle time or overall transfer time to check the validity with help of the time tag.

NOTE To specify the communication requirements, pairs of sources and sinks have to be identified. Sometimes, multicast and broadcast messages may be more convenient for the communication, but this is a matter of implementation.

10.1.2 PICOM attributes to be covered only at configuration time

- Value for transmission (see 10.1.1): test or default value if applicable.
- Attributes for transmission (see 10.1.1).
- Accuracy: classes or values.
- Tag information: if time tagged or not (most data will be time tagged for validation).
- Type: analog, binary, file, etc.
- Kind: alarm, event, status, command, etc.
- Importance: high, normal, low.
- Data integrity: the importance of the transmitted information for checks and retransmissions (details formulated as requirements, see Clause 14).

10.1.3 PICOM attributes to be used for data flow calculations only

- Value for transmission/configuration: (see 10.1.1): test or default value if applicable.
- Attributes for transmission/configuration: (see 10.1.1).
- Format: value type of the signal: I, UI, R, B, BS, BCD, etc.
- Length: the length: i bit, j byte, k word.
- State of operation: reference to scenarios.

NOTE Format and length are a matter of implementation and not a requirement. For data flow calculations, assumptions about these two attributes have to be made.

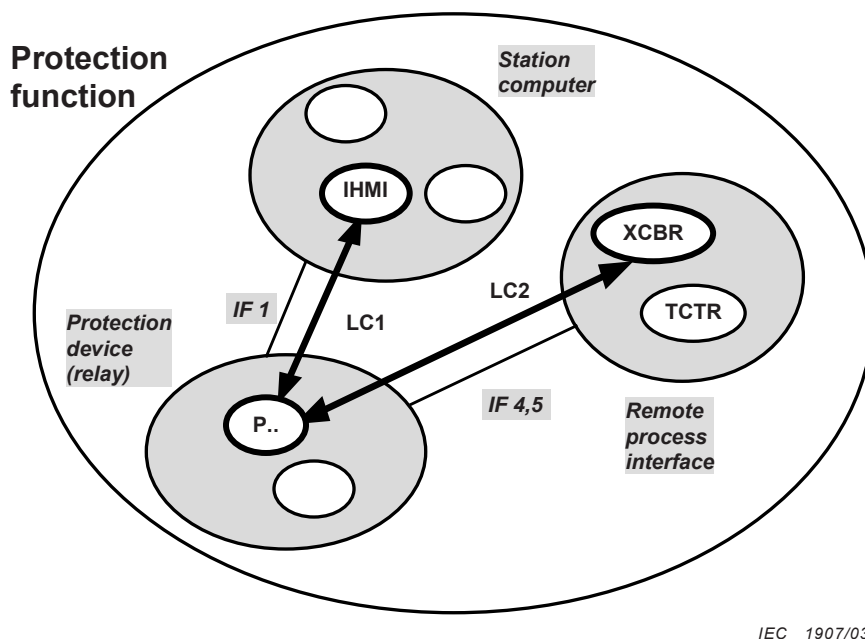
10.2 PICOMs and data models

The information exchange described by PICOMs is based on data which are provided by LNs. Very often, these data are defined in a data model for the source (see for example IEC 81850-7-4). The result is that in the data model, there shall exist at least one data (status and values) or one data change (event) per PICOM.

11 List of logical nodes

Most of the functions consist of a minimum of three logical nodes, i.e. the LN with the core functionality itself, the process interface LN and the HMI (Human-Machine Interface) LN meaning human access to the function. If there is no process bus, the LNs of the remote process interface are allocated to another physical device (in the example shown in Figure 5, the physical "Protection device").

If we call a function for example "protection function" we refer mostly to its core functionality only. Therefore, the function list given for example in CIGRE working group 34.03 (published as CIGRE Technical Report, Ref.No.180) is a list of logical nodes according to definitions in the IEC 61850 series. The standardization of functions in substations is not within the scope of the IEC 61850 series. But if any of these functions is used, its communication shall be based on the LN structure. All details needed to model the communication based on the Logical Nodes defined here are given and standardized in IEC 61850-7-x.



IEC 1907/03

Figure 5 – Protection function consisting of 3 logical nodes

The 3 logical nodes (IHMI = operator interface, P..=protection, XCBR=circuit breaker to be tripped) residing in 3 physical devices (station computer, protection device and remote process interface). The abbreviations for LN designation are the same as those introduced in the tables of Clause 11.

Table columns of Clause 11

Logical Node displays a short description of the task of the LN for common understanding. For full understanding the data to be exchanged have to be considered also.

IEC 61850 means abbreviations/acronyms with a systematic syntax used by the IEC 61850 series

IEEE C37.2-1996 means device function numbers and contact designations used in IEEE if applicable

Description or comments displays the description of the IEEE device number if applicable or/and other descriptive text.

Note that the reference to the IEEE device number does not mean the related devices, but rather its core functionality (see definition of LN and Figure 5) in the context of this part of IEC 61850.

11.1 Logical Nodes for protection functions

11.1.1 Protection

Logical Node	IEC 61850	IEEE C37.2-1996	Description or comments
Transient earthfault protection	PTEF		Transient earth faults happen if there is a fault to ground (isolation breakdown) in compensated networks. The fault disappears very fast since there is not sufficient current to feed it. No trip happens but the fault direction/location has to be detected to repair the faulted part. At least the degradation of the impacted line/cable is reported.
Zero speed and underspeed protection	PZSU	14	An underspeed device is a device that functions when the speed of a machine falls below a pre-determined value.
Distance protection	PDIS	21	A distance relay is a relay that functions when the circuit admittance, impedance, or reactance increases or decreases beyond a predetermined value. The change of the impedance seen by PDIS is caused by a fault. The impedance characteristic is a closed line set in the complex impedance plane. The reach of the distance protection is normally split into different zones (for example 1 to 4 forward and 1 backward) represented by dedicated characteristics.
Volt per Hz protection	PVPH	24	Voltage per Hertz relay is a relay that functions when the ratio of voltage to frequency exceeds a preset value. The relay may have an instantaneous or a time characteristic.
(Time) Undervoltage protection	PTUV	27	An undervoltage relay is a relay which operates when its input voltage is less than a predetermined value.
Directional power/reverse power protection	PDPR	32	A directional power relay is a relay which operates on a predetermined value of power flow in a given direction, or upon reverse power flow such as that resulting from the motoring of a generator upon loss of its prime mover.

Logical Node	IEC 61850	IEEE C37.2-1996	Description or comments
Directional earth fault protection for compensated networks based on wattmetric principle	PWDE	32	This directional power relay is a relay which operates on a predetermined value of earth fault power flow in a given direction in compensated networks. Depending on protection philosophy and quality of current transducers, it is used as a fault indication only or also for tripping (see Annex J).
Undercurrent/underpower protection	PUCP	37	Undercurrent or underpower relay is a relay that functions when the current or power flow decreases below a predetermined value.
Loss of field/Underexcitation protection	PUEX	40	Field relay is a relay that functions on a given or abnormal low value or failure of machine field current, or on an excessive value of reactive component of armature current in an AC machine indicating abnormal low field excitation Underexcitation results in under power.
Reverse phase or phase balance current protection	PPBR	46	Reverse-phase or phase-balance current relay is a relay that functions when the polyphase currents are of reverse-phase sequence, or when the polyphase currents are unbalanced or contain negative phase-sequence components above a given amount
Phase sequence or phase-balance voltage protection	PPBV	47	Phase-sequence or phase-balance voltage relay is a relay that functions upon a pre-determined value of polyphase voltage in the desired phase sequence or when the polyphase voltages are unbalanced, or when the negative phase-sequence voltage exceeds a given amount.
Motor start-up protection	PMSU	48, 49, 51, 66	By supervising the motor start-up, this protection prevents any overload of the motor.
Thermal overload protection	PTTR	49	Machine or transformer thermal relay is a relay that functions when the temperature of a machine armature winding or other load-carrying winding or element of a machine or power transformer exceeds a predetermined value.
Rotor thermal overload protection	PROL	49R	See above (49)
Stator thermal overload protection	PSOL	49S	See above (49)
Instantaneous overcurrent or rate of rise protection	PIOC	50	Instantaneous overcurrent or rate-of-rise relay is a relay that functions instantaneously on an excessive value of current or on an excessive rate of current rise.
AC time overcurrent protection	PTOC	51	AC time overcurrent relay is a relay when the AC input current exceeds a predetermined value, and in which the input current and operating time are inversely related through a substantial portion of the performance range.
Voltage controlled/dependent time overcurrent protection	PVOC	51V	See above (PTOC/51), with voltage control/dependency.
Power factor protection	PPFR	55	Power factor relay is a relay that operates when the power factor in an AC circuit rises above or falls below a predetermined value.
(Time) Overvoltage protection	PTOV	59	Overvoltage relay is a relay which operates when its input voltage is more than a predetermined value.
DC overvoltage protection	PDOV	59DC	See above (PTOV/59)

Logical Node	IEC 61850	IEEE C37.2-1996	Description or comments
Voltage or current balance protection	PVCB	60	Voltage or current balance relay is a relay that operates on a given difference on voltage, or current input or output, of two circuits.
Earth fault protection/Ground detection	PHIZ	64	Ground detector relay is a relay that operates on failure of machine or other apparatus insulation to ground.
Rotor earth fault protection	PREF	64R	See above (PHIZ/64).
Stator earth fault protection	PSEF	64S	See above (PHIZ/64).
Interturn fault protection	PITF	64W	See above (PHIZ/64).
AC directional overcurrent protection	PDOC	67	AC directional overcurrent relay is a relay that functions on a desired value of AC overcurrent flowing in a predetermined direction.
Directional earth fault protection	PDEF	67N	See above (PDOC/67).
DC time overcurrent protection	PDCO	76	DC overcurrent relay is a relay that functions when the current in a DC circuit exceeds a given value.
Phase angle or out-of-step protection	PPAM	78	Phase-angle measuring or out-of-step protective relay is a relay that functions at a predetermined phase angle between two voltages or between two currents or between voltage and current.
Frequency protection	PFRQ	81	Frequency relay is a relay that responds to the frequency of an electric quantity, operating when the frequency or change of frequency exceeds or is less than a predetermined value.
Differential protection	PDIF	87	Differential protective relay is a protective relay that functions on a percentage or phase angle or other quantitative difference of two currents or some other electrical quantities.
Phase comparison protection	PPDF	87P	See above (PDIF/87).
Differential line protection ¹	PLDF	87L	See above (PDIF/87).
Restricted earth fault protection	PNDF	87N	See above (PDIF/87).
Differential transformer protection	PTDF	87T	See above (PDIF/87): Special for transformers are inrush currents with dominant third harmonic which have to be considered by the differential transformer protection.
Busbar protection ²	PBDF	87B	See above (PPDF/87): the complexity of the busbar node with changing topology up to a split into two or more nodes needs special means such as a dynamic busbar image. It has to be considered that at least a second busbar protection algorithm exists which is based on the direction comparison of the fault direction in all feeders.
Motor differential protection ³	PMDF	87M	See above (PDIF/87)
Generator differential protection ³	PGDF	87G	See above (PDIF/87)

- ¹ The logical node differential line protection (PLDF) is used for the communication within the station. The communication between the two relays of two stations (Interface 2) is beyond the scope of the IEC 61850 series.
- ² The decentralized busbar protection consists in addition to the central decision making instance of the PBDF of an instance per bay with appropriate preprocessing and trip output.
- ³ Both the motor protection and the generator protection are no simple functions to be each represented by a single LN, but a set of related LNs. The most important component is the differential LN mentioned here.

All main protection LNs have a communication structure as shown in Figure 6.

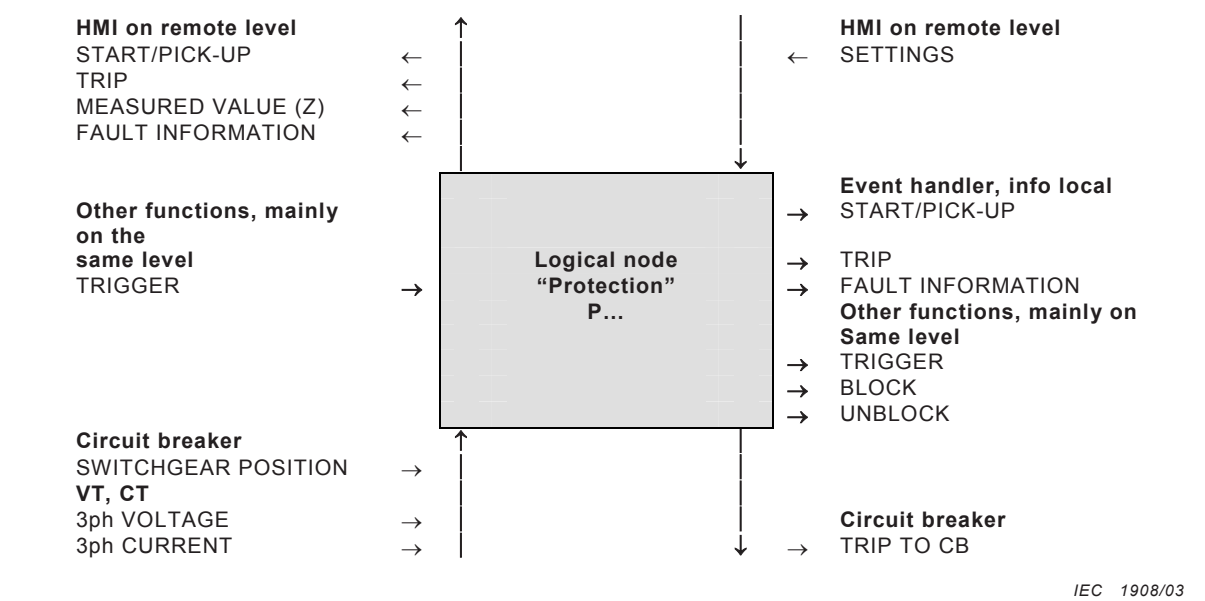


Figure 6 – The basic communication links of a logical node of main protection type

Data from and to the process (switchgear XCBR, current transformer TCTR, voltage transformer TVTR) referring to interface 4 and/or 5
 Data to logical nodes on the same level referring to interface 3 and/or 8
 Data to logical nodes such as IHMI on the station level referring to interface 1

11.1.2 Logical Nodes for protection related functions

Logical node	IEC 61850	IEEE C37.2-1996	Description or comments
Disturbance recording (bay/process level: acquisition)	RDRE		Acquisition functions for voltage and current waveforms from the power process (CTs, VTs), and for position indications of binary inputs. Calculated values such as power and calculated binary signals may also be recorded by this function if applicable.
Disturbance recording (station level: evaluation)	RDRS		The disturbance recording evaluation is needed as a server for HMI on station level (or even on a higher level) or for calculation of combined disturbance records.

Logical node	IEC 61850	IEEE C37.2-1996	Description or comments
Automatic reclosing	RREC	79	AC closing relay is a relay that controls the automatic reclosing and locking out of an AC circuit interrupter (IEEE C37.2-1996). After any successful protection trip, the automatic reclosing tries 1 to 3 times to reclose the open breaker again with different time delays assuming a transient fault.
Breaker failure	RBRF	50BF	Instantaneous overcurrent or rate-of-rise relay is a relay that functions instantaneously on an excessive value of current or on an excessive rate of current rise (IEEE C37.2-1996). In case of a breaker failure, the fault is not cleared. Therefore, neighboring breakers have to be tripped.
Carrier or pilot wire protection ¹	RCPW	85	Carrier or pilot-wire receiver relay is a relay that is operated or restrained by a signal used in connection with carrier-current or DC pilot-wire fault relaying (IEEE C37.2-1996).
Fault locator	RFLO		The fault locator calculates from the protection information (for example the fault impedance of the LN distance function) the location of the fault in km
Synchrocheck/synchronizing or synchronism check	RSYN	25	Synchronizing or synchronism-check device is a device that operates when two AC circuits are within the desired limits of frequency, phase-angle and voltage, to permit or to cause the paralleling of these two circuits (IEEE C37.2-1996). To avoid stress for the switching device and the network, closing of the circuit breaker is allowed by the synchrocheck only, if the differences of voltage, frequency and phase angle are within certain limits.
Power swing blocking	RPSB	78	Phase-angle measuring or out-of-step protective relay is a relay that functions at a predetermined phase angle between two voltages or between two currents or between voltage and current.

¹ A *de facto* communication device which establishes an analog connection between two relays (for example distance or differential protection) in two adjacent substations. If this connection is not serial, it is beyond the scope of the IEC 61850 series, if it is serial it belongs to interface 2, which is also beyond the scope of the IEC 61850 series. The involved picoms all refer to the related protection Ics, for example PLDF and PDIS.

11.2 Logical Nodes for control

11.2.1 Control

Logical Node	IEC 61850	Description or comments
Alarm handling (creation of group alarms and group events)	CALH	For the communication, there is no difference between alarms and events if a time tag is added to any data transmitted. If several events or alarms have to be combined to group alarms, a separate, configurable function is needed. The related LN may be used to calculate new data out of individual data from different logical nodes. Remote acknowledgement with different priority and authority shall be possible. The definition and handling of alarms is an engineering issue.
Switch controller Controls any switchgear, i.e. the devices described by XCBR and XSWI	CSWI	The switch control LN handles all switchgear operations from the operators and from related automatics. It checks the authorization of the commands. It supervises the command execution and gives an alarm in case of an improper ending of the command. It asks for releases from interlocking, synchrocheck, autoreclosure, etc. if applicable.
Point-on-wave breaker controller Controls a circuit breaker with point-on-wave switching capability	CPOW	The point-on-wave breaker controller LN provides all functionality to close or open a circuit breaker at a certain instant of time, i.e. a certain point of the voltage or current wave. It is started by a request either from CSWI or from RREC. Comparing the voltages on both sides of the open breaker in the same way as the synchrocheck function (LN RSYN) it tries to close the contacts exactly at this time when the voltage difference is at an absolute minimum (preferable zero) to get the lowest stress for switchgear and line. This also applies if one of the voltages is zero. For opening, the point of minimum stress is calculated referring to the current wave. The selection command activates the voltage selection. It calculates the point of minimum stress and issues a closing or opening (depending on the intended command) execute command with an absolute time referring to the requested point-on-wave. For these calculations, the conditions in all three phases are considered. If switching per phase is applicable, three execution times are provided.
Interlocking function - at station level and/or - at bay level	CILO	Interlocking may be totally centralized or totally decentralized. Since the interlocking rules are basically the same on bay and station level and based on all related position indications, the different interlocking LNs may be seen as instances of the same LN class Interlocking (IL). 1) Interlocking of switchgear at <u>bay level</u> All interlocking rules referring to a bay are included in this LN. Releases or blockings of requested commands are issued. In the case of status changes affecting interlocking, blocking commands are issued. 2) Interlocking of switchgear at <u>station level</u> All interlocking rules referring to the station are included in this LN. Releases or blockings of requested commands are issued. Information with the LN bay interlocking is exchanged.

11.2.2 Interfaces, logging, and archiving

Logical node	IEC 61850	Description or comments
Operator interface - control local at bay level - control at station level	IHMI	1) Front-panel operator interface at bay level to be used for configuration, etc. and local control. 2) Local operator interface at station level to be used as workplace for the station operator. The role of the different HMI is not fixed for most of the functions and is defined in the engineering phase.
Remote control interface or telecontrol interface	ITCI	Telecontrol interface to be used for remote control from higher control level. Basically, the TCI will communicate the same data as the station level HMI or a subset of these data. The role of the different interfaces is not fixed for most of the functions and is defined in the engineering phase.
Remote monitoring interface or telemonitoring interface	ITMI	Telemonitoring interface to be used for remote monitoring and maintenance using a subset of all information available in the substation and allows no control. The role of the different interfaces is not fixed for most of the functions and is defined in the engineering phase.
Archiving	IARC	Archiving to be used as sink and source for long-term historical data, normally used globally for the complete substation on station level.
In case of seamless communication, some of the remote interfaces may exist only virtually. Depending on the outside world, they may be proxy servers or also any kind of gateway.		

11.2.3 Automatic process control

Logical Node	IEC 61850	Description or comments
Automatic tap changer control	ATCC	Automatic function to keep the voltage of a busbar within a specific range using tap changers. This node operates the tap changer automatically according to given setpoints or by direct operator commands (manual mode).
Automatic voltage control	AVCO	Automatic function to keep the voltage of a busbar within a specific range independently of the means used.
Reactive control	ARCO	Automatic function to keep the reactive power flow in a substation within a specific range using capacitors and/or reactances.
Earth fault neutralizer control (control of Petersen coil)	ANCR	The grounding of the transformer star point influences the short circuit in a network. This grounding is dynamically determined by a Petersen coil (LN ENF) controlled by ENFC.
Zero-voltage tripping	AZVT	If a line connected to a substation is without voltage longer than a predefined time, the line is switched off automatically. In contrast to the PTUV which has settable deviation from the nominal voltage, AZVT is a binary function only (voltage/no voltage).

Logical Node	IEC 61850	Description or comments
Automatic process control (a generic, programmable LN for sequences, unknown functions, etc.)	GAPC	Several functions are sequences. They are collected in the LN type Generic Automatic Process Control (GAPC). This is a generic node for all undefined functions. These sequences may be implemented with standard PLC languages. The data access and exchange is entirely the same as for all other LNs. Examples are 1) Load shedding To shed in a very selective way parts of the consumers to avoid the collapse of the network in overload situations. This load-shedding function may not be restricted only on frequency criteria such as PFRQ but include actual power balance, etc. 2) Infeed transfer switching To detect a weak infeed (for example to an industrial plant) and to switch over to another feeding line. Boundary conditions have to be considered such as the synchronization of motors, if applicable 3) Transformer change To switchover in case of overload to another transformer or to distribute the load more evenly to all related transformers on the busbar. 4) Busbar change To start by one single operator command a sequence of switching operations resulting in a busbar change of a dedicated line or transformer, if applicable. 5) Automatic clearing and voltage restoration To trip all circuits connected to a busbar after detecting zero-voltage conditions (black-out) and to close the same breakers following certain pre-defined rules.

11.2.4 Metering and measurement

Logical Node	IEC 61850	Description or comments
Measuring - for operative purpose	MMXU	To acquire values from CTs and VTs and calculate measurands such as r.m.s. values for current and voltage or power flows out of the acquired voltage and current samples. These values are normally used for operational purposes such as power flow supervision and management, screen displays, state estimation, etc. The requested accuracy for these functions has to be provided. NOTE The measuring procedures in the protection devices are part of the dedicated protection algorithm represented by the logical nodes Pxyz. Protection algorithms such as any function are outside the scope of the IEC 61850 series. Therefore, the LN Mxyz shall not be used as input for Pxyz. Fault related data such as fault peak value, etc. are always provided by the LNs of type Pxyz and not by LNs of type Mxyz.
Metering - for commercial purpose	MMTR	To acquire values from CTs and VTs and calculate the energy (integrated values) out of the acquired voltage and current samples. Metering is normally also used for billing and has to provide the requested accuracy. A dedicated instance of this LN may take the energy values from external meters for example by pulses instead directly from CTs and VTs.

Logical Node	IEC 61850	Description or comments
Sequences and imbalances - for example for stability purpose	MSQI	To acquire values from CTs and VTs and to calculate the sequences and imbalances in a three/multi-phase power system.
Harmonics and interharmonics - for example for power quality purpose	MHAI	To acquire values from CTs and VTs and to calculate harmonics, interharmonics and related values in the power system mainly used for determining power quality.

11.3 Physical device

11.3.1 Common identification and behavior

Logical Node	IEC 61850	Description or comments
Logical node device	LLN0	This LN contains the data related to the IED of the Physical Device (PD) independent from all included logical nodes (device identification/name plate, messages from device self-supervision, etc.). This LN may also be used for actions common to all included logical nodes (mode setting, settings, etc.), if applicable. This LN does not restrict the dedicated access to any single LN by definition. Possible restrictions are a matter of implementation and engineering.
It may be convenient for modeling in IEC 61850-7-4 to introduce more of such nodes for example for device substructures, but this is not a requirement.		

11.4 System and device security

Logical Node	IEC 61850	Description or comments
General security application	GSAL	Containing logs about security violations.

11.5 LNs related to primary equipment

The switchgear related logical nodes represent the power system, i.e. the world seen by the substation automation system via the I/Os. Using switchgear related LNs means a dedicated grouping of I/Os predefined according to a physical device such as a circuit breaker (see XCBR in 11.5.1).

11.5.1 Switching devices and substation parts

Logical Node	IEC 61850	IEEE C37.2-1996	Description or comments
The LN “circuit breaker” covers all kinds of circuit breakers, i.e. switches able to interrupt short circuits - without point-on-wave switching capability - with point-on-wave switching capability	XCBR	52	An AC circuit breaker is a device that is used to close and interrupt an AC power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions (IEEE C37.2-1996). If there is a single-phase breaker, this LN has an instance per phase. These three instances may be allocated to three physical devices mounted in the switchgear.

Logical Node	IEC 61850	IEEE C37.2-1996	Description or comments
The LN "switch" covers all kinds of switching devices not able to switch short circuits • load breakers • disconnectors • earthing switches • high-speed earthing switches	XSWI	89 52	Line switch is a switch used as a disconnecting, load-interrupter, or isolating switch on an AC or DC power circuit (IEEE C37.2-1996). If there is a single-phase switch, this LN has an instance per phase. These three instances may be allocated to three physical devices mounted in the switchgear.

These LNs represent the mentioned switching devices and related equipment with their entire inputs, outputs and communication relevant behavior in the SAS.

11.5.2 LN for monitoring by sensors

Logical Node	IEC 61850	IEEE C37.2-1996	Description or comments
Insulation medium supervision	SIMS		LN to supervise the insulation medium, for example the gas volumes of GIS (Gas Insulated Switchgear) regarding density, pressure, temperature, etc.
Monitoring and diagnostics for arcs	SARC		LN to supervise the gas volumes of GIS (Gas Insulated Switchgear) regarding arcs switching or fault arcs.
Monitoring and diagnostics for partial discharge	SPDC		LN to supervise the gas volumes of GIS (Gas Insulated Switchgear) regarding signatures of partial discharges.

These LNs represent the mentioned sensors with their entire inputs and communication relevant behavior in the SAS.

11.5.3 Instrument transformers

Logical Node	IEC 61850	Description or comments
Current transformer	TCTR	There is one instance per phase. These three/four instances may be allocated to different physical devices mounted in the instrument transformer per phase.
Voltage transformer	TVTR	There is one instance per phase. These three/four instances may be allocated to different physical devices mounted in the instrument transformer per phase.

These LNs represent the mentioned instrument transformers with all its data and related settings (if applicable), and communication relevant behavior in the SAS.

11.5.4 Power transformers

Function	IEC 61850	Description or comments
Power transformer	YPTR	Connects the voltage levels of the power system in different configurations (Δ , Y, two/three windings).
Tap changer	YLTC	Device allocated to YPRT allowing changing taps of the winding for voltage regulation.
Earth fault neutralizer (Petersen coil)	YEFN	Variable inductance (plunge core coil) allowing adaptive grounding of transformer star point to minimize the ground fault current.
Power shunt	YPSH	To bypass the resistor of a resistive grounded transformer star point for fault handling.

These LNs represent the mentioned power transformers and related equipment with all its data and related settings (if applicable), and communication relevant behavior in the SAS.

11.5.5 Further power system equipment

Function	IEC 61850	Description or comments
Auxiliary network	ZAXN	Generic node for information exchange with auxiliary networks (power supplies).
Battery	ZBAT	Provides data about battery status and for control of the charging/de-charging cycles.
Bushing	ZBSH	Provides properties and supervision of bushings as used for transformers or GIS-line connections.
Power cable	ZCAB	Supervised power system element.
Capacitor bank	ZCAP	Controls reactive power flow.
Converter	ZCON	Frequency conversion incl. AC/DC conversion.
Generator	ZGEN	Generic node for information exchange with generators.
Gas isolated Line (GIL)	ZGIL	Mixture of data from SIMS, SARC and SPDC.
Power overhead line	ZLIN	Supervised overhead line.
Motor	ZMOT	Generic node for information exchange with motors.
Reactor	ZREA	Controls reactive power flow.
Rotating reactive component	ZRRC	Controls reactive power flow.
Surge arrestor	ZSAR	Generic node for information exchange with surge arrestors.
(Thyristor controlled) frequency converter	ZTCF	Frequency conversion including AC/DC conversion.
Thyristor controlled reactive component	ZTCR	Controls reactive power flow.

These LNs represent the mentioned power system equipment with all its data and related settings (if applicable), and communication relevant behavior in the SAS. Since entities like generators are outside the scope of substations but have often an communication interface to Substation Automation Systems anyhow, they are described as minimum by one single LN only. If the data exchange needs more details, these have to be covered by appropriated PICOMs or the additional use of generic LNs such as GGIO.

11.5.6 Generic process I/O

Function	IEC 61850	Description or comments
Generic I/O	GGIO	Outputs such as analog outputs, auxiliary relays, etc. not covered by the above-mentioned switchgear related LNs are sometimes needed. In addition, there are additional I/O's representing devices not predefined such as horn, bell, target value etc. There are input and outputs from non-defined auxiliary devices also. For all these I/O's, the Generic Logical Node GIO is used to represent a generic primary or auxiliary device (type X..., Y..., Z...).

11.6 LNs related to system services

Function	IEC 61850	Description or comments
Time master	STIM	LN to provide the time to the system (setting and synchronization).
System supervision	SSYS	LN to start, collect and process all data for system supervision.
Test generator	GTES	LN to start tests by using process signals, but avoiding any impact on the process (blocking of process outputs).

System functions such as time synchronization and system supervision are requirements from the substation automation system and have to be supported by the IEC 61850 series. Depending on the selected stack, these support functions may be provided from a level below the application. The test generator (GTES) depends on the function to be tested and is therefore declared as a generic logical node.

12 The application of LN (informative)

12.1 Basic principles

12.1.1 Free allocation of LNs

The free allocation of functions or LNs respectively is not restricted to the common level structure. The levels below are mentioned as common supplementary information only. All the figures shown with these levels are only examples, demonstrating the requested flexibility and interaction.

12.1.2 Station level

These logical nodes represent the station level, i.e. not only the station level IHMI, but all other functions such as station wide interlocking (CILO), alarm and event handling (CALH), station-wide voltage control (ATCC), etc. The most common prefix is I, but others such as A and C may appear also.

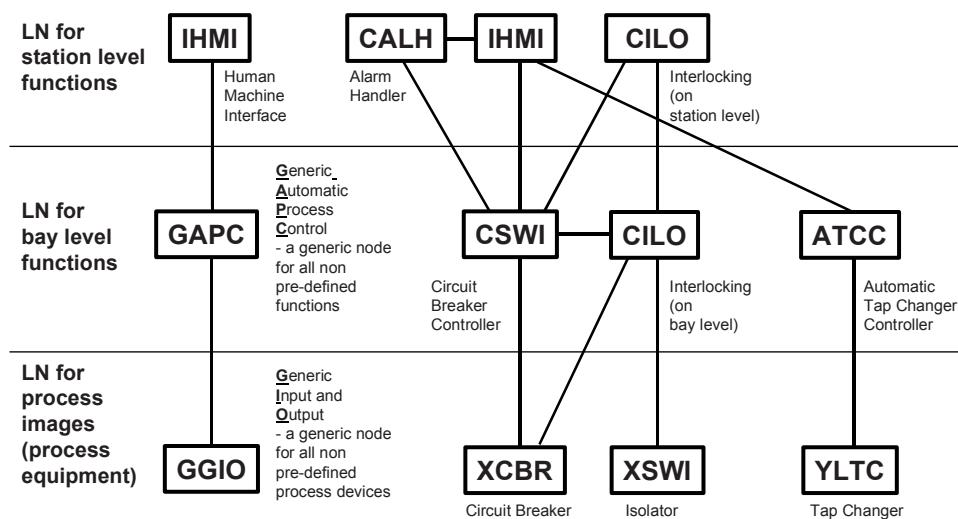
12.1.3 Bay level

These logical nodes represent the bay level control, automatic, measuring, and protection functions (for example, CILO, ATCC, MMXU, CSWI, PDIS, PZSU, PDOC, ...). Therefore, for combined control and protection devices, the protection LN appears here together with the control LN. If there is no process bus, the LNs of bay level and process level appear together in one single physical device. The XCBR then represents the I/O card functionality and the CSWI the control processor functionality. The most common prefixes are P, C and A but others such as X may also appear.

12.1.4 Process/switchgear level

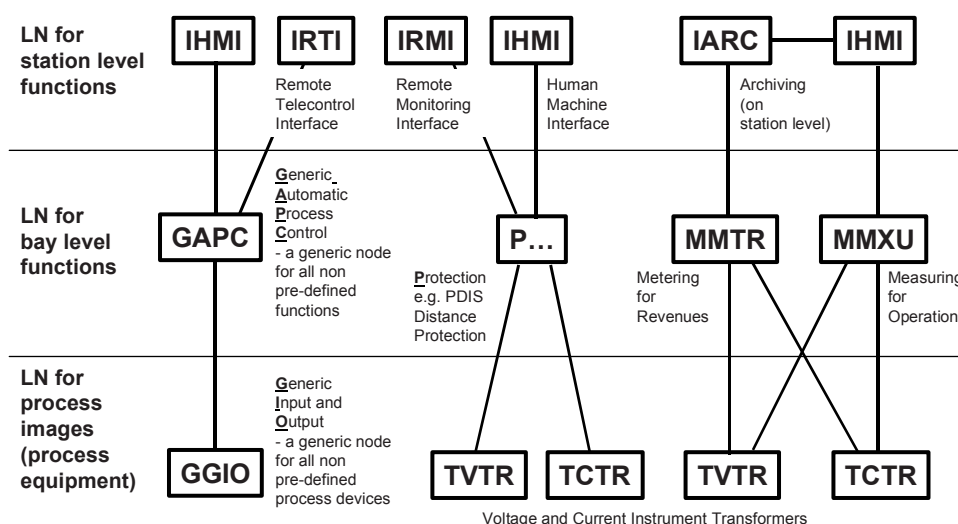
These logical nodes represent the power (primary) system, i.e. the power system world as seen from the secondary system via the I/Os. They may contain some simple functionality such as device-related supervision as well as blocking. In case of intelligent I/Os, logical nodes from the bay level may move also down to the process level. The most common prefixes are X, Y and Z.

12.2 Basic examples



IEC 1909/03

Figure 7 – Decomposition of functions into interacting LNs on different levels: examples for generic automatic function, breaker control function and voltage control function



IEC 1910/03

Figure 8 – Decomposition of functions into interacting LN on different levels: examples for generic function with telecontrol interface, protection function and measuring/metering function

12.3 Additional examples

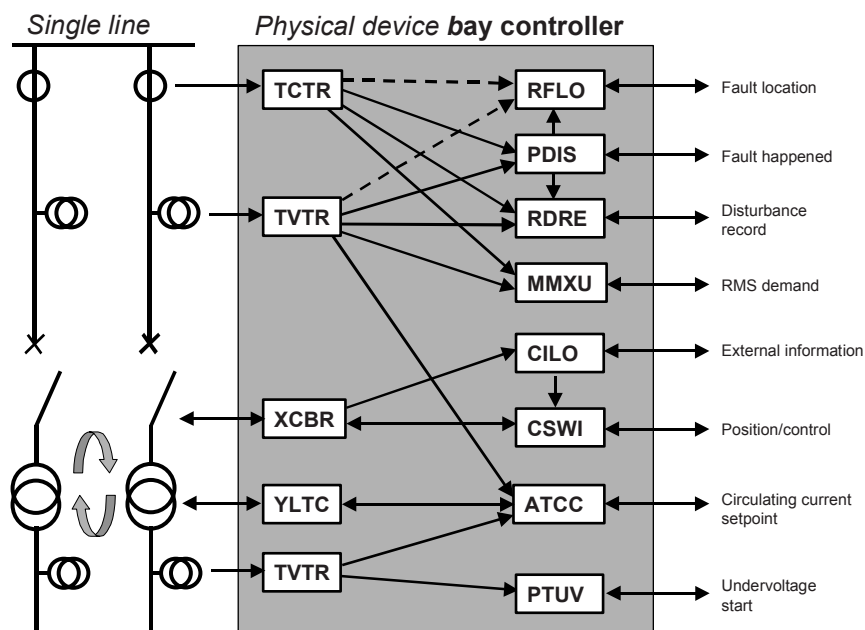
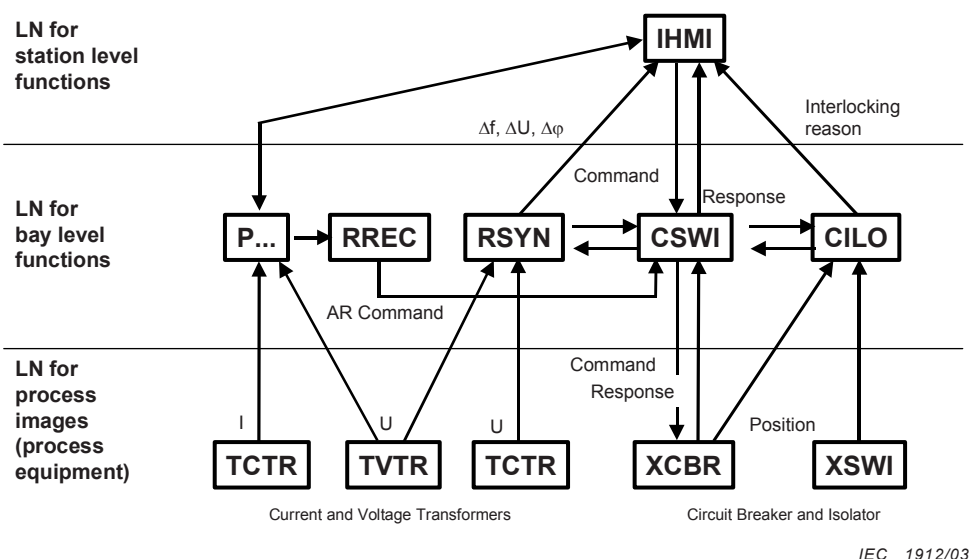


Figure 9 – Example for control and protection LNs of a transformer bay combined in one physical device (some kind of maximum allocation)



IEC 1912/03

Figure 10 – Example for interaction of LNs for switchgear control, interlocking, synchrocheck, autoreclosure and protection

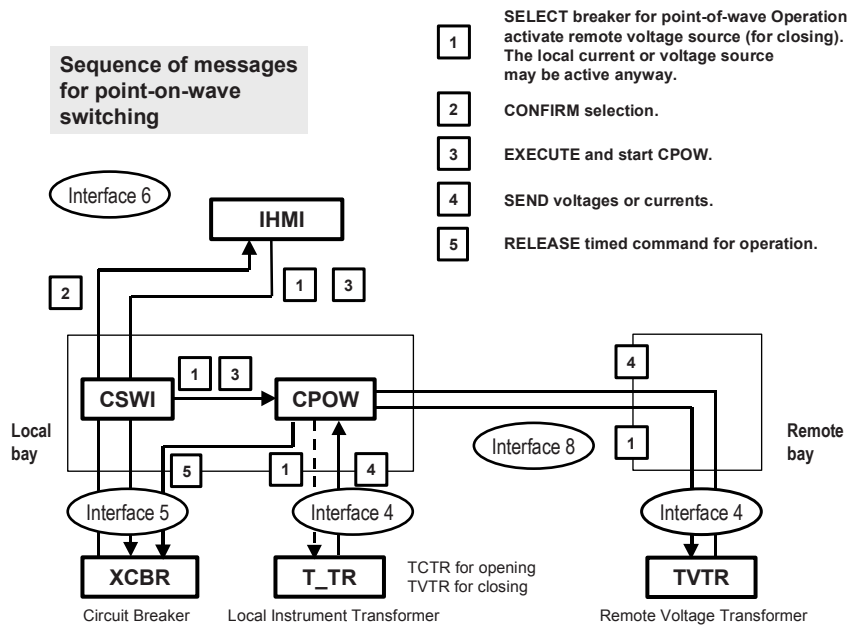


Figure 11 – Example for sequential interacting of LNs (local and remote) for a complex function such as point-on-wave switching – Sequence view

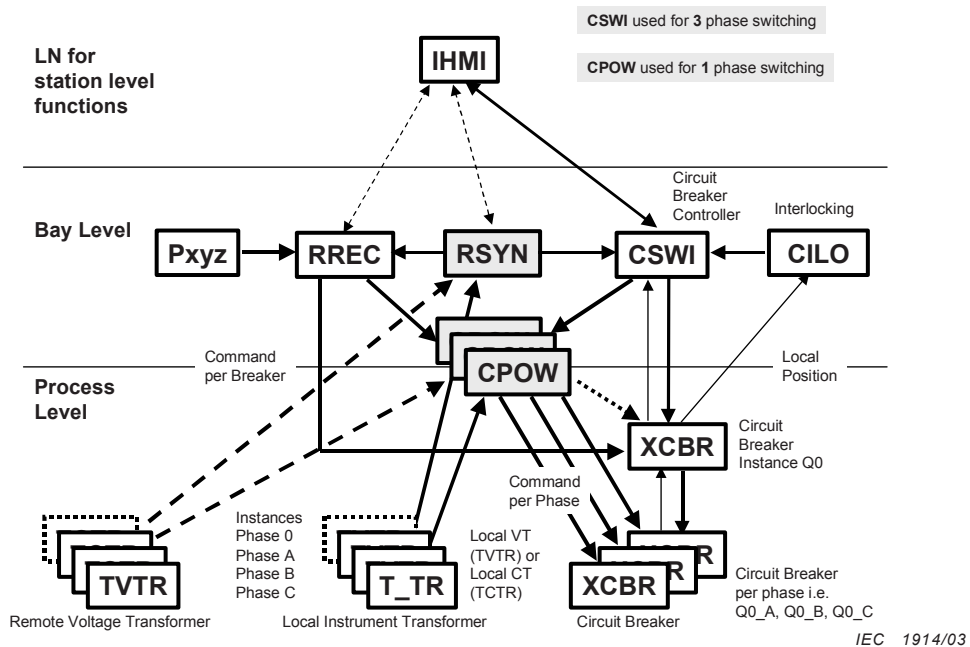


Figure 12 – Example for functional interacting of LNs (local and remote) for a complex function such as point-on-wave switching – Architecture view