PD IEC TS 60255-216-1:2025

BSI Standards Publication

Measuring relays and protection equipment

Part 216-1: Digital interface — General requirements and tests for protection functions using digital communication as input and output

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Full document details: PD IEC TS 60255-216-1:2025

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The UK participation in its preparation was entrusted to Technical Committee PEL/95, Measuring relays and protection systems.

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

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ISBN 978 0 539 35505 5

ICS 29.120.70

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2025.

Amendments/corrigenda issued since publication

Date	Text affected

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Full document details: PD IEC TS 60255-216-1:2025

IEC TS 60255-216-1

Edition 1.0 2025-08

TECHNICAL SPECIFICATION

Measuring relays and protection equipment -
Part 216-1: Digital interface - General requirements and tests for protection functions using digital communication as input and output

ICS 29.120.70

ISBN 978-2-8327-0626-8

IEC TS 60255-216-1:2025-08(en)

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CONTENTS

FOREWORD 8
INTRODUCTION 10
1 Scope 12
2 Normative references 13
3 Terms and definitions 14
4 Abbreviated terms 19
5 Functional chain of the protection function 22
5.1 General 22
5.2 Operate time of the functional chain 23
6 Engineering of digitally interfaced protection functions 26
6.1 IEC 61850 series communication configuration 26
6.2 Setting of protection functions 27
6.2.1 Reference values for protection function settings 27
6.2.2 Online change of settings 27
6.2.3 Import of protection application settings from SCL 28
6.2.4 Determination of setting values 30
6.3 Implementation of test mode and simulation 31
7 Digital inputs of protection functions 31
7.1 General 31
7.2 Input signal source 32
7.3 Attributes and flags 32
7.3.1 Quality Attribute 32
7.3.2 Data Attribute "source" 34
7.3.3 operatorBlocked 34
7.3.4 Test 34
7.3.5 Simulation 35
7.4 Sampled values 36
7.4.1 General 36
7.4.2 Redundant SV streams 37
7.4.3 Accuracy and performance characteristics of the protection function 38
7.4.4 Frequency transfer function 39
7.4.5 Buffering and Layer of the entry stage of the IED hosting protection functions 40
7.4.6 Comparison of the protection chain between protections with digital inputs and hard wired interfaced protections 42
7.4.7 Expected behaviour in case of non-nominal situation 43
7.5 GOOSE 57
7.5.1 General 57
7.5.2 Time performances 57
7.5.3 Expected behaviour in case of non-nominal values 59
7.6 Report of SV and GOOSE supervision 63
7.6.1 Description 63
7.6.2 Inconsistency detection and report generation 64
7.6.3 Time synchronisation and related supervision 64
7.7 Implementation of subscription supervision of GOOSE and SV 65
7.8 Specification of requirements related to abnormal values of Digital Inputs 66
7.9 Operating states of protection functions 67

AVA Documents
Document Sharing Hub

Full document details: PD IEC TS 60255-216-1:2025

7.10 Maintenance, testing and virtual isolation of IED inputs 69
7.11 Robustness to abnormal disturbing events 70
7.12 Resilience of communication inputs 71
8 Digital outputs of protection functions 72
8.1 General 72
8.2 Accuracy of time stamp of published data 72
8.3 Use of Tr and Op attributes 72
8.4 GOOSE 72
8.4.1 Interoperability 72
8.4.2 Time performance 73
8.4.3 Quality Attributes of published GOOSE 76
8.5 MMS 77
8.5.1 General 77
8.5.2 LN used to supervise communication 77
8.5.3 Other MMS information published by protection function 78
8.5.4 Requirements for server MMS association 79
9 Requirements for the IED hosting the protection function 79
9.1 General 79
9.2 Time synchronisation of the IED hosting the protection function 79
9.2.1 Requirements for the time synchronisation of the IED 79
9.2.2 Supervision of the time synchronisation signal 80
9.3 PICS and communication requirements 81
9.4 PIXIT 84
9.5 Cyber security requirements 85
10 Requirements for documentation 85
11 IEC 61850 based supervision and monitoring of protection functions 88
11.1 General 88
11.2 Recording of communication network events 88
12 Tests 89
12.1 General 89
12.2 Requirements regarding documentation and declaration 90
12.3 Verification of PICS 90
12.4 Accuracy of thresholds and measurements and related setting 90
12.5 Dynamic and static performance tests 92
12.5.1 General 92
12.5.2 Static performance tests 92
12.5.3 Dynamic performance tests 93
12.6 Functional tests 93
12.7 Verification of simulation and test according to the IEC 61850 series 94
12.8 Testing of setting changes performed by IEC 61850 services 95
12.9 Test of SV inputs 96
12.9.1 Quality Attributes 96
12.9.2 Handling of unused quality attributes 96
12.9.3 TimeStamp and supervision of synchronisation 96
12.9.4 Loss of synchronisation of the IED hosting the protection function 97
12.9.5 Switchover of SV streams 98
12.9.6 Inconsistent or delayed SV 98
12.9.7 Verification of confRev 100

AVA Documents
Document Sharing Hub

Full document details: PD IEC TS 60255-216-1:2025

12.9.8 Robustness to abnormal events 101
12.10 Loss of client/server association 102
12.10.1 General 102
12.10.2 Server tests related to MMS association 102
12.10.3 Communication recovery test 103
12.10.4 Robustness to abnormal events 103
12.11 Testing of GOOSE inputs 104
12.11.1 Quality attributes 104
12.11.2 Time stamp and supervision of synchronisation 105
12.11.3 Loss of GoCB publisher and GOOSE recovery 105
12.11.4 Robustness to abnormal events 105
12.11.5 Verification of confRev 106
12.12 GOOSE performance 106
12.13 Verification of MMS report 107
12.14 Tests related to cybersecurity 107
12.15 Verification after the download of a CID 107
12.16 Recommendations for FAT and SAT testing for digitally interfaced protection functions 107
12.16.1 General 107
12.16.2 Verifications prior to FAT or SAT 108
12.16.3 FAT (Factory Acceptance Test) 109
12.16.4 SAT (Site Acceptance Test) 110
Annex A (informative) Example of a specification of the expected behaviour of a protection function depending on the quality of received data 111
Annex B (informative) Redundant SV streams received by protection functions 114
B.1 General 114
B.2 Example of double A/D redundant mechanism 114
Annex C (informative) Example for criteria for the function supervising the GOOSE and SV 116
C.1 General 116
C.2 Sampled values 116
C.3 GOOSE 116
C.4 Advanced considerations 117
C.4.1 General 117
C.4.2 Monitoring of SV 118
C.4.3 Monitoring of GOOSE 118
Annex D (informative) Advantages and drawbacks of explicit and structured data sets 120
D.1 Explanation of explicit and implicit datasets 120
D.2 Implications related to the use of the two approaches 121
Annex E (informative) Stand-alone network recording device 123
Annex F (informative) Guidance for the evaluation of the overall error of the analog acquisition chain 124
Annex G (informative) General description of the digital processing of sampled values in the protection function 127
G.1 General 127
G.2 Acquisition chains for analog data 127
G.3 Frequency tracking 128
Annex H (informative) Expected behaviour of protection functions for non-nominal conditions 131

Documents
Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

Annex I (informative) Use case for functional testing of a blocking function 135
Annex J (informative) Use case for detection of transmission time delay of SV between MU and subscribing IED 137
J.1 Description 137
J.2 Operate time of the functional protection chain 137
J.3 Post-fault analysis for events related to communication network 139
Annex K (informative) Additional considerations for digitally interfaced protection functions 140
K.1 Characteristics of the analog acquisition IED 140
K.1.1 Accuracy classes of analog values 140
K.1.2 Sample rate 146
K.1.3 Frequency response and accuracy requirements for harmonics 147
K.1.4 Effects of electromagnetic interference 151
K.1.5 Publication of the data quality 152
K.1.6 Time synchronisation 153
K.1.7 Jitter and time delay 157
K.1.8 Robustness and start up 158
K.2 System related aspects 159
K.2.1 Architecture and configuration 159
K.2.2 System redundancy features 160
K.2.3 Time synchronisation 162
K.2.4 Client – server MMS associations 164
K.2.5 R-GOOSE and R-SV 165
K.3 Grouping of Logical Nodes related to a protection function 165
K.4 Version and consistency check of SCL configuration data 166
K.4.1 Context 166
K.4.2 ICD and IID file management 168
K.4.3 SCD file management 168
K.4.4 CID file management 169
K.4.5 Consistency check of CID 169
Annex L (informative) Role and responsibilities of the system integrator 170
Bibliography 172

Figure 1 – Functional chain of a digitally interfaced protection function 12
Figure 2 – Operate time of the functional chain of a protection function (example: LPIT) 23
Figure 3 – Time delay in case of two SV streams 25
Figure 4 – Processing and transmission time and (symmetrical) jitter of SV 26
Figure 5 – Workflow for import of settings in IED based on SCD (see IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018) 30
Figure 6 – Data used for receiving simulation signals (IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020, Figure 40) 36
Figure 7 – Operation of SV input buffer of a protection function 42
Figure 8 – Comparison of Operate time of digitally interfaced protection chain and wire terminal interfaced protection IED 43
Figure 9 – Relation between quality attributes and range of analog energising values 46
Figure 10 – GOOSE timing considering simple protection application 58
Figure 11 – Process of reporting detection of abnormal SV or GOOSE data 63
Figure A.1 – Example of a dynamic data model for the distance protection function 111

AVA Documents
Document Sharing Hub

Full document details: PD IEC TS 60255-216-1:2025

Figure B.1 – Dataset for a current SV stream with redundant values 114
Figure D.1 – Example of one member of a structured data set of DO Op 120
Figure D.2 – Example of explicit and implicit data sets in SCL 121
Figure D.3 – Content of the structured member of the dataset of DO Op 121
Figure F.1 – Analog acquisition chain of an ECT (based on IEC 61869-9:2016) 124
Figure F.2 – Analog acquisition chain represented as functional chain 124
Figure F.3 – Combined error of the acquisition chain (based on IEC 61869-13:2021) 125
Figure G.1 – Acquisition of analog data of a protection IED with analog inputs 127
Figure G.2 – Acquisition chain for analog data of a MU 128
Figure G.3 – Measurement chain of an IED based on process bus 128
Figure G.4 – DFT window set for 50 Hz in a 43 Hz waveform 129
Figure G.5 – Frequency response of sine and cosine filters 129
Figure I.1 – Example of functional testing of a digitally interfaced protection function implemented in an IED 135
Figure K.1 – Dynamic range concept example according to IEC 61869-13:2021, Figure 1305 143
Figure K.2 – Frequency response mask for measuring accuracy class 1 (f_r = 60 Hz, f_s = 4 800 Hz) IEC 61869-1:2023 with an additional bode plot of a realistic frequency response 148
Figure K.3 – Tolerance scheme and a typical amplitude response of a SAMU 150
Figure K.4 – Global Error of time synchronisation 154
Figure K.5 – Time adjustment after reacquisition of synchronisation (IEC 61869-9:2016) 158
Figure K.6 – Protection function subscribing to redundant SV streams (example 1) 161
Figure K.7 – Redundant Protection functions subscribing to single SV streams (example 2) 161
Figure K.8 – Time synchronisation states 163
Figure K.9 – Inconsistent recovery of synchronisation of different MUs 164
Figure K.10 – IED configuration procedure (based on IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018) 166

Table 1 – List of acronyms 19
Table 2 – Link between DA "detailQual" and validity (IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Table D.1) 34
Table 3 – Interpretation of DA "detailQual" for Sampled Values and other analog values received by Protection Functions 44
Table 4 – Options for detailed specification for the expected behaviour of a protection function in case of non-nominal input signal 46
Table 5 – Definition of expected functional behaviour of a protection function 47
Table 6 – Definition of warnings or alarms generated by a protection function 47
Table 7 – Definition of propagation of the quality attribute by a protection function 48
Table 8 – Template to specify the expected behaviour of a protection function depending on the quality of received data 49
Table 9 – Interpretation of detailQual of a DO containing discrete information (Boolean or enumerate) received by Protection Functions 59

Documents
Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

Table 10 – Interpretation of signals of LGOS and LSVS [based on the simulation state machine defined in IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020 66
Table 11 – Interpretation of the combination of status of LGOS.St and LGOS.SimSt 66
Table 12 — Overview of different operating states of protection functions 68
Table 13 – Expected behaviour of protection and supervision functions in case of abnormal disturbing events 70
Table 14 – Value table for AND and OR default values for protection functions subscribing to Boolean type inputs 77
Table 15 – Required ACSI Basic Conformance functionality for IED hosting protection functions based on Table A.1 of IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 81
Table 16 – Required ACSI Model Conformance functionality for IED hosting protection functions based on Table A.2 of IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 82
Table 17 – Required ACSI services for IED hosting protection functions based on Table A.3 of IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 83
Table 18 – Required PIXIT information for IED hosting protection functions 84
Table 19 – Manufacturer declarations required for IED hosting protection functions 86
Table 20 – Overview over specified tests and associated requirements 89
Table 21 – Test cases for Sim flag and test bit in the received stream 95
Table A.1 – Example for the specification of the expected behaviour for the operation under non-nominal conditions for the distance protection function (The colours used in this table are defined in Table 5) 113
Table B.1 – Example of instance names of TCTR for redundant acquisition 115
Table C.1 – SV abnormalities 116
Table C.2 – GOOSE abnormalities 117
Table F.1 – Combined accuracy class table (IEC 61869-13:2021) 126
Table H.1 – Proposed requirements for digitally interfaced protection functions 132
Table K.1 – Errors related to acquisition of analog signals in the functional protection chain – overview and applicable standards 140
Table K.2 – Limits of current error and phase error for SAMU measuring accuracy current channels according to IEC 61869-13:2021, Table 1303 142
Table K.3 – Limits of current errors for SAMU protection accuracy current channels according to IEC 61869-13:2021, Table 1304 144
Table K.4 – Limits of voltage ratio error and phase error for SAMU voltage channels according to IEC 61869-13:2021, Table 1305, for voltages between 20 % and F_V of the rated input voltage 145
Table K.5 – Standard sample rates of MU according to IEC 61869-9:2016 (Table 902) 147
Table K.6 – Requirements for protective accuracy classes according to IEC 61869-1:2023, Table 9 149
Table K.7 – Requirements for anti-aliasing according to IEC 61869-1:2023, Table 10 149
Table K.8 – Overview of data attributes of packed list "Quality" according to IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 152
Table K.9 – Limitation of quality attributes according to IEC 61869-9:2016 152
Table K.10 – Value of selected quality attributes for SV according to IEC 61869-9:2016 153

Documents
Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

Table K.11 – Application of time synchronisation classes for time tagging or sampling (IEC 61850-5:2013 and IEC 61850-5:2013/AMD1:2022, Table 3) 155
Table K.12 – Values of synchronisation declaration of the merging unit (SmpSynch) (see IEC 61850-9-2:2011 and IEC 61850-9-2:2011/AMD1:2020) 156
Table K.13 – Maximum processing delay time limits according to IEC 61869-9:2016, Table 901 157
Table L.1 – Responsibility of the system integrator 170

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The text of this Technical Specification is based on the following documents:

Draft	Report on voting
95/593/DTS	95/598/RVDTS

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

The language used for the development of this Technical Specification is English.

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INTRODUCTION

Process bus based on the IEC 61850 series (referred to as “IEC 61850” in this document) is being introduced widely in the protection automation and control systems (PACS). There are standards for digitally interfacing instrument transformers, in particular IEC 61869-9. In order to ensure functional interoperability, the standards of protection functions are being adapted to take this into account. The intention of this document is to define characteristics and requirements to be implemented to reach functional interoperability and simplify Protection, Automation and Control System (PACS) design and implementation for users.

This document describes the global framework for digitally interfaced protection functions, namely the relevant features in IEC 61850 and the properties of the sampled values (SV) defined in IEC 61869-1 and IEC 61869-9 used by protection functions. This is done in Annex K (Clause K.1). Subclause K.1.1 covers SV published by Stand Alone Merging Units (SAMU) (IEC 61869-13:2021) or Low Power Instrument Transformers (LPIT) (future IEC 61869-7 and IEC 61850-8). Specific requirements for protection functions are defined on this base in the clauses (Clauses 5 through 11). Sometimes this concerns an extension or a specific profile of IEC 61850 (e.g. some requirements to be mandatory instead of optional) and sometimes new requirements specific for protection functions are formulated. The associated tests are specified in Clause 12.

Compared with wire terminal interfaced Intelligent Electronic Device (IED) hosting protection functions, the digitally interfaced functional protection chain contains two or more IED types, including the merging unit interfacing the instrument transformers and the IED with hard wired binary inputs and outputs (BIOI) interfacing the circuit breaker (see Figure 1). This results in advantages of sharing IEDs and data, but also uses transmission of data between the different IEDs. This architecture is also considered for the overall operation time of the functional protection chain.

Time synchronisation is a sensible aspect for some protection functions receiving multiple sample value (SV) streams. This aspect is discussed in several clauses of this document.

Protection functions use data contained in generic object-oriented system event (GOOSE) and SV messages. These messages are technically subscribed by the IED hosting the protection function via its communication port and IEC 61850 stack. In this document, this chain is referenced to as "GOOSE signals or SV received by a protection function".

It is clear that the use of digital technology also

– facilitates automatic preventive maintenance based on the available recorded data,
– allows for substation self-supervision where automatic warnings are given in case of failures or abnormality, reducing the Mean Time To Restoration (MTTR),
– increases the availability, dependability and security of the protection system by detecting communication failures and enabling countermeasures to minimise the number of unwanted events (e.g. trips),
– facilitates simplified fault analysis and post event analysis.

The pick-up time, start time and other properties related to a specific protection function are defined in the relevant functional protection standard and are extended to the digitally interfaced protection function. See also Annex H “Expected behaviour of protection functions for non-nominal conditions”, trying to anticipate indication of properties for different protection functions.

Often the term "start" is used as synonym for "pick-up". The data object "operate" can be published by several functional elements but does not always lead to a trip. This document uses all of these terms.

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This document is intended to serve as a basis for standards developed in the IEC 60255 series. For this reason, details from other standards are included for informational clarity. For standards referencing to this document, it is intended to reference the source standard in application of the IEC editorial guidelines without reproducing them.

Future evolutions on several aspects of IEC 61850 are possible, including time synchronisation, start-up, processing of quality packed list and in particular the detailed quality (detailQual). This can have an impact on product standards, including the standards of the IEC 61869 series (Instrument Transformers) and IEC 60255 (protection functions), which will have to be adapted accordingly in due time.

This document reflects the version of the product standards and of IEC 61850 series known as “edition 2.1” and of the product standards as published at the time of its completion. Formally, the amendments to the IEC 61850 documents are no standalone documents and are always read with their base edition. For this reason the formal way in IEC to refer to a consolidated “edition 2.1” document is to reference the edition 2 document and the amendment #1. E.g. for part 6, “IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018” refers to the consolidated version of edition 2.1. This system of referencing edition 2.1 documents is applied in the whole document.

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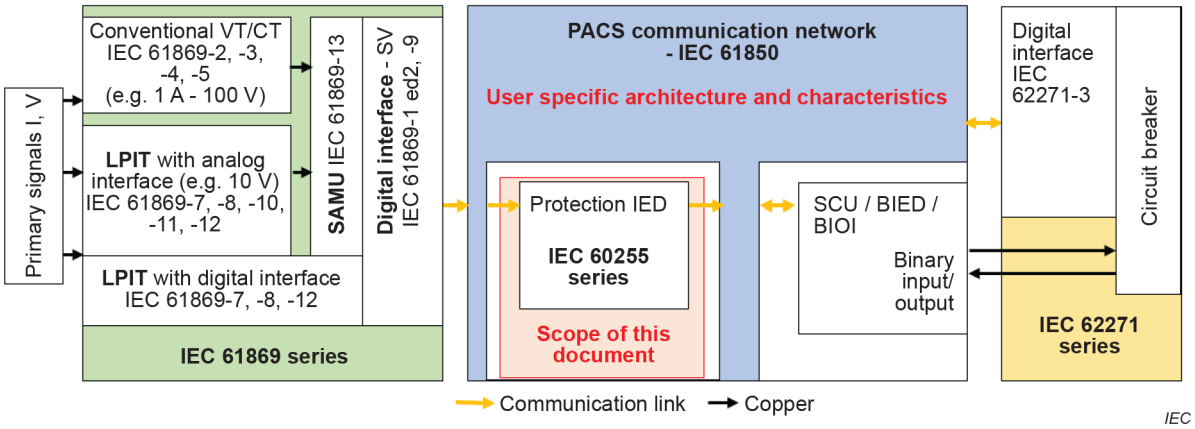
1 Scope

This document covers protection functions with digital inputs and outputs complying with IEC 61850 series and IEC 61869 series, in particular regarding

– subscription to sampled values (SV) streams representing energising inputs instead of analog inputs (see Figure 1);
– subscription to GOOSE (e.g. circuit breaker position, circuit breaker failure);
– publication of GOOSE messages (e.g. trip signals);
– subscription to time synchronisation messages.

On this basis, this document formulates requirements for protection functions with digital inputs and outputs and for the IED hosting them. The document also covers tests related to the functional interoperability and functional requirements of these protection functions, in addition to the general conformance tests required by IEC 61850-10:2012 and test related requirements in IEC TR 61850-10-3:2022 [1][1].

Requirements regarding characteristics of the communication network are not within the scope of this document. Delays and jitter due to the network are taken into account by network engineering. The expected behaviour of protection functions in case of delays, jitter or loss of SV is covered by this document. Figure 1 below shows the functional chain of a protection function, where each IED is connected to the PACS communication network. This document only considers the data received and published by the protection function as shown in Figure 1. It describes the coordination between the digitally interfaced protection functions and the characteristics of the analog acquisition chain.



NOTE 1 See the list of abbreviations in Clause 4.

NOTE 2 IEC 61869-12 is under development.

Figure 1 – Functional chain of a digitally interfaced protection function

If not mentioned otherwise, the term “switch” in this document refers to the switches used in the communication network.

The PACS communication network engineering and cyber security measures to be applied on PACS level are out of scope of this document.

[1] Numbers in square brackets refer to the Bibliography.

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Requirements for protection functions switching over between two redundant SV streams acquired by different acquisition chains but reflecting the same primary values are covered in this document.

This document is applicable to protection functions for AC networks implemented in IEDs subscribing SV streams. Parts of the considerations can also apply to IEDs combining analog inputs connected to Instrument Transformers and SV subscription.

If an IED hosting protection functions is interfacing analog inputs connected to Instrument Transformers and publishes the associated SV streams, it is a multifunctional IED and complies additionally with the relevant IEC 61869 standards. This type of device is out of scope of this document.

Some aspects related to cyber security are considered in this document, e.g. reception of duplicated or corrupted messages. The implementation of specific cyber security standards, such as IEC 62351-6 [2] is covered by the general implementation requirements of the IEC 61850 series. Detailed cyber security requirements for IEDs hosting protection functions are out of scope of this document.

2 Normative references

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

IEC 60255-1:2022, *Measuring relays and protection equipment - Part 1: Common requirements*

IEC 60255-26:2023, *Measuring relays and protection equipment - Part 26: Electromagnetic compatibility requirements*

IEC 61588:2021, *Precision clock synchronization protocol for networked measurement and control systems*

IEC TS 61850-1-2:2020, *Communication networks and systems for power utility automation - Part 1-2: Guideline on extending IEC 61850*
IEC TS 61850-1-2:2020/AMD1:2022

IEC 61850-5:2013, *Communication networks and systems for power utility automation - Part 5: Communication requirements for functions and device models*
IEC 61850-5:2013/AMD1:2022

IEC 61850-6:2009, *Communication networks and systems for power utility automation - Part 6: Configuration description language for communication in electrical substations related to IEDs*
IEC 61850-6:2009/AMD1:2018
IEC 61850-6:2009/AMD2:2024

IEC 61850-7-1:2011, *Communication networks and systems for power utility automation - Part 7-1: Basic communication structure - Principles and models*
IEC 61850-7-1:2011/AMD1:2020

IEC 61850-7-2:2010, *Communication networks and systems for power utility automation - Part 7-2: Basic information and communication structure - Abstract communication service interface (ACSI)*
IEC 61850-7-2:2010/AMD1:2020

Documents
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Full document details: PD IEC TS 60255-216-1:2025

IEC 61850-7-3:2010, *Communication networks and systems for power utility automation - Part 7-3: Basic communication structure - Common data classes*
IEC 61850-7-3:2010/AMD1:2020

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 61850-7-4:2010/AMD1:2020

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 61850-8-1:2011/AMD1:2020

IEC 61850-9-2:2011, *Communication networks and systems for power utility automation - Part 9-2: Specific communication service mapping (SCSM) - Sampled values over ISO/IEC 8802-3*
IEC 61850-9-2:2011/AMD1:2020

IEC 61850-10:2012, *Communication networks and systems for power utility automation - Part 10: Conformance testing*

IEC 61869-1:2023, *Instrument transformers - Part 1: General requirements*

IEC 61869-9:2016, *Instrument transformers - Part 9: Digital interface for instrument transformers*

IEC 61869-13:2021, *Instrument transformers - Part 13: Stand-alone merging unit (SAMU)*

IEC TS 62351-100-1, *Power systems management and associated information exchange - Data and communications security - Part 100-1: Conformance test cases for IEC TS 62351-5 and IEC TS 60870-5-7*

IEC TS 62351-100-3, *Power systems management and associated information exchange - Data and communications security - Part 100-3: Conformance test cases for the IEC 62351-3, the secure communication extension for profiles including TCP/IP*

IEC TS 62351-100-4, *Power systems management and associated information exchange - Data and communication security - Part 100-4: Cybersecurity conformance testing for IEC 62351-4*

IEC TS 62351-100-6, *Power systems management and associated information exchange - Data and communication security - Part 100-6: Cybersecurity conformance testing for IEC 61850-8-1 and IEC 61850-9-2*

IEC/IEEE 61850-9-3:2016, *Communication networks and systems for power utility automation - Part 9-3: Precision time protocol profile for power utility automation*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

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3.1
functional interoperability
set of requirements which, if satisfied, guarantees an expected and defined behaviour in all conditions of, on one hand, a function, and on the other hand, all functions from which it receives data and all functions using its data

Note 1 to entry: This definition goes beyond the definition of interoperability in the IEC 61850 series, which is limited to the interoperability between IEDs without considering the aspects related to the interaction between functions hosted by them.

3.2
operate time of the functional protection chain
T_{op}
duration of the time interval between the instant when the characteristic quantity is changed at the power system primary, under specified conditions, and the instant when the trip command to the circuit breaker is given

Note 1 to entry: The operate time takes into account the complete functional chain.

Note 2 to entry: The instant when the characteristic quantity is changed is also called "fault inception".

Note 3 to entry: The instant of trip command to the circuit breaker corresponds to the closing of the trip contact used for the circuit breaker opening circuit when the circuit breaker is interfaced by copper wire. This contact can be implemented in protection IED or Binary Input / Output IED (BIOI) (also known as SCU, BIED, see Clause 4).

Note 4 to entry: In case of circuit breakers interfaced by the IEC 61850 series, a part of T_{op} is included in the circuit breaker operating time. This is part of T3 (Intelligent switchgear Total Operating Time) as defined in IEC 62271-3:2015, Figure 1.

3.3
operate time of the IED hosting protection functions
t_p
duration of the time interval between the instant when the characteristic quantity of a protection function in reset condition is received by the communication interface of the IED hosting the protection function, under specified conditions, and the instant when the IED publishes the output representing the trip after the operation of the protection function

Note 1 to entry: t_p includes optional time delay settings.

Note 2 to entry: In a multifunction IED, there can be different t_p for each implemented protection function.

Note 3 to entry: Reset condition means that the protection function is reset and disengaged.

Note 4 to entry: t_p does not include the time delay of the communication network or the acquisition time of the merging unit.

3.4
jitter
sudden, small, irregular time deviations from the expected occurrence with respect to a defined period

Note 1 to entry: The SVs are received or published with an expected period. The variation with respect to the expected instant is referred to as "jitter". This is superposed to an average or mean processing or transmission delay. This jitter is due to both the processing delay of the merging unit publishing the SV stream and to transmission time delay variations in the communication network.

Note 2 to entry: This definition is in line with the concept laid out in IEC TR 61850-90-12:2020 [3], which is in turn based on the definition of Packet Delay Variation in RFC 3393 [4].

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3.5
digital input
digital information received by an IED hosting an application function, having a standardised format, transmitted via a standardised digital interface and communication link, and defined in the IEC 61850 series

Note 1 to entry: The following IEC 61850 services are referred to in this document as digital inputs for a protection function: received GOOSE or R-GOOSE messages, received SV or R-SV messages, received MMS commands, PTP time synchronisation message.

3.6
digital output
digital information sent by an IED hosting an application function, having a standardised format, transmitted via a standardised digital interface and communication link, and defined in the IEC 61850 series

Note 1 to entry: The following IEC 61850 services are referred to in this document as digital outputs for a protection function: published GOOSE or R-GOOSE messages, sent MMS reports.

Note 2 to entry: SAMU or IED hosting a merging unit function also publishes SV as digital output.

3.7
digital interface
standardised input and output port used to perform the interoperability of IEC 61850 Ethernet based digital messages, such as GOOSE/SV/MMS for functional messages, PTP for synchronisation messages and HSR/PRP for networking topology messages

Note 1 to entry: The Ethernet port, electrical or optical, of an IED is an example for Digital Interfaces associated to the IEC 61850 series.

Note 2 to entry: In this document, only Digital Interfaces compliant to IEC 61850 are considered. The proprietary interface required for e.g., Line Differential Protections for communication between different line ends is not covered by this document. Synchronisation signals other than PTP or SNTP are not considered to be digital interfaces, either.

3.8
duplicated message
message published by one or more publishers within a specified time interval having the same subscription criteria for the subscriber

Note 1 to entry: Subscription criteria can include GOOSE Control Block reference or SVID. Further possible criteria include multicast MAC address, application ID, confRev.

Note 2 to entry: The SIM flag is also considered. Therefore, a SV stream with SIM flag = "true" is not duplicating a SV stream with SIM flag = "false".

Note 3 to entry: In case of one publisher, duplicated messages can appear in case of incorrectly configured communication networks or in case of RSTP reconfiguration. HSR and PRP messages are not considered to be duplicated messages.

3.9
redundant message
message published by one or more publisher reflecting the same information acquired with a different acquisition chain

Note 1 to entry: Redundant SV streams can be used to implement a switch over for protection functions.

Note 2 to entry: Redundant GOOSE messages can, e.g., be used to acquire a circuit breaker position with two different BIOI.

3.10
corrupted message
message with a corrupted Ethernet frame resulting in a frame with invalid or damaged content

Note 1 to entry: A corrupted message is often due to alternation during transmission of the frame.

Note 2 to entry: Corrupted content of the message is not considered in this document.

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3.11
Single Event Upset
SEU
change of state caused by one single ionizing particle (ions, electrons, photons...) striking a sensitive node in a micro-electronic device, such as in a microprocessor, semiconductor memory or power transistor, which can result in an error in device output or operation

Note 1 to entry: SEU may cause internal errors, e.g. in memory. Mitigation strategies can be implemented to avoid this internal error to cause an error in device output or operation.

Note 2 to entry: The state change is a result of the free charge created by ionization in or close to an important node of a logic element (e.g. memory “bit”).

3.12
missing Sampled Value
Sampled Value expected by a subscribing function which is not received within a specified time window

Note 1 to entry: The criteria for a sampled value to be considered as missing are defined in 7.4.7.11.

Note 2 to entry: A SV received out of sequence can in some cases still be used by the subscribing function. In this case, it would not be seen as a "missing SV".

3.13
non-nominal
Data Object with a quality attribute with a value different from "good"

Note 1 to entry: For Data Objects or Sampled Values defined under IEC 61850, this means that their quality attribute of the DO is either "questionable" or "invalid".

3.14
Factory Acceptance Test
FAT
customer agreed functional tests of the specifically manufactured system or its parts, using the parameter set for the planned application

Note 1 to entry: This test is typically performed in the factory of the system integrator by the use of process simulating test equipment.

[SOURCE: IEC 61850-4:2011 [5], 3.26]

3.15
Site Acceptance Test
SAT
verification of each data and control point and the correct functionality inside the PACS and between the PACS and its operating environment at the whole installed plant by use of the final parameter set

Note 1 to entry: The SAT is a precondition for the automation system being put into operation.

[SOURCE: IEC 61850-4:2011 [5], 3.27, modified — “Automation system” replaced with “PACS”.]

3.16
operating range
range for which the protection function, under specified conditions, is able to perform its intended function(s) in accordance with the specified requirements

[SOURCE: IEC 60050-447:2020[6], 447-03-16, modified — "interval" replaced by "range", "measuring relay or protection equipment" replaced by "protection function"; the note has been deleted.]

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3.17
effective range
part of the operating range of an input energising quantity or characteristic quantity within which the accuracy requirements are met

[SOURCE: IEC 60050-447:2020[6], 447-07-08, modified – “interval of” replaced by “part of the operating range”; the note has been deleted.]

3.18
analog acquisition chain
series of components situated between the primary input and a digital output delivering a representation of the primary signal, including sensors, analog processing, A/D converter, numeric algorithms, time synchronisation and correlated time stamping implemented in the primary converter or the merging unit

Note 1 to entry: The SVs are synchronised at least to a clock within the merging unit. This clock, in turn, can be synchronised to a local or global time source.

3.19
functional chain
sequence of elements aiming to provide an overall function, in which all elements, except the first, use the output of a preceding element of the set as input, and in which the last element provides the resulting output

EXAMPLE Merging unit, protection function and binary output constitute a functional protection chain.

3.20
ignore input
automatic substitution of the received value by a defined preset value or by the last valid value

Note 1 to entry: It is expected that the next revision of IEC 61850-7-3 provides possibilities for this.

3.21
functional standard
standard included in the IEC 60255-1xx series specifying the requirements for a protection function

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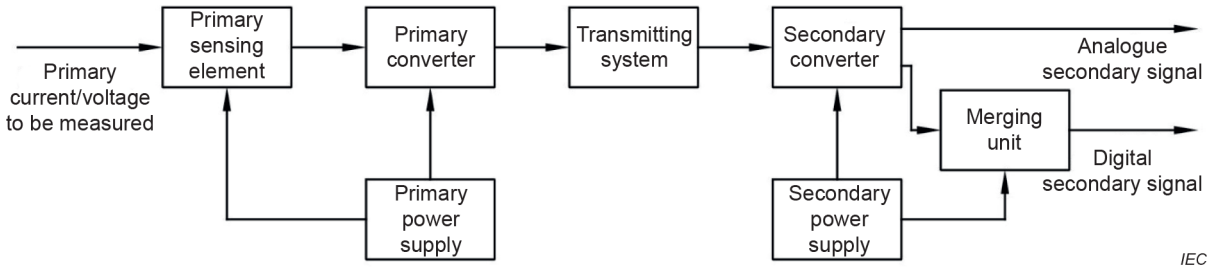
3.22
Low Power Instrument Transformer
LPIT
instrument transformer with no rating assigned to the analogue or digital output power as it is irrelevant

Note 1 to entry: A general block diagram of an LPIT is given in the following figure.



In practice some blocks may be omitted or combined, according to the specific technology of the LPIT under consideration.

Note 2 to entry: The published standards for LPIT (current and voltage) with analog outputs use a low voltage as rated secondary output

[SOURCE IEC 61869-99:2022[7], 3.2.14, modified — Addition of “analogue or digital” in the definition; Addition of a Note 2 to entry.]

4 Abbreviated terms

Table 1 contains a list of acronyms used in this document.

Table 1 – List of acronyms

Acronym	Meaning	Comment
1PPS	1 Pulse Per Second	
ACSE	Association Control Service Element	
ACSI	Abstract Communications Service Interface	See IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020
A/D	Analog to Digital [converter]	
ASDU	Application Service Data Unit	IEC 61850 (all parts), IEC 61869-9:2016
BAP	Basic Application Profile	See IEC TR 61850-7-6:2024 [6]
BCU	Bay Control Unit	
BIED	Breaker I/O IED	IED associated to the circuit breaker. See also BIOI
BIOI	Binary Input/Output IED	Also known as BIED, SIED or CBC when associated to a circuit breaker or SCU when associated to switchgear. No single term is used in the different IEC 61850 series for this equipment. The use of "SCU" for a binary input/output IED associated with switchgear is preferred. However, this abbreviation does not cover other potential uses for binary inputs/outputs to the process level (transformer pumps, cooling system, etc).
CBC	Circuit Breaker Controller	
CID	Configured IED Description	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018, Clause 7

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Full document details: PD IEC TS 60255-216-1:2025

Acronym	Meaning	Comment
CIGRE	Conseil International des Grands Réseaux Électriques	See https://www.cigre.org/
CPU	Central Processing Unit	Inside a microprocessor
CT	Current Transformer	See IEC 61869-2:2012. Includes also LPCT (future IEC 61869-8)
CVT	Capacitor Voltage Transformer	See IEC 61869-5:2011
DA	Data Attribute	Parts of a IEC 61850 Data Object (DO)
DFT	Discrete Fourier Transformation	
DO	Data Object	See IEC 61850-7-3:2010 and IEC 61850-7-3:2010/AMD1:2020
ECT	Electronic Current Transformer	Active LPCT (future IEC 61869-8)
EIT	Electronic Instrument Transformer	Active LPIT
FAT	Factory Acceptance Test	See 3.14
FC	Functional Constraint	See IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020
FCD	Functional Constraint Data	See IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020
FCDA	Functional Constraint Data Attribute	See IEC 61850-7-2 2010 and IEC 61850-7-2:2010/AMD1:2020
FPGA	Field Programmable Gate Array	
F_V	SAMU rated voltage factor	See IEC 61869-13:2021
GNSS	Global Navigation Satellite System	
GOOSE	Generic Object-Oriented System Event	See IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Clause 18
HMI	Human-Machine Interface	
HSR	High-availability Seamless Redundancy	See IEC 62439-3:2021
ICD	IED Capability Description	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018, Clause 7
ICT	IED Configuration Tool	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018
IID	Instantiated IED Description	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018, Clause 7
IED	Intelligent Electronic Device	
IT	Instrument Transformer	Covered by the IEC 61869 series Comprises e.g. Voltage Transformers (VT) and Current Transformers (CT).
K_{SSC}	SAMU rated symmetrical short-circuit factor	for transient performance See IEC 61869-13:2021
LD	Logical Device	See IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020
LGOS	LN GOOSE Subscription (LN used for the supervision of GOOSE)	IEC 61850 Logical Node – see IEC 61850-7-4:2010 and IEC 61850-7-4: 2010/AMD1:2020
LSVS	LN Sampled Value Subscription (LN used for the supervision of SV)	IEC 61850 Logical Node – see IEC 61850-7-4:2010 and IEC 61850-7-4: 2010/AMD1:2020
LTMS	LN Time Master Supervision (LN used for the configuration and supervision of time synchronisation)	IEC 61850 Logical Node – see IEC 61850-7-4:2010 and IEC 61850-7-4: 2010/AMD1:2020
LN	Logical Node	See IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020
LPCT	Low Power Current Transformer	LPIT for acquisition of currents.

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Acronym	Meaning	Comment
LPIT	Low Power Instrument Transformer	Sometimes also referred to as NCIT (Non-Conventional Instrument Transformer) – see IEC 61869-1:2023
LPVT	Low Power Voltage Transformer	LPIT for acquisition of voltages.
MICS	Model Implementation Conformance Statement	See IEC 61850-10:2012
MMS	Manufacturing Message Specification	
MTTR	Mean Time To Restoration	See IEC 60050-192:2015, 192-07-23
MU	Merging Unit	See IEC 61869-9:2016
NTP	Network Time Protocol	See RFC 4330 [9]
PACS	Protection, Automation and Control System	
PAS	Publicly Available Specifications	
PhV	Phase to ground voltages for phases	Phasor – IEC 61850 Data Object – see IEC 61850-7-4:2010
PICS	Protocol Implementation Conformance Statement	See IEC 61850-10:2012
PIXIT	Protocol Implementation eXtra Information for Testing	See IEC 61850-10:2012
P_{ICT}	Protection related settings contained in the ICT tool	
P_{SCL}	Protection related settings contained in a SCL file	
PRP	Parallel Redundancy Protocol	See IEC 62439-3:2021
PTP	Precision Time Protocol	See IEC/IEEE 61850-9-3:2016
R-GOOSE	Routable GOOSE (GOOSE used in inter-substation communication)	See IEC TR 61850-90-1:2010 [10]
R-SV	Routable SV (SV used in inter-substation communication)	See IEC TR 61850-90-1:2010 [10]
RBAC	Role Based Access Control	
RSTP	Rapid Spanning Tree Protocol	See IEEE 802.1Q-2022 [11]
SAMU	Stand Alone Merging Unit	See IEC 61869-13:2021
SAT	Site Acceptance Test	See 3.15
SCADA	Supervisory Control And Data Acquisition	
SCD	System Configuration Description	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018
SCL	Substation Configuration Description Language	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018
SCT	System Configuration Tool	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018
SCU	Switchgear Control Unit	See BIOI. Other existing abbreviations or designations for this equipment are – IEC 62271-3:2015 – switchgear controller – IEC 61850-4:2011 and 61850-4:2011 /AMD1:2020, 5.1 – digital switchgear interface [5] – IEC 61850-90-2 (xml file annex) – CBC – circuit breaker controller [12] – IEC 61850-7-500 [13] Use case Breaker BIED
SE	Setting Group (editable)	Functional constraint – see IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Table 4

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Full document details: PD IEC TS 60255-216-1:2025

Acronym	Meaning	Comment
SED	System Exchange Description	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018
SEU	Single Event Upset	See 3.11
SER	Supervision Event Recorder	
SG	Setting Group	Functional constraint – see IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Table 4
SIED	Switch I/O IED	IED associated to switches (disconnectors). See also BIOI
SNTP	Simple Network Time Protocol	See RFC 4330 [9]
SOTF	Switch On To Fault	Subfunction available in some protection functions
SP	Setting (outside setting group)	Functional constraint – see IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Table 4
SSD	System Specification Description	See IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018, Clause 7
SV	Sampled Value	IEC 61850-9-2:2011 and IEC 61850-9-2:2011/AMD1:2020, IEC 61869-9: 2016
TAL	Time Allowed to Live	Parameter used for GOOSE
TCP	Transmission Control Protocol	
TICS	TISSUE Implementation Conformance Statement	See IEC 61850-10:2012
TISSUE	Technical ISSUE	See https://iec61850.tissue-db.com/parts.mspx
TR	Technical Report	
TPAA	Two Party Application Association	Applies to MMS client/server association See IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020
TPM	Protection rated SAMU current channel	See IEC 61869-13:2021
TPX	CT Accuracy Classes	See IEC 61869-2:2012
TPY		
TPZ		
UCA	Utility Communications Architecture	See http://www.ucaiug.org
VT	Voltage Transformer	See IEC 61869-3:2011 and IEC 61869-5:2011. Includes also LPCT (future IEC 61869-7)
9-2LE	Acronym for UCAIuG – Implementation Guideline	See [14]

5 Functional chain of the protection function

5.1 General

As mentioned in Clause 1, requirements regarding characteristics of the communication network and its architecture are not within the scope of this document. As a consequence, characteristics and configuration of network switches and VLAN are not discussed here. This is addressed by IEC TR 61850-90-4:2020 [15].

Clause K.2 discusses the impact of the communication network, its architecture and its components on the digitally interfaced protection function.

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5.2 Operate time of the functional chain

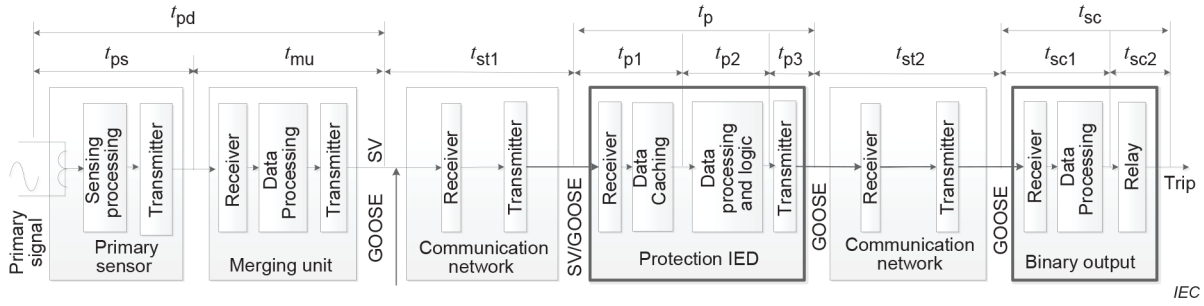

Figure 2 – Operate time of the functional chain of a protection function (example: LPIT)

The operate time T_{op} of the functional protection chain is defined by the following equation (see Figure 2):

$$T_{op} = t_{pd} + t_{st} + t_p + t_{sc}$$

where

t_{pd} is the actual time between an event taking place on the primary and its result(s) appearing in the output of the merging unit (IEC 61869-9:2016). The maximum time for t_{pd} for a MU is given by the setting LPHD.MaxDI (see IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020, 6.3.2);

NOTE 1 According to IEC 61869-9:2016, t_{pd} ≤ 2 ms for AC protection and measuring applications (see Table K.13).

NOTE 2 The delay time t_{pd} can occur in LPIT due to, for instance, band limiting filters and digital processing.

t_{st} is the transmission delay of the communication network;

t_p is the operate time of the protection function in the hosting IED;

t_{sc} is the delay of the IED hosting the Binary Output (BIOI).

NOTE 3 In case of circuit breakers interfaced by the IEC 61850 series, t_{sc} forms part of the circuit breaker operating time. This is part of t_3 (Intelligent switchgear Total Operating Time) as defined in IEC 62271-3:2015, Figure 1.

In the scheme presented in Figure 2, $t_{pd} = t_{ps} + t_{mu}$, where

t_{ps} is the time delay related to the primary sensor;

NOTE 4 For SAMU, t_{ps} related to the associated Instrument Transformers is considered to be zero. For active LPIT, t_{ps} reflects the delay associated to the primary sensor which depends on the employed technology.

t_{mu} is the delay of reception, processing and transmission of the MU.

NOTE 5 For Instrument Transformers with digital output, see IEC 61869-9:2016.

NOTE 6 In this document, it is considered that the Instrument Transformer output refers to the digital interface publishing the IEC 61850 series SV stream.

The scheme presented in Figure 2 contains two publisher / subscriber links. The total transmission time related to the communication network is in this case $t_{st} = t_{st1} + t_{st2}$, where

t_{st1}, t_{st2} are the delay of reception and transmission between publisher and subscriber (leg 1 and 2, respectively) of the communication network. This can include the delay related to several switches in series. In case of point-to-point connection, t_{st1} or t_{st2} = 0.

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In the scheme presented in Figure 2, the operate time of the protection function t_p is

$$t_p = t_{p1} + t_{p2} + t_{p3}$$

where

t_{p1} is the delay of reception, buffering and decoding of SV and GOOSE by the protection function. For multiple SV streams, this includes the sample coherency alignment performed by the input alignment buffer (input alignment table) of the protection function (Figure 3). t_{p1} also depends on the maximum acceptable time for the protection function for a complete sample to arrive. It does not correspond to a fixed value but depends on the reception of the different SV.

NOTE 7 t_{p1} mainly reflects the buffering and decoding of the SV. The corresponding time for GOOSE is expected to be different.

t_{p1min} is the minimum time for reception and decoding of SV and GOOSE by the protection function without any buffering of the SV.

For the scheme shown in Figure 2,

– $t_{p1} = t_{p1min}$ for protection functions subscribing to one SV stream or for the SV with longest $t_{pd} + t_{st1}$

– $t_{p1} > t_{p1min}$ for the SV streams with shorter $t_{pd} + t_{st1}$

If the protection function receives different streams, the operate time shall be determined based on the arrival of the most delayed SV (see 7.4.5, Figure 3).

t_{p2} is the processing time of protection algorithm. This time is within a certain range and is dependent on the implemented processing execution cycle of the protection algorithm, associated filtering and any intentionally set time delay. IEC 61850-8-1:2011 and IEC 61850-8-1:2011/AMD1:2020 require that the time stamp of the associated DO in published dataset (e.g. Tr or Op) corresponds to the instant when the protection function changes the value of the DO, independent from the time information of the SV having caused this change.

t_{p3} is the output processing time of trip GOOSE.

For the IED hosting protection functions, t_{p1}, t_{p2} and t_{p3} are conceptual and it is possible that they are not accessible for measurement for the user. The time stamp in the frame of the published GOOSE message corresponds to the instant of its publication. The operate time t_p will vary within a certain range. The minimal and maximal expected time delay for t_p shall be reported by the manufacturer according to the relevant functional standard.

The publication time of the GOOSE can be described as the time difference between the time stamp in the GOOSE message and the time stamp of the message frame.

In the scheme presented in Figure 2 the delay of the BIOI hosting the binary outputs is split into two components:

$$t_{sc} = t_{sc1} + t_{sc2}$$

where

t_{sc1} is the delay of reception, decoding and processing of the BIOI;

t_{sc2} is the delay related to the activation of the output contacts of the BIOI.

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The user shall design the PACS and specify the different delays in accordance with his requirements for the operate time of the functional protection chain T_{op} (e.g. T_{op} < 30 ms for busbar faults).

For the IED implementing the Binary Outputs, t_{sc1} and t_{sc2} are conceptual and it is possible that they are not accessible for measurement for the user.

For protection functions subscribing to more than one SV stream, there can be cases with a negligible time delay for the connection to one merging unit and a bigger time delay for the reception of SV from another merging unit (see Figure 3). As mentioned before, in this case, t_{p1} of the SV stream arriving first is increased accordingly ($t_{p1}{}^{B}$ in Figure 3). Requirements related to this for protection functions are specified in 7.4.5. The relevant functional standard shall specify the time synchronisation requirements in case of multiple subscribed SV streams.

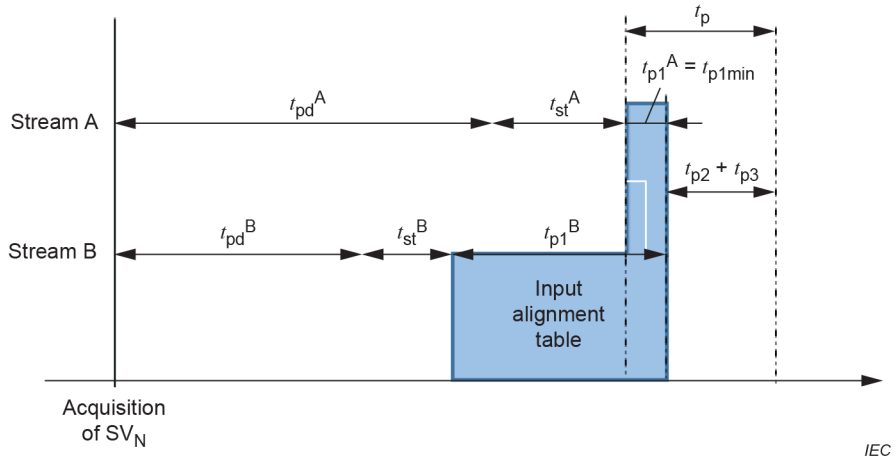

Figure 3 – Time delay in case of two SV streams

In addition to the time delays described above, every sampled value ASDU reaching the subscribing function contains a variation, called jitter. Figure 4 illustrates the composition of the total transmission time delay and the total jitter between the instant of acquisition of an analog value by the merging unit and its reception by the IED hosting the subscribing protection function.

For a given sampled value ASDU, the time delay t_{dsv} between the acquisition of the primary value and its reception at the protection input port can be split in an average (or median in case of asymmetrical distribution) time delay t_{dsvav} and a variable jitter j_{sv}.

$$t_{dsv} = t_{dsvav} \pm j_{sv}$$

The maximum time delay t_{dsvmax} is associated to the maximum jitter j_{svmax}:

$$t_{dsvmax} = t_{dsvav} + j_{svmax}$$

t_{dsvav} takes into account the processing time of the merging unit t_{pd} and the transmission time of the communication network t_{st1}. (Figure 2)

j_{svmax} is the corresponding sum of the jitters (Figure 4).

The user can give additional requirements for the delay of the analog data acquisition chain.

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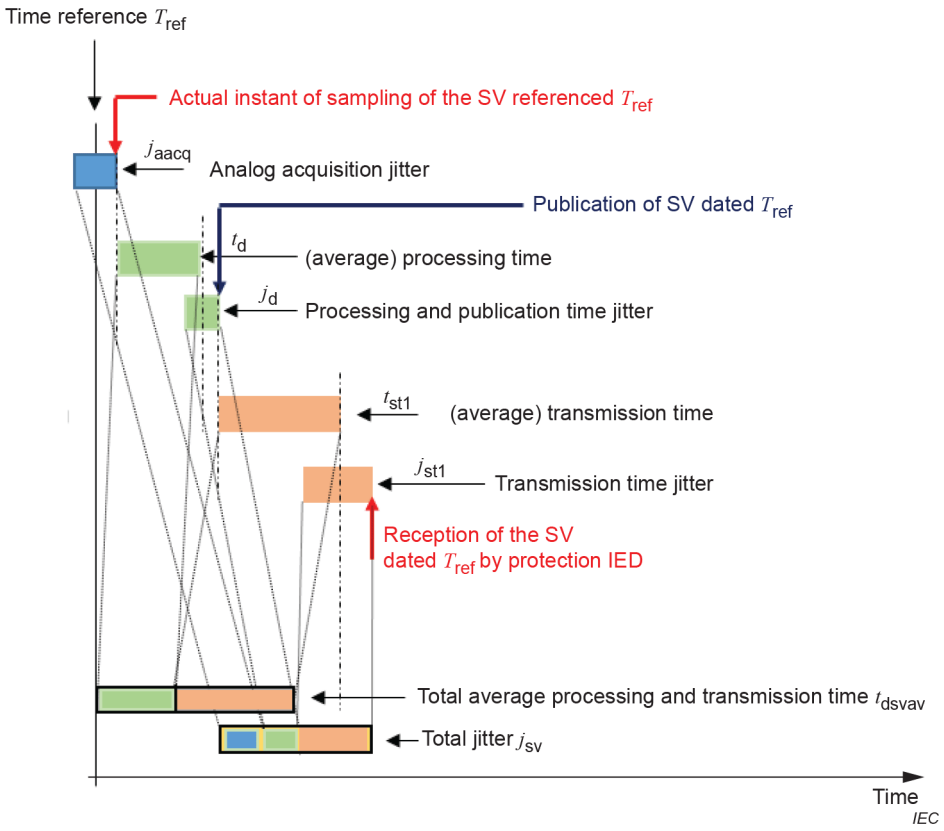

Figure 4 – Processing and transmission time and (symmetrical) jitter of SV

6 Engineering of digitally interfaced protection functions

6.1 IEC 61850 series communication configuration

IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018 define the import of the communication configuration of the IED hosting the protection function, including control blocks, input sections, datasets etc. by the ICT from the common SCD file describing the complete PACS.

The configuration tool associated to the IED hosting protection function shall be able to use the input section in the SCD file in order to configure the subscription of signals used by the protection function received via SV and GOOSE messages. This implies the SV published by the merging unit to be included in the SCD file and also to be used for the configuration of the merging unit through its own ICT tool. The ICT tool associated to the IED hosting the protection function shall support “later binding” of subscribed data as described in IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018, 9.3.13.

The configuration tool associated to the IED protection function shall be able to use the information in the SCD file in order to configure the GOOSE messages to be published by the protection function and all other IEC 61850 services which are used (for example client-server).

The top-down engineering approach based on SCD is the preferred engineering method for IED hosting protection functions (see IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018). For some applications, it is acceptable to configure the communication interface of the IED hosting the protection function with other methods, for instance with the ICT, with direct setting of communication parameters on the IED HMI, or by importing a partial SCL configuration.

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Full document details: PD IEC TS 60255-216-1:2025

For protection applications using communication between substations based on IEC TR 61850-90-1:2010 [10] via communication tunnels or via R-GOOSE and R-SV, exchange configuration information is provided in SED files. According to IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018, Figure 1, the SED file is imported by the SCT and not by the ICT. The configuration parameters of R-GOOSE and R-SV are provided for the ICT in the SCD file.

6.2 Setting of protection functions

6.2.1 Reference values for protection function settings

In general, secondary values and secondary rated values have no significance for digitally interfaced protections as all analog values are expressed in primary quantities (IEC 61869-9:2016).

If parameters or thresholds of a protection function are expressed in % or p.u., then a reference (or base) value or range is required. An associated rated primary value shall be defined by the user. This could be e.g. based on rated values of Instrument Transformers, rated values of Power Transformers or nominal values common to a feeder or to a voltage level in a substation.

If no such base values are available, it is recommended to use the primary rated values of the Instrument Transformers, if possible. The advantage of this choice is a consistency with the accuracy ratings of the Instrument Transformer in the functional chain (see K.1.1).

This concerns in particular the following parameters:

– Rated primary phase-to-phase voltage
– Rated primary phase-to-ground voltage
– Rated primary phase current
– Rated power system frequency

NOTE 1 In general, voltages measured by VT represent phase-to-ground voltage and the nominal voltage of a network is expressed as phase-to-phase voltage.

NOTE 2 Some substations can be connected to systems having different system frequencies on the same or on different voltage levels (e.g. HVDC converter stations, back-to-back converter stations).

The effective and operating ranges of a protection function shall be declared by the manufacturer in the technical documentation and stated in the test report according to the relevant functional standard (see 8.4 and 7.4.3).

The effective range and the operating range for the voltages and currents for the digitally interfaced protection function shall be expressed in terms of RMS primary values. It may also be presented in form of % or p.u. associated to a base primary value. In this case, the manufacturer shall indicate the value or the possible range for the base value.

A setting expressed in terms of RMS secondary values is not applicable.

6.2.2 Online change of settings

A MMS client can change setting parameters of a digitally interfaced protection function online via MMS if the server of the IED hosting the protection function provides this functionality. The capability to support setting via MMS is optional in IEC 61850. If implemented in the IED hosting the protection function, the change of settings via IEC 61850 services shall be compliant with IEC 61850-7-3:2010 and IEC 61850-7-3:2010/AMD1:2020.

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Full document details: PD IEC TS 60255-216-1:2025

IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020 define for each logical node class a set of optional setting parameters. The standard offers the possibility to define additional product specific data objects for settings using related private namespace, for the case that the optional defined objects are not sufficient or incomplete. In case of extension to add settings, the rules specified in IEC TS 61850-1-2:2020 and IEC TS 61850-1-2:2020/AMD1:2022 shall be applied.

According to IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, 5.7, two variants of settings are available (see also IEC 61850-7-3:2010 and IEC 61850-7-3:2010/AMD1:2020, 7.6):

– individual settings: they have a functional constraint SP (Setting). Individual settings can be written and the new value is applied immediately.
– settings that belong to a setting group: they have a functional constraint SG (Setting Group). The values of these settings can be edited through the functional constraint SE (Editable Setting Group).

If not specified otherwise in the relevant functional standard, if a change of setting related to the protection is applied to a protection function which has started, this setting change shall be applied immediately, and the protection function shall be reset. The IED hosting the protection function shall not reboot in this case. Effective application of online setting changes to the protection function shall be confirmed by a positive acknowledgement.

NOTE 1 There are protection functions for which it is possible that a reset after setting change will not be required, e.g. for thermal overload protection.

The manufacturer of the protection function shall declare if there are conditions under which a change of the settings is rejected, and the time required for the change of settings.

NOTE 2 IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 specify the positive and negative response after a setting group change request. A similar request response is defined for setting change (constraint SP).

NOTE 3 The user can read out the setting after change to confirm that the setting update is applied.

IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 define a specific service called “SetDataValues” to change individual settings with functional constraint SP. A dedicated set of services is provided according to IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Clause 16 to change a setting group or a single setting parameter of a setting group with functional constraint SG/SE.

If a setting group cannot be changed, a negative acknowledgement is sent to the client according to IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020. In this case, no value of the new setting group shall be applied.

The services themselves are already tested during the conformance test according to IEC 61850-10:2012. This includes the verification that the IEC 61850 communication service is interoperable but not the verification of the function itself. IEC 61850-10:2012 does not specify which data objects are used and if the connection to the related protection function is implemented and provided correctly.

To simplify the understanding and reference of the setting parameter, the SCL file (ICD, IID) of the IED hosting a protection function should contain for each setting data object a description text with the parameter name similar as used in the ICT. This secures identification the right setting is selected on test client side when the data model contains this information.

6.2.3 Import of protection application settings from SCL

The IEC 61850 series defines settings of the protection LN. Although these settings are only a subset of the settings defined by the manufacturer for the protection functions, this would give the users a common base for the management of settings.

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The import of settings from SCL is an optional feature defined in IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018. ICT associated to IEDs hosting protections functions shall have the capability to import settings from an SCL file (e.g. SCD) and to export settings to an SCL file (e.g. IID).

The following aspects should be taken into account:

– The settings defined in the corresponding Logical Nodes of the IEC 61850 series should be used. For each protection function, it should be verified if settings available in existing Logical Nodes need to be extended when reviewing the relevant functional standard. A generic workflow is shown in Figure 5 for import of settings in the IED Configuration Tool (ICT). This workflow is consistent with the one defined in IEC 61850-4:2011 and IEC 61850-4:2011/AMD1:2020, 5.3.6 [5]. In this process, the user settings are mapped to IEC 61850 settings in the SSD file. The values of the settings can then be imported into the System Configuration Tool (SCT). These settings are referred to as P_{SCL} in Figure 5. The SCD file (System Configuration Description) with these settings is imported in the ICT. When importing into the ICT, the value of the protection settings can be converted to IED and ICT specific settings (referred to as "P_{ICT}" in Figure 5), which can then be downloaded to the IED. The settings are expected to be discussed in IEC TR 61850-90-30 [16] and are also covered in IEC TR 61850-7-6:2024 (BAP) [6].

  If the IED or ICT specific parameters are to be modified online, these parameters have to comply with the rules for extension of IEC 61850 Logical Nodes as specified in IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020.

– Top-down setting approach based on a list of user defined settings or settings defined from IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020 or from the relevant functional standard should be possible. These settings can be contained in the SSD or SCD file. In this case, the conversion to any internal proprietary format shall be covered by the engineering process. It is possible that this requires simple calculations in order to map the settings to the format used by this particular manufacturer of the protection functions.

– If applicable, settings shall be defined using primary values (see 6.2.1). SV received by protection functions are published with primary values and secondary values are not available for digitally interfaced protection functions. In addition, in case of LPIT, secondary values expressed in Volt and Ampere may have no physical meaning.

NOTE IEC 61850 requires the use of primary values for settings. Secondary values can be used in some legacy applications (see 6.2.1). However, user HMI or tools (SCT, ICT, etc.) can provide the possibility to enter and to edit setting values expressed in secondary quantities or p.u or %.

– It shall be possible to use IEC 61850 services to read out and, if implemented and activated, to write settings.

Relevant settings are defined as optional DO for all protection LN in IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020. In case of extension, the rules to add further DO, including settings, specified in IEC TS 61850-1-2:2020 and IEC TS 61850-1-2:2020/AMD1:2022 shall be applied. On this base, additional settings could be added in the relevant Logical Nodes.

For each protection function, the applicable settings under IEC 61850 and their definitions shall be defined in the corresponding functional standard.

IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018 require the IID or ICD files corresponding to the IED hosting the protection to indicate which setting parameters.

– can be imported directly from the SCD file,

– can be set online via the ICT or IEC 61850 services.

If a setting parameter is not contained in the SCL, it is understood that the setting shall be managed in a proprietary way.

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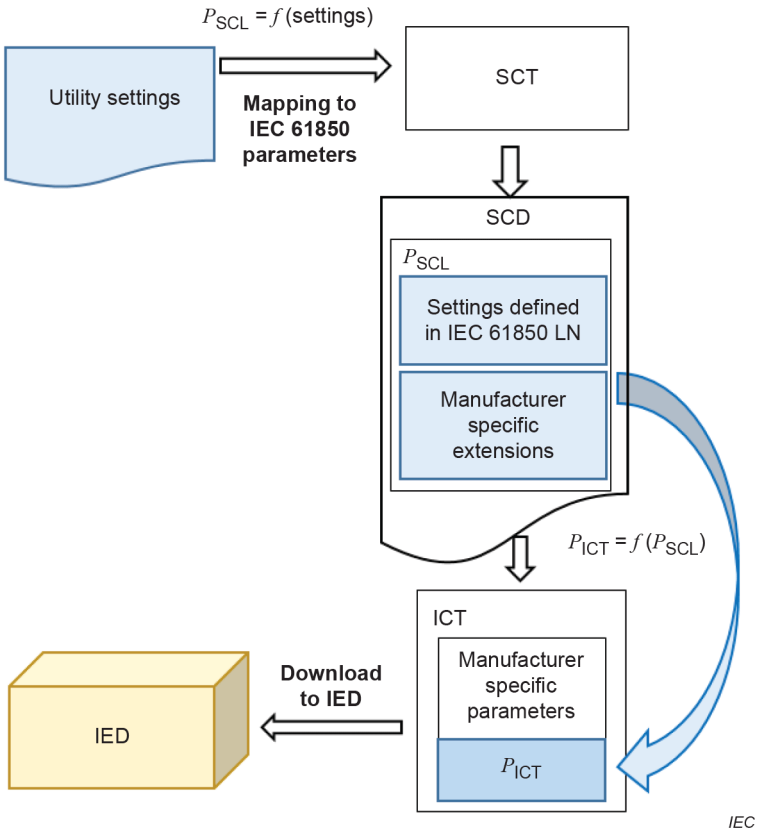

Legend

P_{ICT} Protection related settings contained in the ICT tool,

P_{SCL} Protection related settings contained in a SCL file.

Figure 5 – Workflow for import of settings in IED based on SCD (see IEC 61850-6:2009 and IEC 61850-6:2009/AMD1:2018)

6.2.4 Determination of setting values

The possible setting range for a protection function shall be declared by the manufacturer. For digitally interfaced protection functions, the maximum setting range shall be within the effective range declared by the manufacturer. The definition of accuracy and settings of the timers and time settings can be identical to the analog interfaced protection functions.

The possible setting range of protection functions can be greater than the capability of the analog acquisition chain. As for analog interfaced protections, the user shall make sure that the settings used in a specific system are consistent with the characteristics of the implemented analog acquisition chain, including

– the merging unit associated to LPIT and the associated primary current and voltage sensors
– SAMU including interfaced CT, VT, LPCT or LPVT.

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For digitally interfaced protection functions, the settings as defined in the relevant DO shall be applied. Depending on the unit defined in the concerned data attribute (e.g. ASG) in the SCL file, these can be either

– settings expressed directly in primary values,
– or relative settings e.g. as a % of a rated or nominal base value of an element of the power system (rated voltage, line impedance, etc.) or of a rated primary value of the Instrument Transformer (see 6.2.1). In this case, the relevant functional standard shall specify how the reference value is determined.

NOTE The settings in the case of analog interfaced protection functions are often expressed in % or in per unit (p.u.) of the setting range or of a nominal or reference value (see 6.2.1). In IEC 61850 setting DO, they are normally expressed as primary values.

The accuracy requirements for digitally interfaced protection functions are covered in 7.4.3.

6.3 Implementation of test mode and simulation

The Logical Nodes associated to protection functions shall implement test mode. They can be grouped together in one or more Logical Device(s) associated to a protection function or a protection function group (see K.3). The DO of LN Pxxx.Mod and the DO LLN0.Mod (in case of LN grouped in a LD) shall be controllable and shall provide at least the states "off", "on" and "test".

NOTE Values "blocked" and "test/blocked" only come into effect for IED with hard wired process interface. For protection functions implemented in IEDs without direct process interface, they are not required.

The IED in which the protection function is implemented shall support the processing of simulated messages for both SV and GOOSE according to IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020.

7 Digital inputs of protection functions

7.1 General

IEC 61850 based protection functions are associated to Logical Nodes or Logical Devices. One IED can contain several protection functions with possibly different needs and different operation modes. The consequence of this is that the subscribed data (SV and GOOSE) may have to be processed in a different way for different functions in the IED.

Most of them use data published by several other Logical Nodes, which contain, e.g. the Data Attributes (DA) stVal (Status Value), q (quality), the Data Objects (DO), and the service parameter SmpSynch (only for SV, see IEC 61850-9-2:2011 and IEC 61850-9-2:2011/AMD1:2020). Both analog data (e.g. sampled values) and binary data (e.g. GOOSE) are concerned.

A simple example is a protection function subscribing to several SV streams or to several GOOSE, like blocking signals or the position of the circuit breaker. At a given moment, one or several of these sources may be in test mode, not time synchronised, etc.

This clause defines the methodology to be used for protection functions to specify their expected functional behaviour depending on the values, flags and attributes associated to IEC 61850 Data Objects (7.3) and their application for sampled values (7.4), GOOSE (7.5) and reports (7.6).

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7.2 Input signal source

The input signals to an LN can be switched between process signals from other functions and tests signals from functions dedicated to testing (even from testing devices) defined through the data object InRef. The selection of the source does not depend on the value of the DO Beh of the Logical Node. In any case, the data is processed and published according to the value of DO Beh (see IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020).

Data attribute setSrcRef specifies the object reference to the input that is normally used as input while setTstRef specifies the reference to data object used for testing. By setting the data attribute tstEna to "true", the application will use the test signal referred to by setTstRef instead of the data object referenced by setSrcRef used for normal operation. A function LN can have multiple instances of InRef for multiple inputs (see IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020). The DA “tstEna” can be set independently from the DO Mod (e.g “test”) of the LN or LD to change the input sources. This enables to execute different test scenarios. In order to guarantee a consistent testing of protection functions, the user should set the DA “tstEna” of all InRef to the same value for all Logical Nodes or for the Logical Device under test (see Clause K.3).

NOTE 1 In the general case, it is preferable to change first the Mod of the LN or LD to “test” and then to set “tstEna” to “true”. This is expected to be defined in the test procedure depending on the constraints of the test case.

Digitally interfaced protections functions shall support the capacity to switch all inputs to a test source. The implementation of the test system also has to be taken into account by the engineering of the PACS communication system.

If the protection function is represented by a group of Logical Nodes (Clause K.3), the switching of the input references using tstEna shall be performed simultaneously on all those Logical Nodes.

NOTE 2 There is no requirement in this document for the capacity to change setSrcRef and setTstRef in runtime.

7.3 Attributes and flags

7.3.1 Quality Attribute

Data Attributes contained in data quality q (see K.1.5 Table K.8) are defined in IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Subclause 6.2.3.9, Table 10. The data attribute and its associated quality attribute are recommended to be always included in the same GOOSE or SV dataset subscribed by the IED hosting the protection function.

EXAMPLE 1 Associate PTOC.Op.general with PTOC.Op.q.

This can be verified by the SCT (System Configuration Tool) or by the ICT (IED Configuration Tool), when importing the SCL file for configuration. The ICT of the IED hosting the protection function shall give a warning if a Data Set in the SCL files does not contain a Quality Attribute associated to the status or measurement values.

The Time Data Attribute (e.g. PTOC.Op.t) for the same Data Object (signal), it is not necessary in the Data Set of the GOOSE message and is normally not required for real-time applications like protection functions.

IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 describe the meaning of each attribute of q, but this description is not always sufficiently detailed to be used as a base to specify the expected functional behaviour of applications, in particular protection functions. For this reason, the relevant functional standard for protection functions shall define the understanding of the received q attribute and the related behaviour. This may depend on the use case and for this reason shall be configurable for the protection function.

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Full document details: PD IEC TS 60255-216-1:2025

IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Table 11 defines the "detailQual" identifiers as follows:

– overflow: if true, the value of the attribute to which the quality has been associated is beyond the capability of being represented properly (used for measurand information only).

EXAMPLE 2 A measured value can exceed the range that can be represented by the selected data type, for example the data type is a 16-bit unsigned integer and the value exceeds 65 535.

– outOfRange: if true, the attribute to which the quality has been associated is beyond a predefined range of values. IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 require the server to decide if validity shall be set to “invalid” or “questionable” (used for measurand information only).

EXAMPLE 3 A measured value can exceed a predefined range, however the selected data type can still represent the value, for example the data type is a 16-bit unsigned integer, the predefined range is 0 to 40 000, if the value is between 40 001 and 65 535, it is considered to be out of range.

– badReference: if true, the value may not be a correct value due to a reference being out of calibration. IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 require the server to decide if validity shall be set to “invalid” or “questionable” (used for measurand information and binary counter information only).

– oscillatory: to prevent overloading of event driven communication channels, it is desirable to detect and suppress oscillating (fast changing) binary inputs. If a signal changes in a defined time (t_{osc}) twice in the same direction (from 0 to 1 or from 1 to 0) then IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 require it to be defined as an oscillation and this attribute to be set to true. If a configured number of transient changes is detected, IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 require them to be suppressed and the validity status to be set to "questionable” in this time. If the signal is still in the oscillating state after the defined number of changes, IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 require the value to be left in the state it was in when this flag was set and the 'Quality.validity' to be changed from "questionable" to "invalid" and kept so as long as the signal is oscillating.

  If the configuration is such that all transient changes are to be suppressed, IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020 require the 'Quality.validity' to be set immediately to 'invalid' and 'oscillatory' flag to true (used for status information only).

– failure: if true, a supervision function has detected an internal or external failure.

– oldData: if true, an update is not made during a specific time interval. The value can be an old value that may have changed in the meantime. This specific time interval can be defined by an allowed-age attribute.

NOTE "Fail silent" errors, where the equipment stops sending data, will cause oldData to be set to true. In this case, the last received information was correct.

– inconsistent: if true, an evaluation function has detected an inconsistency.

– inaccurate: if true, the value does not meet the stated accuracy of the source.

EXAMPLE 4 The measured value of power factor can be noisy (inaccurate) when the current is very small.

IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Annex D define a relation between the value of the validity attribute ("good", "invalid", "questionable") and the detailed quality (see Table 2). It is possible to publish this validity attribute without associated detailed quality. In this case, it is considered that the data is “questionable” or “invalid” for another reason than those listed in the detailed qualities.

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Table 2 – Link between DA "detailQual" and validity (IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Table D.1)

detailQual	invalid	questionable
overflow	X	
outOfRange	X	X
badReference	X	X
oscillatory	X	X
failure	X	
oldData		X
inconsistent		X
inaccurate		X

If the detailQual of received data is not consistent with its validity q, the data shall be processed as invalid by the protection function.

IEC 61869-9:2016 has requirements for the Quality Attributes associated to sampled values published by merging units (see IEC 61869-9:2016, 6.903.9) (see K.1.5).

7.3.2 Data Attribute “source”

It is considered that the change of the value of the data attribute “source” is intentional. The protection function shall thus process normally the data, regardless of the value of the DA “source”, and indicate and log that the data attribute “source” of a component of the received data has changed.

7.3.3 operatorBlocked

The operator is able to block communication outputs by setting **‘blkEna**’ to “true”. This intervention is done on data level, i.e. on the individual information produced by a function. Upon activation of ‘blkEna’ on a certain data, the published data is frozen. IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Table 10 asks that the indications ‘**operatorBlocked**’ and ‘**oldData**’ are set to the associated data quality attribute, as the value is no longer updated.

This feature is different and independent from the modes ‘blocked’ or ‘test/blocked’ of Logical Nodes, which affect all the process outputs of a function, while ‘blkEna’ has effect on data level (see [17]). The expected behaviour of a protection function is specified in 7.4.7.2 for subscribed SV and in 7.5.3.2 for subscribed GOOSE.

NOTE IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020 indicate that BlkEna is applicable to communication outputs only. This applies to all functions implemented in the same IED. There is a need to also have the possibility to block communication inputs. This is at the moment only covered for commands (CmdBlk). These aspects could be addressed in future editions of IEC 61850 (all parts).

7.3.4 Test

The behaviour of a function is a result of the object “Beh” of its superior hierarchical level, if implemented (see Clause K.3), and of its controllable object ‘Mod’. To reach a definite behaviour among these two access variants, the states are sorted by priority, where ‘off’ has priority over ‘test’ which has priority over ‘on’ (IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020).

EXAMPLE If the superior Logical Device is set to ‘test’, Logical Nodes on a lower hierarchical level can only be varied into ‘test/blocked’ behaviour or switched ‘off’, never be set to ‘on’ (see [17]).

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For a function which is ‘on’ or ‘blocked’, IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020, Table A.2 requires that an information received from a function under test (Beh = test) is processed as invalid. Therefore, the application of a function in ‘on’ or ‘blocked’ state shall ignore input data with q.test set to “true”. The meaning of “ignore” shall be defined for each application and for each Data Object used as input.

Logical Nodes publishing states of physical inputs can also be in test mode. This can be used by the operators to indicate that tests are performed

– with a test set representing the primary equipment,
– on the primary equipment itself,
– on the secondary equipment.

Since the test bit (e.g XCBR.Pos.q.test) will be set to “true” in that case, these inputs have to be processed accordingly.

If the DA q.validity of a DO representing incoming data is “good”, a function which is set to “test” or to “test/blocked” processes both DO with q.test = “false” and DO with q.test = “true” “as valid”. This characteristic has an important impact on the test methodology. The processing principles expressed in various chapters of the standard are summarised in IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020, Annex A. These principles are needed to secure the interoperability of functions in the way the user expects applications to work.

NOTE The behaviour for commands from a client is different, see IEC 61850-7-4:2010 and IEC 61850-7-4:2010/AMD1:2020, Annex A.

In order to achieve interoperability and enable testing, digitally interfaced protection functions shall properly implement the data quality processing rules as given in the IEC 61850 series. Only if all functions participating in a scheme are processing data quality (e.g. validity, test, source...) in the same understanding, an effective isolation and testing of a function can be reached.

7.3.5 Simulation

At the IED level, the option to set the logical node LPHD data Sim.stVal to “true” or “false” allows the IED to select the multicast messages that will be processed and the therewith received signals. In order to use this feature to test an IED, Sim.stVal is set to “true” and the test simulation device has to inject GOOSE messages with the simulation bit in the header set to “true”. The same behaviour applies to a sampled value stream.

Figure 6 (IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020) shows an IED receiving simultaneously two similar GOOSE messages (Goose 1). Goose 1 from the test simulation device has its message header simulation bit set to “true” while the other Goose 1 message coming from the configured nominal source has its simulation bit set to “false”. If the physical device logical node LPHD1 data Sim.stVal of the IED is also set to “true”, it will process only the Goose 1 message from the test device. The Goose 1 signal from the normal source (“actual device” in Figure 6) will continue to be ignored until the LPHD1 data Sim.stVal is reset to “false”. If the data Sim.StVal is set to “false” it will process the Goose 1 message with simulation bit set to “false” from the normal source.

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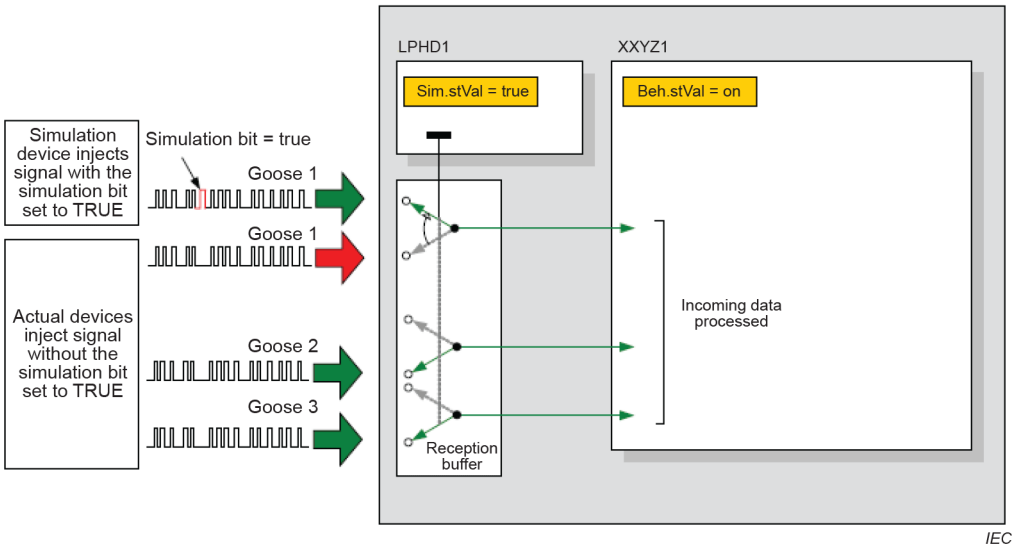

Figure 6 – Data used for receiving simulation signals (IEC 61850-7-1:2011 and IEC 61850-7-1:2011/AMD1:2020, Figure 40)

While LPHD1 data Sim.stVal remains “true”, two other GOOSE messages from actual devices, Goose 2 and Goose 3, with simulation bits “false” will still be processed according to the IEC 61850 series as shown in Figure 6 as there are no other Goose 2 or Goose 3 messages on the network that have the simulation bit set to “true”. As soon as there will be a Goose 2 or Goose 3 that have the simulation bit set to “true”, the device will subscribe to this/these GOOSE. Messages with simulation bit set to “true” are expected to be only published by test systems. IEDs belonging to the PACS are expected to always publish all messages with simulation bit set to “false”. IEDs hosting protection functions shall always publish all messages with simulation bit set to “false”.

Not all input signals systematically come from the test tool. Therefore, the Simulation is not completely equivalent to the use of a traditional physical commutator switch (“test handle” / physical test switch) diverting all wired input signals associated to a wire terminal-interfaced IED. Also, when designing the test cases and test scenarios, the effects of GOOSE coming from the system under operation shall be taken into account. Depending on the test aim, it might be preferable to combine the use of SIM and the test mode.

Test sets should publish messages as default with the SIM flag set to “true”. The user has to intentionally set the SIM flag to “false” if this is needed (see 7.7). This avoids unintended tripping in SAT or maintenance tests in PACS.

IEC TR 61850-10-3:2022 [1] and CIGRE TB 760 [17] discuss in detail testing aspects related to IEC 61850 based functions.

7.4 Sampled values

7.4.1 General

This clause describes the general requirements related to sampled values as inputs for the protection function, including protocol, network interface and time synchronisation performance.

The sampled values subscribed by the IED hosting the protection function shall be published by merging units which are compliant with IEC 61869-1:2023 and IEC 61869-9:2016 and, as consequence, with IEC 61850-9-2.

NOTE 1 SAMU compliant with IEC 61869-13 are also compliant with IEC 61869-9:2016 and to IEC 61869-1:2007 and IEC 61869-6:2016. The later two are now deprecated and covered by IEC 61869-1:2023.

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Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

For this reason, protection functions shall be compliant with sample rates of IEC 61869-9:2016 identified for protection applications (see K.1.2, Table K.5). The IED hosting the protection functions shall accept

– 4 800 Hz with two ASDU per data frame (IEC 61869-9:2016, Subclause 6.903.3, Table 902 line #3 – preferred sample rate).

In order to support backward compatibility with UCA guideline “9-2LE” [14], the IED hosting the protection functions should also accept

– 4 000 Hz with one ASDU per data frame (IEC 61869-9:2016, Subclause 6.903.3, Table 902 line #1 (50 Hz systems).
– 4 800 Hz with one ASDU per data frame (IEC 61869-9:2016, Subclause 6.903.3, Table 902 line #2 (60 Hz systems).

NOTE 2 The option “4 000 Hz with one ASDU per data frame” and “4 800 Hz with one ASDU per data frame” is intended to cover backward compatibility and application in retrofitting. This option is intended to be deleted in a future revision from this list. Additional conditions need to be fulfilled to be backwards compatible with the UCA guideline (“9-2LE”) [14], such as length and number of channels and number of members of the data set.

NOTE 3 With respect to a publication of 2 samples per frame, the publication of only 1 sample per frame leads to an increased traffic in the communication network. It enables a slightly shorter operate time of the protection function.

NOTE 4 The preferred sample rate according to IEC 61869-9:2016 is a fixed sample rate of 4 800 Hz for power systems with a nominal frequency of both 50 Hz and 60 Hz.

NOTE 5 Special applications like transient earth fault protection or Travelling Wave based protection can have higher sample rates.

A protection function which receives several SV streams is not required to have the capacity to receive SV streams with different sampling frequencies or different numbers of ASDU per data frame. However, this could be a user requirement related to constraints e.g. for retrofitting.

In any case, the manufacturer of the protection function shall declare the number of SV streams and their respective characteristics (sample rates, composition of ASDU and ASDU per data frame) that can be subscribed simultaneously by the IED hosting the protection function and received by the protection function, using the naming convention specified in IEC 61869-9:2016, Subclause 6.903.2.

NOTE 6 Sample rates, composition of ASDU and ASDU per data frame of subscribed SV is expected at least to be based on IEC 61869-9:2016, Table 902.

The following major information are included in each SV ASDU:

– 1 or 2 samples per ASDU (see IEC 61869-9:2016, Subclause 6.903.3, Table K.5 Rows 1 to 4).
– one or more quantities per dataset

NOTE 7 IEC 61869-9:2016, 6.903.2 indicates a limitation of 24 analog quantities per dataset for 100 Mbit/s networks

– SmpCnt associated to the TimeStamp. The instant of acquisition of the analog values is given by the Time Stamp which can be calculated from the SmpCnt.
– SmpSynch and SynchSrcID giving the time synchronisation information of the MU publishing the SV (see K.1.6).

7.4.2 Redundant SV streams

Protection functions can receive redundant SV streams on application level (e.g. two SV streams reflecting the same primary values acquired with a different acquisition chain) and dynamically switch over to the redundant stream if a problem with the default stream appears. Examples are described in K.2.2.

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The criteria for switching over are not covered in this document. When implemented, the manufacturer of the protection function shall document which criteria can be implemented to perform the switch over and the reset to the initial stream.

If implemented, the unavailability of the protection function in case of sudden loss of one of the redundant SV streams shall be less than 1 s if not specified otherwise in the relevant functional standard. The reset behaviour of the protection function in case of switch over of SV streams shall be specified in the relevant functional standard.

7.4.3 Accuracy and performance characteristics of the protection function

Several protection functions can be implemented independently in an IED. The relevant functional standards in the IEC 60255-1xx series require the manufacturer to describe the accuracy characteristics for each protection function in the product documentation. The accuracy of digitally interfaced protection functions and the accuracy of MU including the analog acquisition chain shall be identified independently (see K.1.1.2). For the complete functional chain of the protection function (primary and secondary analog sensors, MU, communication network, protection function, circuit breaker interface), the user shall verify that his overall accuracy requirements are respected.

Manufacturers of protection functions shall specify requirements related to the behaviour of voltage and current transformer with digital output (LPIT or CT/VT+SAMU) for each protection function. This also can include the associated type test protocol. These requirements include:

– Recommended accuracy class of IT (see K.1.1), LPIT and SAMU.

NOTE 1 A sensitive ground fault detection probably needs a higher accuracy class compared to a normal overcurrent protection.

– Recommended attenuation of higher harmonics (anti-aliasing, often combined with accuracy class of IT) (see K.1.3 and 7.4.4).
– Minimum low pass cutoff frequency of the Anti-aliasing filter (to coordinate the attenuation of 2^{nd} and of 5^{th} harmonics which is used in some algorithms).
– behaviour for DC component and used High Pass time constant (similar to the combined use of TPX, TPY, TPZ, see IEC 61869-2:2012 [18]).
– Maximum value of voltages and currents of merging units (K_{ssc}, clipping level).

NOTE 2 It is important that the system integrator ensures the interoperability between MU /SAMU and digitally interfaced protection function and the respect of the overall performance requirements of the functional chain.

– CT and VT requirements. They are identical to those specified in relevant functional standard (IEC 60255-1xx series) for the analog interface protection function.
– Requirements regarding special behaviour of IT (CVT, trapped charges…).
– Requirements regarding the coordination between voltage and current channels of (e.g. transient performance, time constant, DC rejection)
  - SAMU associated to CT and VT. This should be based on the nameplate of the SAMU (see IEC 61869-13:2021).
  - Digitally interfaced LPIT. This should be based on the nameplate of the LPIT (see future IEC 61869-7 and IEC 61869-8).

This clause concerns the accuracy requirements related to the protection function. A guidance to determine the accuracy of the overall functional chain this is provided in Annex F.

In addition, the manufacturer of the protection function shall declare resulting requirements for the acquisition chain, including VT, CT and merging units. In order to indicate the expected characteristics of the LPIT, MU and SAMU required for functional interoperability with the protection function, the manufacturer of the protection function shall perform and document end-to-end tests with at least one typical functional chain (SAMU or LPIT).

Documents
Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

The indications of characteristics of VT, CT, LPIT, MU and SAMU shall be included in the product documentation.

The error of a protection function with digital input is only related to the processing of the input SV stream(s), including errors related to the calculation of derived quantities (e.g. impedance), resampling, approximations and application of digital filters.

The accuracy errors related to the protection function shall be defined as either:

– a relative error with respect to the indicated value (example ± 3 %), or;
– as an absolute error (example ± 50 V primary), or;
– a relative error (example ± 3 %) or an absolute error (example ± 50 V primary), whichever is greater.

The accuracy requirements for the protection function should not be based on rated quantities. This shall be covered by the relevant functional standard.

Regarding the effective range of voltages and currents, the system integrator shall take into account the characteristics of the entire chain together with those of the protection function. It is expected that the analog acquisition chain represents a greater limitation than that of the protection function.

NOTE 3 The system integrator is supposed to verify the consistency of the analog acquisition chain in the design phase according to the technical documentation of the different devices forming the functional protection chain. However, users can perform complete tests of the functional chain.

To determine the operating range of the protection function, the user has to take into account the characteristics of the entire chain including the transfer function of the MU.

The protection function shall be able to process analog values in its effective range and in its operating range. The relevant functional standards (i.e. IEC 60255-1xx series) shall specify the accuracy requirements for effective and operating range and other performance characteristics for the digitally interfaced protection function based on IEC 60255-1:2022. The other performance characteristics include:

– Operate time: The operate time is defined as duration of the time interval between the instant of fault inception and the instant of relay operation. For protection functions with digital inputs, this corresponds to the duration of the time interval between the instant the SV corresponding to the fault inception is received by the function and the instant it publishes the corresponding GOOSE message (see t_p, 3.3 and 5.2).
– Reset time;
– Reset ratio;
– Stability;
– Steady state accuracy (for threshold).

7.4.4 Frequency transfer function

Regarding transient phenomena and frequency range, it shall be verified that the digitally interfaced protection function is compatible with

– the transfer function of the merging unit publishing the SV stream according to IEC 61869-9:2016 (see K.1.3);
– transient characteristics of LPIT and/or SAMU (e.g. TPM class, K_{ssc}, T_i, …) (see K.1.3);
– in addition, the saturation characteristics of the primary CT in case of SAMU connected to current transformers.

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Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

Regarding the characteristics of the CT (saturation, remanence, flux,) the same approach as that in IEC 60255-1xx series to formulate the requirements of the primary CT can be taken for the digitally interfaced protection function.

Regarding the transfer function of the merging units, tests using models of MU in real-time simulators can be used to verify the correct performance of the protection algorithm. This can imply a large number of tests.

The manufacturer of the digitally interfaced protection function shall declare if the protection function is compatible with the transfer function mask according to IEC 61869-1:2023 (see K.1.3) or describe the restrictions for the acceptable transfer function mask. In any case, the digitally interfaced protection function shall be able to process SV streams with low frequency component (≤ 1 Hz).

NOTE 1 IEC 61869-13:2021 associates an IEC 61850 DO to the input time constant T_{sec} of the SAMU which can be used by the protection function.

NOTE 2 The exact cut-off frequency or time constant can be important and can be considered depending on the protection function. This time constant is asked to be included in the documentation of the merging unit.

With a particular reference to SAMU (IEC 61869-13:2021), the manufacturer of the digitally interfaced protection function shall also give advice on choosing

– devices with suitable accuracy class (equal or perhaps preferably one class better than the primary CT),
– the TPM class of the device (depending on phase accuracy requirements of protection functions used),
– K_{SSC} – This parameter should be chosen sufficiently high in order to make sure that the characteristics of the primary CT and of the SAMU are coordinated and correspond to the requirements of the protection function. In particular, the effective range and the operating range of the protection function have to be covered (see K.1.1.2),
– T_I which should be chosen higher than the primary time constant of the power system,

NOTE 3 T_I is the specified time constant of the signal used for the transient performance test of the SAMU (see IEC 61869-13:2021, 3.4.1301). A value of T_I higher than the time constant of the network allows a correct representation of the primary values.

– T_{sec} should be chosen higher than that of the associated primary CT.

With a particular reference to LPIT (future IEC 61869-8), the manufacturer of the digitally interfaced protection function shall also give an advice on the parameters defined for LPCT.

7.4.5 Buffering and Layer of the entry stage of the IED hosting protection functions

Based on requirements of IEC 61869-9:2016, a jump of SmpCnt is possible if it is related to a resynchronisation (see K.1.6). This shall be taken into account by the input processing of SV of the protection functions in the following way:

If SV arrive with SmpCnt out of sequence while the value of SmpSynch is not 0, the input buffer of the function may consider the missing samples as lost (see 7.4.7.11). In case of loss of synchronisation (SmpSynch = 0), no discontinuity of SmpCnt is expected except in case of jumps related to re-synchronisation.

NOTE Guidelines for the time synchronisation architecture are being developed under the umbrella of the IEC 61850 series, including expected behaviour of the different components in case of loss of synchronisation and in case of re-synchronisation.

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Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

For all digitally interfaced protection functions in one IED or for each digitally interfaced individual protection function, the manufacturer shall declare how many consecutive missing or invalid samples are acceptable. When this number is reached, the protection function shall be dynamically blocked (see 7.9, Table 12). The manufacturer shall declare how many consecutively received valid SV are required to unblock the protection function.

Subclause 6.902.2 of IEC 61869-9:2016 gives the maximum processing delay time limits of MU for publishing the sampled data (see K.1.7, Table K.13). For protection applications, this maximum processing time delay is 2 ms. The delay of the PACS communication network has also to be considered for the maximum time delay of the SV seen by the input port of the protection function.

The average time delay and jitter caused by the communication network has to be taken into account. These values can be obtained by communication network system studies (see K.2.1).

For protection functions subscribing to one SV stream, the time delay has no impact other than a shift of the processing time. It has, however, an impact on the total operate time of the functional chain (see 5.2 Figure 2). The size of the input buffer of the protection function is determined by the expected jitter.

The manufacturers of the protection function should declare whether the function is sensitive to the jitter or not. If yes, the manufacturer should declare the maximum acceptable jitter for one SV stream. The user has to verify the match of combined jitter of the merging unit (jitter of t_{pd}, see 5.2 Figure 2) and of the communication network (jitter of t_{st1}, see 5.2 ,Figure 2) on one side, and the acceptable jitter of the protection function on the other side.

For protection functions subscribing to more than one SV stream, the maximum relative time delay between the SV streams also defines the size of the receiving buffer of the protection function. The principle of the buffer with an input alignment table is shown in Figure 7. The worst case would be a negligible time delay for the connection to one merging unit and a big transmission time delay for the connection to another merging unit (see 5.2 Figure 3). The protection function shall be able to process SV streams with relative delays of up to 3 ms. If a SV is not received in the delay specified by the manufacturer, it shall be considered as missing (see 7.4.7.11).

For some use cases, such as MU used in point-to-point mode and if the IED hosting protection functions has a limited input buffer, there may be additional requirements concerning the interval between the publication of two (or more) consecutive SV (i.e. the jitter). In this case this jitter shall be specified by the user besides the maximum time delay limit indicated in Table 901 of IEC 61869-9:2016 (see K.1.7, Table K.13).

The relevant functional standard shall define the expected behaviour of the protection function in case of loss of global or local synchronisation indicated by SmpSynch (see Annex H).

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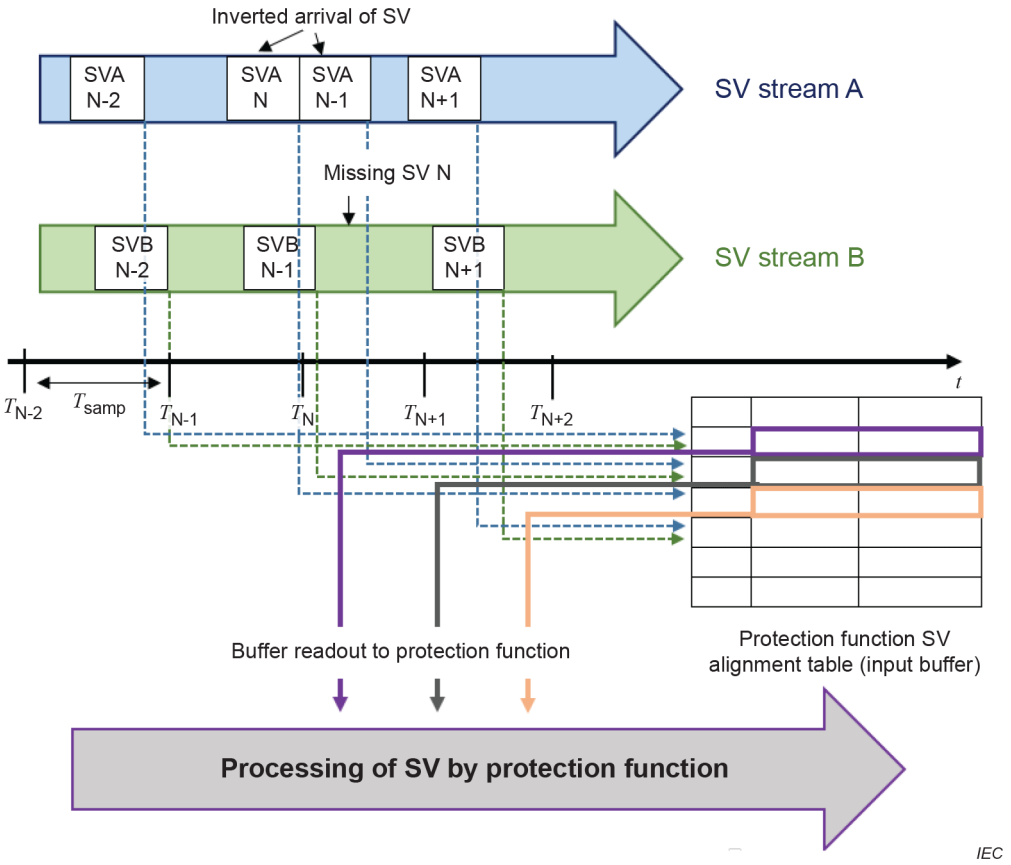

Figure 7 – Operation of SV input buffer of a protection function

7.4.6 Comparison of the protection chain between protections with digital inputs and hard wired interfaced protections

Compared with the wired terminal interfaced protection IED, the functional protection chain in a fully digital PACS as described in 5.2 has an additional time delay ΔT. Figure 8 shows the comparison between a functional protection chain in a fully digital PACS represented in Figure 2 and a wired terminal interfaced protection IED. The resulting difference of time delay is:

$$\Delta T = t_{mu} + t_{st1} + t_{st2} + t_{p1} + (t_{p3} - t_{p3}') + t_{sc1} - t_{adc}$$

where

t_{mu} is the delay for reception, processing and transmission of the MU (see 5.2). In practice, this delay is generally about 1 ms to 2 ms;

t_{sti} is the delay for reception and transmission of path i of the communication network (see 5.2). If the point-to-point mode is used, there is no such delay. If there are several switches, or several communication exchanges through the same switch, each time delay is designed by an additional indice i (t_{sti}). In the example shown in Figure 8, the time delay of two communication switches (t_{st1}, t_{st2}) are taken into account;

t_{p1} is the delay for reception, buffering and decoding of SV and GOOSE by the protection function, including sampled value interpolation and processing time of IED;

t_{p1}' represents the analog signal acquisition and conversion in the wired terminal interfaced IED;

t_{p3}' represents an eventual internal communication delay in the wired terminal interfaced IED;

t_{sc1} is the delay of reception and decoding for the Binary Output;

t_{adc} is the time delay for the A/D conversion in the wire terminal interfaced protection IED.

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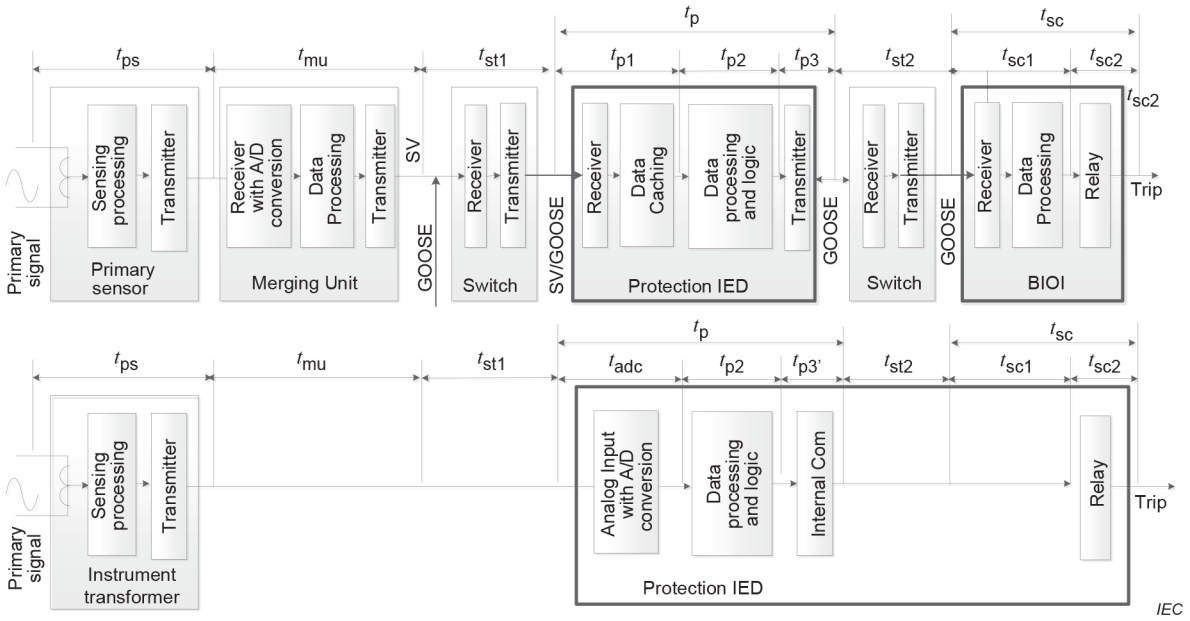

Figure 8 – Comparison of Operate time of digitally interfaced protection chain and wire terminal interfaced protection IED

Compared with protection IED with analog input and wired output, the protection chain with digital inputs can contain up to four IED types, including primary sensor, merging unit, IED hosting the protection function and BIOI interfacing the circuit breaker (see Figure 8). Depending on the application cases and the number of IEDs, the total operation time of the complete functional protection chain could be longer than for wire terminal interfaced IED. The impact of this additional delay shall be evaluated with regard to the given application case.

NOTE Additional delays of 1 ms to 10 ms have been observed in the past, and less than 2 ms in more recent implementations. This also depends on the engineering of the communication network (see 5.2). It is expected that this difference will be reduced further as technology progresses.

7.4.7 Expected behaviour in case of non-nominal situation

7.4.7.1 General

Non-nominal sampled values are sampled values with a quality attribute which is not "Valid" (i.e. "Questionable" or "Invalid" (see 3.13 and K.1.5, Table K.8)). This concerns the validity bits only (validity and detailQual). In IEC 61850-9-2:2011 and IEC 61850-9-2:2011/AMD1:2020, Table 21, the validity value "reserved" is mapped to "Invalid".

Sampled Values with Simulation service parameter in the SV ASDU set shall also be processed according to the value of their quality data attributes.

7.4.7.2 Quality Attributes

The interpretation given in Table 3 for the quality attribute "detailQual" (see 7.3.1 – Table 2) shall be used for protection functions. Table 3 lists the "detailQual" attributes as defined in IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, the corresponding requirements for sampled values published by MU according to IEC 61869-9:2016 (see K.1.5) and the application for protection functions as defined in this document.

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Full document details: PD IEC TS 60255-216-1:2025

Table 3 – Interpretation of DA "detailQual" for Sampled Values and other analog values received by Protection Functions

Definition in IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1: 2020		IEC 61869-9:2016 [applicable to SV published by MU]			Meaning and expected behaviour for the protection function of DetailQual for received data
detailQual	**Definition**	**Specified use**	**invalid**	**question-able**	
Not applicable			X		Applicable to any type of received input data. The protection shall process the input as invalid.
Not applicable				X	Applicable to any type of received input data. The relevant functional standard shall specify how to process the input
overflow	Value beyond the capability of being represented properly.	Not Used. Always set to "false"	X	Prohibited by IEC 61850-7-2: 2010 and IEC 61850-7-2: 2010/AMD1:2020, Annex D	Not used in IEC 61869-9:2016. May be applicable to other analog information, e.g. phasors (PhV, A). The protection shall process the input as invalid.
outOfRange	Value beyond a predefined range of values.	True in case of Clipping. Publication with validity attribute "questionable"		X	Publication with validity attribute set to "questionable" preferred. The relevant functional standard shall specify how to process the input. Applicable to SV and other analog information, e.g. phasors (PhV, A)
inaccurate	The value does not meet the stated accuracy of the source.	True if signal may not respect the specified accuracy	Prohibited by IEC 61850-7-2: 2010 and IEC 61850-7-2: 2010/AMD1:2020, Annex D	X	Applicable to any type of received input data. The relevant functional standard shall specify how to process the input. Applicable to SV and other analog information, e.g. phasors (PhV, A).
badReference	Value may not be a correct value due to a reference being out of calibration.	Not Used. Always set to "false"		X	Publication with validity attribute set to "questionable" preferred. The relevant functional standard shall specify how to process the input. Not used in IEC 61869-9:2016. Can be applicable to other analog information, e.g. phasors (PhV, A).
oscillatory	Signal changes in a defined time twice in the same direction.	Not Used. Always set to "false"	not applicable	not applicable	Not Applicable to analog input data (SV, phasors, etc..), only to binary input data. The protection shall process the input as invalid.

Documents
Document Sharing Hub
Full document details: PD IEC TS 60255-216-1:2025

Definition in IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020		IEC 61869-9:2016 [applicable to SV published by MU]			Meaning and expected behaviour for the protection function of DetailQual for received data
detailQual	**Definition**	**Specified use**	**invalid**	**question-able**	
failure	Indicates that a supervision function has detected an internal or external failure	Used to detected errors.	X	Prohibited by IEC 61850-7-2: 2010 and IEC 61850-7-2: 2010/AMD1:2020, Annex D	Applicable to any type of received input data. The protection shall process the input as invalid.
oldData	If an update is not made during a specific time interval.	Not Used. Always set to "false"	Prohibited by IEC 61850-7-2: 2010 and IEC 61850-7-2: 2010/AMD1:2020, Annex D	X	Not used in IEC 61869-9:2016. May be applicable to other information, e.g. phasors (PhV, A). The relevant functional standard shall specify how to process the input.
inconsistent	Indicates that an evaluation function has detected an inconsistency.	Not Used. Always set to "false"	Prohibited by IEC 61850-7-2: 2010 and IEC 61850-7-2: 2010/AMD1:2020, Annex D	X	Not used in IEC 61869-9:2016. May be applicable to other information, e.g. phasors (PhV, A). The relevant functional standard shall specify how to process the input.
NOTE The table indicating the Relation of the detailed quality identifiers with invalid or questionable quality has been moved in edition 2.1 of IEC 61850 (all parts) to IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020, Annex D. In edition 2, it was in IEC 61850-7-3:2010, 6.2.3.					

Based on relevant entries in Table 3, the value range of analog energizing quantities received by protection functions and the associated detailed quality attributes are visualised in Figure 9. This figure shows the amplitudes for

– the rated range of utilisation until the limit of rated accuracy;
– the extended range of utilisation between the limit of rated accuracy and the maximal numeric representation.

Regarding the "inaccurate" DetailQual attribute, IEC 61869-9:2016 (Subclause 6.903.9) asks this attribute to be set to "true" when an instrument transformer supervision function has detected an error condition other than the loss of synchronism indicating that the sampled value does not meet the nameplate measuring accuracy class, but may be useable.

This can have several causes and also lead to the "inaccurate" data validity to be independent of the value of the measured current or voltage and to be true over the whole measurement range. This case is not reflected in Figure 9. Between "Limit of Rated Accuracy" and "Clipping", no accuracy requirement is given by the standards. For this reason, "inaccurate" data validity in Figure 9 can still be "false" in this range even if the nameplate accuracy may no longer be respected. There is no direct relation between "questionable" data validity and the amplitude of the analog value.

Consistently with the use of the quality attributes defined in Table 3 and Figure 9, the expected functional behaviour of a protection function shall be defined for each received SV stream in the relevant functional standard. This should be done in a way aiming at a globally optimised performance of the PACS. A proper specification and validation of this aspect are basic requirements for a functional interoperability between merging units publishing sampled values and subscribing protection functions.

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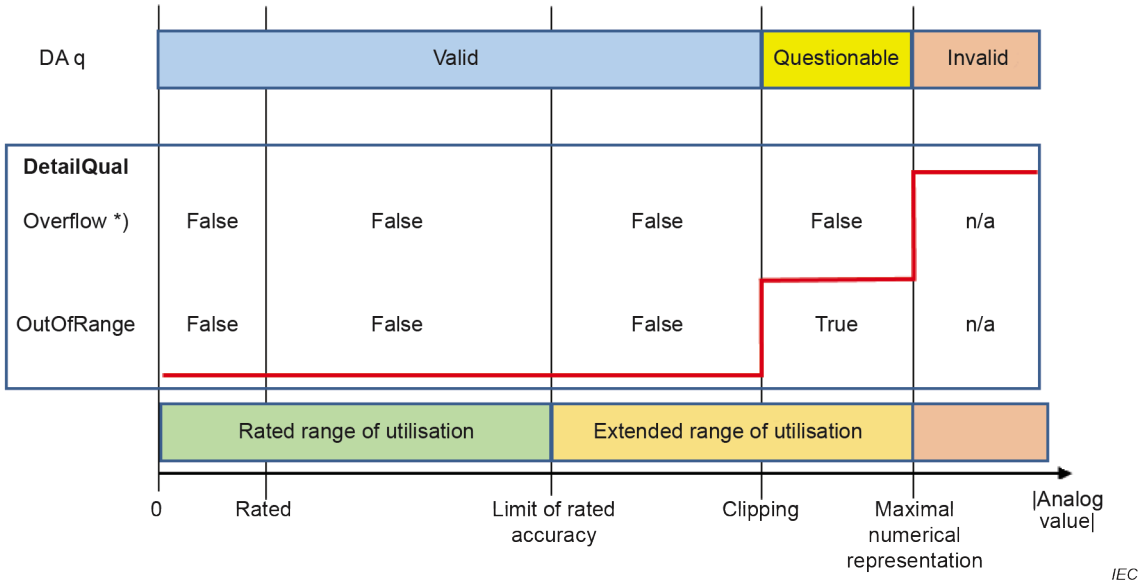

NOTE Case marked by *) prohibited by IEC 61869-9:2016 but possible in the more general profile given by IEC 61850-7-2:2010 and IEC 61850-7-2:2010/AMD1:2020.

Figure 9 – Relation between quality attributes and range of analog energising values

The expected functional behaviour of the function (process input as valid, ignore input- see 3.20, block dynamically) is described using the options defined in Table 4 and Table 5. It should be possible to select the propagation of the quality attribute (Table 7) independently. The colour code of Table 5 is an aid for the interpretation by humans, whereas the associated letter facilitates processing by configuration tools.

Table 4 – Options for detailed specification for the expected behaviour of a protection function in case of non-nominal input signal

	Expected functional behaviour of the protection function	Signal	Propagation of the quality attribute
Possible entries	V: Valid I: Ignore B: function dynamically blocked (see 7.9)	-: Ok A2: Warning A3: Alarm	-: no propagation P: propagation
Default value	V	-	-
Definition of the entries	Table 5	Table 6	Table 7

NOTE 1 Table 5 is consistent with one of the options, suitable for protection functions, defined in IEC TR 61850-90-11:2020, Annex E and Annex F. There is also an effort ongoing to formalise the expected behaviour of functions in a more detailed way in the IEC 61850 series. When this approach is published (new edition of IEC 61850-7-3), the simple behaviour defined in Table 5 needs to be mapped to that update. The discussed approach includes the possibility to define the expected behaviour in a more detailed way and the associated method of configuration. E.g. the proposal includes to maintain a last acquired valid value. For protection functions, the best solution for some inputs can be to substitute with a safe fallback value and not to keep the last valid value.

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