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Edition 1.0 2022-02

TECHNICAL REPORT

colour inside

Communication networks and systems for power utility automation – Part 10-3: Functional testing of IEC 61850 systems

IEC TR 61850-10-3:2022-02(en)

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COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

Part 10-3: Functional testing of IEC 61850 systems

FOREWORD

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IEC TR 61850-10-3, which is a Technical Report, has been prepared by IEC technical committee 57: Power systems management and associated information exchange.

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

Draft	Report on voting
57/2199/DTR	57/2328/RVDTR

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 Report is English.

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

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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INTRODUCTION

The growing success of the IEC 61850 series calls for guidelines for testing of substations implementing this standard. This Technical Report aims at producing a practical guide for protection, automation and control (PAC) engineers on best practise for testing of the latest amended IEC 61850 based devices and systems.

Since the release of the first edition of the IEC 61850 standard in 2002-2005 thousands of substations have been built making use of the new multi-part standard. Most of those systems are more integrated and complex than the previously deployed, making use of multi-function capable IEDs and the rich feature set of IEC 61850. Especially the sending and receiving of protection trips via GOOSE messaging control commands/indications, monitoring and time synchronisation information over the same shared equipment or network will need to drive changes to existing test methods and practices as many of the traditional test boundaries have changed.

Despite the large number of commissioned IEC 61850 substations, considerable uncertainty among end-users (system integrators and power utilities) regarding the correct testing procedures still exists. Devices implemented according to the first edition of the standard also utilized a limited part of the test related functionality in the standard. Much of the functionality included in IEC 61850 to allow efficient, functional oriented testing has been clarified and extended in the second edition of IEC 61850-6, IEC 61850-7-1 to IEC 61850-7-4, IEC 61850-8-1 and IEC 61850-9-2. Therefore, there is a need to help the industry by describing the methods and principles for testing the IEC 61850 based applications.

This Technical Report provides insight into the changing requirements and practice of testing following the introduction of IEC 61850 based devices and systems. One example is the disappearance of so-called 'hardwired' connections between substation automation devices. These connections are replaced by communication networks and this means that traditional simulation and isolation of signals for the purpose of testing is no longer possible.

COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

Part 10-3: Functional testing of IEC 61850 systems

1 Scope

This part of IEC 61850, which is a technical report, is applicable to testing of applications within substations. It is intended to give practical guidelines to perform the stages of quality assurance defined in IEC 61850-4:2011. However, while the quality assurance in that document begins with the IED manufacturer development stage and focuses on the role of the system integrator this document focuses on end-user requirement fulfilment.

The report may be useful to users applying IEC 61850 to other domains, however testing of IEC 61850 systems outside the substation domain is not within the scope of this document.

This document describes:

- A methodical approach to the verification and validation of a substation solution
- The use of IEC 61850 resources for testing in Edition 2.1
- Recommended testing practices for different use cases
- Definition of the process for testing of IEC 61850 based devices and systems using communications instead of hard wired system interfaces (ex. GOOSE and SV instead of hardwired interfaces)
- Use cases related to protection and control functions verification and testing

This document does not cover the conformance testing of devices according to IEC 61850-10 or methodologies for testing of abstract device independent functions.

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 61850-4:2011, *Communication networks and systems for power utility automation - Part 4: System and project management*

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/AMD1:2018

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

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 81346-2, *Industrial systems, installations and equipment and industrial products - Structuring principles and reference designations - Part 2: Classification of objects and codes for classes*

3 Terms, definitions, abbreviated terms and acronyms

3.1 Terms and definitions

3.1.1 Testing types

3.1.1.1
acceptance tests
tests which serve to verify if an IED or a scheme meets the customer requirements

Note 1 to entry: This could include a specific FAT if it is required by the customer.

3.1.1.2
commissioning tests
test on an item carried out on site, to prove that it is correctly installed and can operate correctly

Note 1 to entry: The commissioning phase is carried out on site (in the substation) when the installation phase is complete. These tests are performed to ensure the safe and reliable operation of the system with associated substation interfaces. The commissioning phase is a global operation which follows the installation and runs until the energization, load tests and adjustments are completed.

[SOURCE: IEC 60050-151:2001, 151-16-24]

3.1.1.3
conformance tests
first of the functional tests of the components of an integrated substation automation system (SAS)

Note 1 to entry: Every IED or Device Under Test (DUT) which belongs to the SAS, is tested. The conformance tests are performed to show that the IED are compliant to requirements relative to environment, data model, communication and functional standards. These tests can be performed by a vendor or by an independent authority who certify test results.

3.1.1.4
Factory Acceptance Tests (FAT) of schemes and systems
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 3.20]

3.1.1.5
installation tests
tests carried out by the contractor after installation in order to verify if the system is ready to be commissioned

3.1.1.6
interoperability tests
tests applied to an assembly of IEDs of the same or different vendors

Note 1 to entry: They shall demonstrate that these IEDs, when interconnected by a proper communication system, may operate together, sharing information and performing their functions in a secure way and with specified level of performance. They should be performed with the customer acceptance during system development and factory acceptance tests.

3.1.1.7
Communication Interface tests:
tests applied to two function elements of a distributed function interfacing over a substation communication interface in order to evaluate the impact of the communications architecture and traffic on the performance of the distributed function or sub function

3.1.1.8
Maintenance Tests
all testing activities which occur after the IED or PAC scheme has been put into service

3.1.1.9
Site Acceptance Tests (SAT)
tests consisting of the verification of each data and control point and the correct functionality inside the automation system and between the automation system 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 3.21]

3.1.1.10
End-to-End test
End-to-end testing is used to ensure that the integrated components of an application function as expected – from the input from the process to the output to the processTesting Methods

3.1.1.11
black-box testing
testing based upon the requirements with the function or system treated as a "black-box" when the internal workings of the system are unknown

Note 1 to entry: In black-box testing the system is given a stimulus (input) and if the result (output) is what was expected, then the test passes. No consideration is given to how the process was completed.

3.1.1.12
bottom-up testing
testing which starts with the function elements and works upwards

Note 1 to entry: It involves testing the function elements at the lower levels in the hierarchy, and then working up the hierarchy of sub-functions until the final function is tested.

3.1.1.13
closed-loop testing

testing characterized by the fact that the output from the device or system under test is looped back and affects the next stage of the simulation

3.1.1.14
local testing

process where all simulation tasks, the assessment of the tested device performance and the documentation of the results from the test are performed by the tester at the site of the tested devices or system using mobile test equipment

3.1.1.15
manual testing

manual testing is the process where most of the simulation tasks, the assessment of the tested device performance and the documentation of the results from the test are performed manually by the tester.

3.1.1.16
negative testing

testing process where the system validated against the invalid input data

Note 1 to entry: A negative test checks if a application behaves as expected with its negative inputs.

3.1.1.17
positive testing

testing process where the system is validated against the valid input data

Note 1 to entry: In this testing the tester always checks for only valid set of values and checks if an application behaves as expected with its expected inputs. The main intention of this testing is to check whether the software application is not showing an error when not supposed to and showing an error when supposed to.

3.1.1.18
remote testing

process where all simulation tasks, the assessment of the tested device performance and the documentation of the results from the test are performed by the tester from a remote location over a communications link to the site of the tested devices or system using test equipment permanently installed at the site

3.1.1.19
top-down testing

testing method which tests the high levels of a system before testing its detailed functional components

Note 1 to entry: Testing starts with the overall function test and goes down the hierarchy testing sub-functions until the function elements at the bottom of the hierarchy are tested.

3.1.1.20
white-box testing

testing based upon the requirements with the internal workings of the function or system known

Note 1 to entry: In white-box testing the system is given a stimulus (input) and if the result (output) is what was expected, then the test passes, however consideration is also given to how the internal elements of the function worked.

3.2 Abbreviated terms and acronyms

The following abbreviations and acronyms are used in this document:

BFP: Breaker Failure Protection
GOOSE: Generic Object-Oriented Substation Event
IED: Intelligent Electronic Device
PAC: Protection, Automation and Control
PACS: Protection, Automation and Control System
PUAS: Power Utility Automation System
SAS: Substation Automation System
SBO: Select Before Operate

4 Testing-related features in IEC 61850

4.1 General

Functions in Power Utility Automation Systems (PUAS) are not performed by a single function element (Logical Node, LN), but implemented through an interaction of multiple Logical Nodes, each contributing its specific functionality. The different functions may be accommodated in different logical devices, even hosted by different physical devices, which imposes the usage of agreed-upon basics:

- standardized function interfaces content and behavior (from a communicational perspective) through LN,
- evaluation of the information received in a predictable manner,
- exchange of information of a common semantic.

While during normal operation the information flow is defined by the communication configuration, testing requires a user interference into this scheme prior to the test, to avoid inadvertent reactions onto information created during testing. Disconnecting of a device under test is not the appropriate way of doing, moreover as this device may require information from the other components of the system to perform its function.

The above mentioned basics of IEC 61850 are used for testing purposes to functionally isolate a definable structure of functions in a system environment without disturbing the components in normal operation. The following chapters will present the principles of how functional isolation is achieved.

4.2 Test features defined in IEC 61850

4.2.1 General

Some of the features described in this subclause are not mandatory and therefore may not be available in all IEDs which conform to IEC 61850. It is in the responsibility of the user to re-establish operational conditions in the device under test after having finalized the tests.

It shall be well understood which testing-related features defined in IEC 61850 and described in the following clauses are implemented in the devices used in the substation. The user shall develop procedures that will use the testing features for virtual isolation of the different active protection, automation and control devices during the testing in a live substation. This includes resetting of all interventions made onto controllable elements for testing purposes as well as clearing of buffers, logs, counters if applicable. Considering the possibility that the actual operational conditions may include settings which deviate from the as-built status, manipulating a device under test requires careful considerations. The user is welcome to be supported by tools during this task.

4.2.2 Simulation based testing in substations under normal operation

Simulation in the context of IEC 61850 is the capability of a test device to send messages with a "simulation" flag activated in parallel to the real message to support the distinction between the actual messages from the equipment in the live substation and the messages from devices used for testing purposes. It is NOT related to a generic simulation of the process. It is also the ability of the subscribing device to process simulated messages.

At the IED[1] level the option to set the logical node LPHD data attribute Sim.stVal to TRUE or FALSE allows the IED to select the multicast signals that will be processed. In order to test an IED, Sim.stVal is set to TEST. The test device shall inject GOOSE and/or SV messages with the simulation flag in the header set to TRUE.

Figure 1 shows IED1 receiving simultaneously two similar GOOSE messages (GOOSE 1). The GOOSE message 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. The IED1 with its physical device logical node LPHD1 data Sim.stVal also set to TRUE will listen for messages from the test devices with the Simulation bit set to TRUE and will process only these GOOSE 1 message after the first such message is received from the test device. If the data Sim.stVal is set to FALSE it will process the GOOSE 1 message from the actual device that has the simulation bit set to FALSE.

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 IEC 61850 as shown in Figure 1 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 is a GOOSE 2 or GOOSE 3 that has the simulation bit set to TRUE, the device will subscribe to this/these GOOSE.

NOTE 1 Data flow of signals using client/server communication channels to the IED are not affected by the simulation option bit of LPHD.

NOTE 2 Simulation status is not propagated to the output of the function using simulated streams, i.e. downstream treatment will not have any means to discriminate between a simulated output and a normal one.

NOTE 3 If LSVS.SimSt is true, subscribed SV messages with the simulation bit set are being received and accepted.

NOTE 4 If LGOS.SimSt is true, subscribed GOOSE messages with the simulation bit set are being received and accepted.

The simulation is thus not completely equivalent to the use of a "test handle" diverting all input data associated to a conventional IED since not all input signals systematically come from the test tool. Also, when designing the test cases and 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 LPHD.Sim and the test mode.

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[1] In this subclause an IED refers to a LD including a LPHD LN, i.e it will affect also all children LDs in case of nested LDs to the concerned LD.

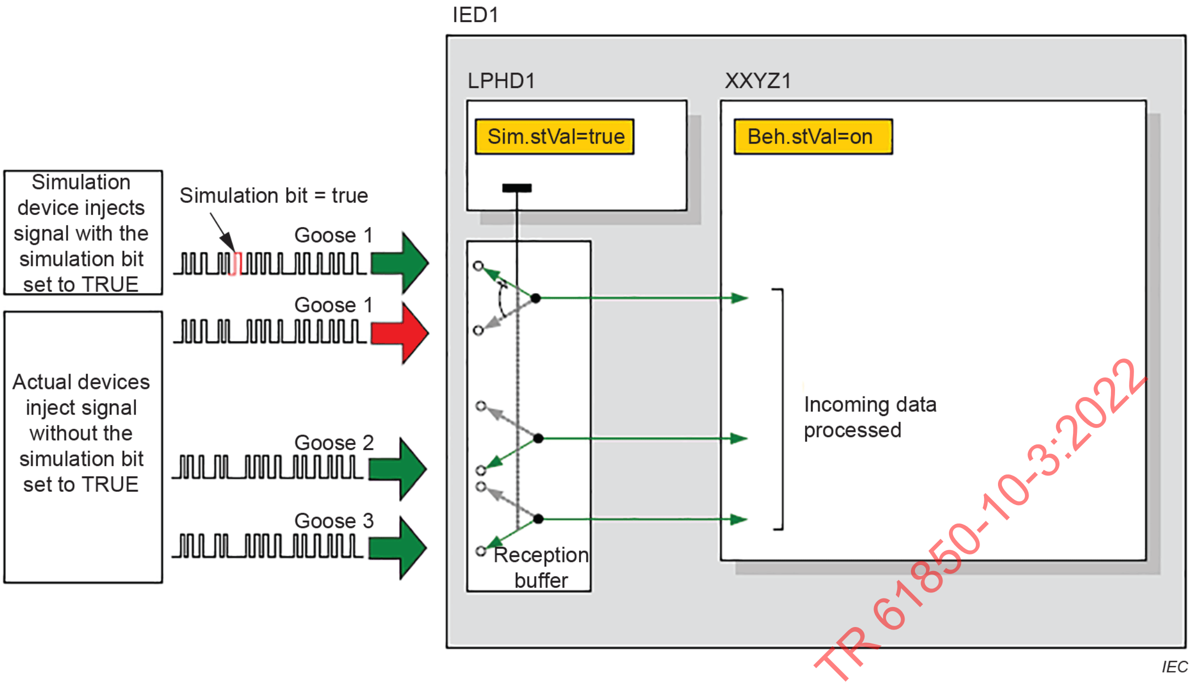

Figure 1 – Data used for receiving simulation signals (IEC 61850-7-1 Fig. 40)

Simulation is applicable in the LPHD at the level of the Physical Device and defines the processing of the data by the communication processor of the LD(s) "connected to[2]" the Physical Device. There shall be one subscription per later simulation stream. If different logical devices need to process different simulated streams (for example of 1 1/2 breaker) then more than one subscription may be required to allow the later independent testing using simulation.

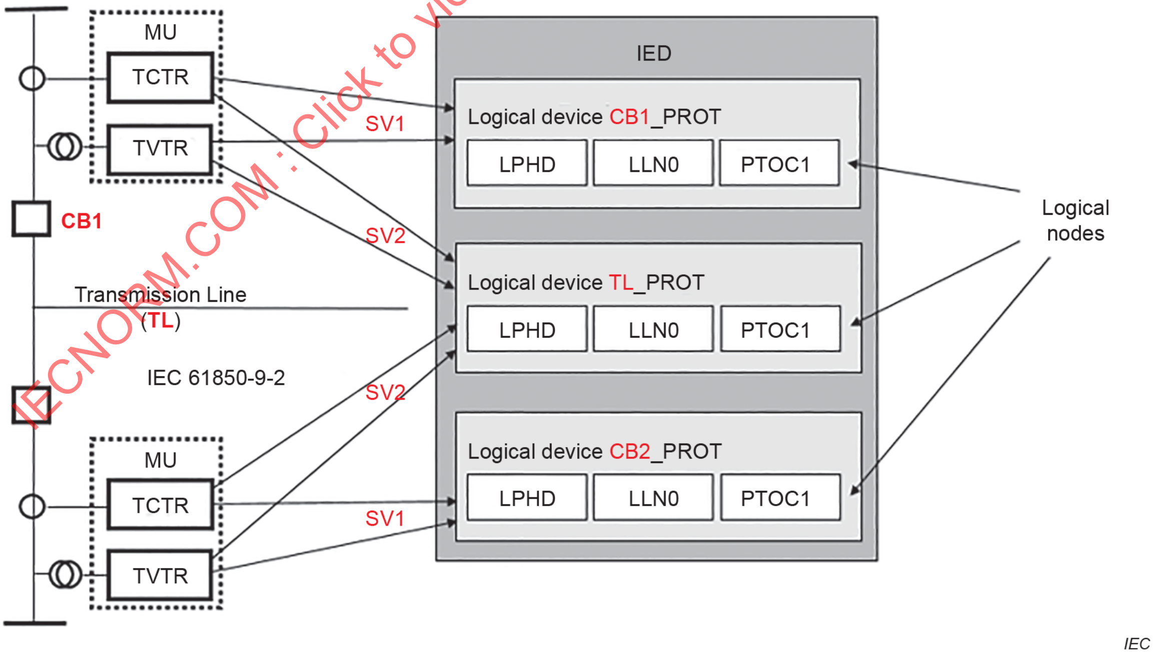

Figure 2 – IED with multiple process interfaces

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[2] LDs may be nested and refer to a « root » LD hosting the LPHD as explained in 4.2.3.

Figure 2 gives an example of the use of multifunctional IED for the transmission line protection in in a double breaker configuration, but also applies to breaker-and-a-half or ring bus.

In this case, a single IED requires separate interfaces with the merging units on each of the individual breakers (CB1 and CB2). If we are to test for example a PTOC function element protecting CB1, we will need only sampled values simulation for CB1.

If we are to test a PTOC function element protecting CB2, we will need only sampled values simulation for CB2.

Remember that the processing of simulated values starts only after receiving the first message with the Simulation parameter set to TRUE.

In order to use the simulation flag, LPHD.Sim of the receiving Physical Device must adopt the value "TRUE" **and** the simulation bit in the message received from the test device also must be "TRUE".

However, the mixing of sampled values coming from the actual process (the MU of CB2) and from a test device simulating sampled values from the MU of CB1 creates a problem from the testing point of view due to the fact that this is not a fully controlled test environment. Because of that in case of maintenance testing in an energized substation all logical nodes that are using sampled values from both CB1 and CB2 merging units should be in test mode before the start of the simulation. This can be solved by CB1.MU and CB2.MU sending two streams (SV1 and SV2) of sampled values each. Thus CB1.MU stream SV1 can be simulated for LDevice CB1, while TL is using the real value of CB1.MU stream SV2.

4.2.3 Mode and behavior of functions

In IEC 61850, each function, represented by a Logical Node or a Logical Device, can adopt one of five different modes resulting in five different functional and communicational behaviors (cf. IEC 61850-7-4:2010, Annex A):

> on, blocked, test, test/blocked, off

If the LN behavior is reported as 'on', the application of a function is operative, all communicating features are in service.

If the LN behavior is reported as 'blocked', the LN behavior is almost identical to 'on' with only one difference depicted below:

> The featured difference between the 'on' and the 'blocked' can only be used by functions which have a direct interaction with the process (i.e. no other intermediate LN). For these boundary Logical Nodes the outputs through contacts or analogue ports can be blocked. This means that these outputs are not changed for the duration of the blocking. All communicating features are in service.

Testing shall not impact other functions in normal operation. Therefore a function which is set to 'test' is operative, but propagates the testing information downstream by formally indicating information as being produced under test conditions. Details are provided further in the document.

The output to the process of a function in 'test' can be blocked in a similar way to 'blocked' using the 'test/blocked' behavior, blocking the outputs contacts or analogue ports. The application indicates information as being produced under test conditions and it reacts on control commands with a test flag set.

A function can be set to 'off', which disables its application. As the application does not work, it neither processes inputs nor produces physical outputs, communication output is provided with data quality 'invalid', except Mod, Beh and Health. Control commands from a client are rejected with negative responses, except Mod, in case it is controllable.

The behaviour of a function is controlled jointly by its superior hierarchical level as well as through its controllable object 'Mod'. To reach a definite behavior among of these two access variants, the states are ordered by priority, where 'off' has priority over 'test' which has priority over 'on' (cf. Table 1, Example: If the superior Logical Device is set to 'test', Logical Nodes or nested Logical Devices on a lower hierarchical level may only be varied into 'test/blocked' behavior or switched 'off', never be set to 'on'.

Table 1 – LD/LN Mode/Beh inheritance

LNMode or nested **LDMode** XXXX.Mod	**LDMode** LLN0.Mod	**LNBeh** (read only) XXXX.Beh
on	on	on
on	blocked	blocked
on	test	test
on	test/blocked	test/blocked
on	off	off
blocked	on	blocked
blocked	blocked	blocked
blocked	test	test/blocked
blocked	test/blocked	test/blocked
blocked	off	off
test	on	test
test	blocked	test/blocked
test	test	test
test	test/blocked	test/blocked
test	off	off
test/blocked	on	test/blocked
test/blocked	blocked	test/blocked
test/blocked	test	test/blocked
test/blocked	test/blocked	test/blocked
test/blocked	off	off
off	on	off
off	blocked	off
off	test	off
off	test/blocked	off
off	off	off

Regardless of the status of a LN, the communication service to control its behavior through its Mod is always in service, even in 'off' status.

For testing purposes, Mod shall be set to TEST; to allow "processing as valid" of a control service command with a test service parameter set to TRUE or a GOOSE data signal with q.test service parameter value of TRUE as shown in Figure 3. Subclause 4.2.4 provides an insight into the processing of information specific for the states of a function.

A command with test service parameter value of FALSE will not be processed if the receiving element is in test mode. When Mod is set to test-blocked it will behave as in TEST but the result of the processed reactions will not be issued as output data to the process. IEC 61850-7-4:2010, Annex A, cf. Table 2 provides a detailed explanation of the behavior for various settings of the data object Mod.

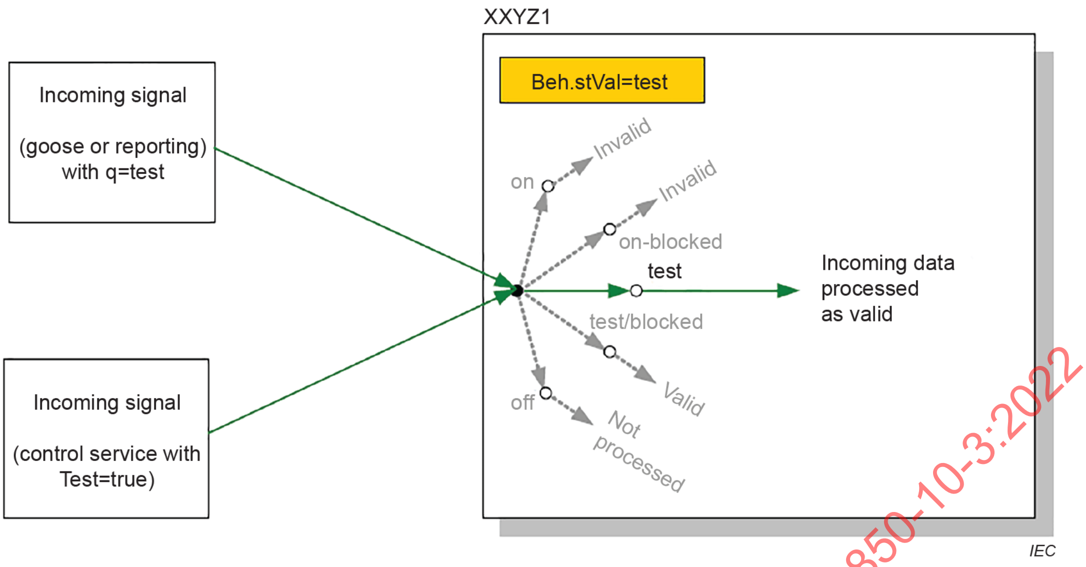

Figure 3 – Processing of test signals (Part 7-1, Figure 42)

4.2.4 Logical devices management hierarchy

The management of logical nodes according to Edition 2 of IEC 61850 is based on the functional hierarchy represented by the nesting of logical devices. Logical devices which offer ways of grouping functions may be used to represent a group of typical automation, protection or other functions. The functions generally rely on sets of function elements represented by logical nodes in the IEC 61850 object model. The logical nodes are contained and managed in logical devices.

It is important to note that LDs offer more than grouping functions, they also offer ways to manage general common properties (such as the control authority) and behaviours (as explained above through Mod/Beh). Nesting LDs offers then ways to "propagate" these common properties and behavior down to all elements of the hierarchy.

The following text illustrates how this can be used in a concrete example.

In a multifunctional protection IED we typically have several main function types:

- Protection
- Automation
- Control
- Measurements
- Recording
- Condition monitoring
- Other

In this example, we assume that specialized LD are used to reflect these function types, i.e. one LD will be used for each of this function types, offering ways to share some common properties and behavior, as if they were in different physical entities.

Depending on the type of protection IED, each function may contain several sub-function types. For example, in a distribution feeder protection IED we may have:

- Overcurrent protection
- Overvoltage protection
- Underfrequency protection

Then we assume that specialized LD are used to reflect these sub-function types, i.e. one LD will be used for each of this sub-function types, offering ways to share some common properties and behavior. Nesting these with the root LN PROT enables dispatching common properties and behavior set at the root level down to each of these LDs.

Figure 4 shows such an example of a protection logical device PROT which contains a nested logical device ocp, representing the overcurrent protection sub-function. PROT is called the "root" logical device. The overcurrent LD (LD ocp) is even further broken down into two more logical devices – gnd and phs, which accordingly represent the ground and phase overcurrent protection sub-functions.

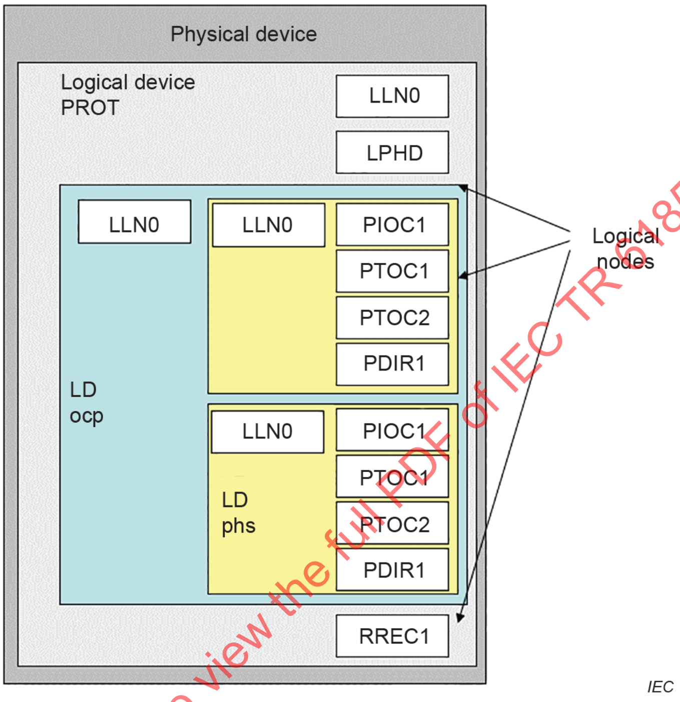

Figure 4 – Nesting of logical devices representing the functional hierarchy

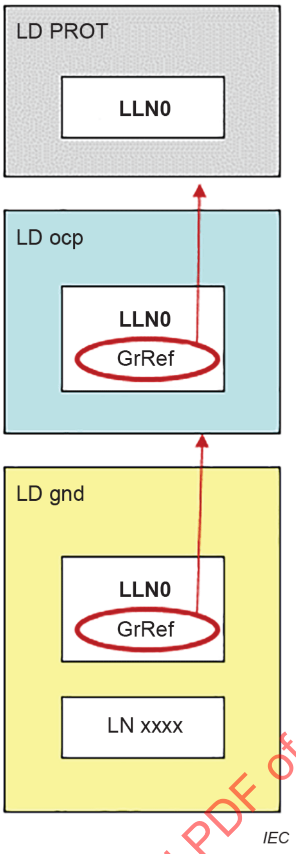

Figure 5 – Use of GrRef in the modelling of nested logical devices

LLN0 of the logical device LD ocp contains a setting data named GrRef whose common data class is ORG ("object reference setting group"). The referenced value of GrRef in LD ocp is PROT, meaning that the logical device function refers to the functional group represented by the logical device PROT.

Likewise, LLN0 of LD gnd refers to the functional group represented by the logical device LD ocp. In other words, LNs in LD gnd are sub-functions of LD ocp.

The use of the object reference GrRef is shown in Figure 5.

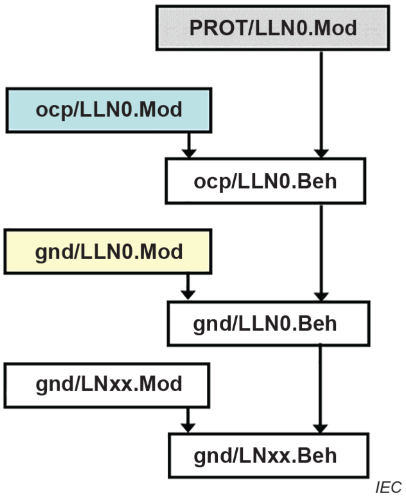

Figure 6 – Management hierarchy of nested logical devices

The management of the behavior within a logical device is based on the Mod setting of its LLN0, which contains common information for the LD like health, mode, behavior and name plate.

The hierarchy determines how the mode (e.g. on, off, test) of these functions and sub-functions is managed (cf. 4.2.3).

The referenced value of GrRef is PROT, meaning that the logical device function refers to the functional group represented by the logical device PROT.

The hierarchical management of the mode and behavior is shown in Figure 6.

In Figure 6, the mode of the LNs in LD gnd may be changed individually or globally by means of LLN0 of LD gnd.

Their mode may also be changed either by means of LLN0 of LD ocp or by means of LLN0 of LD PROT. For example, if the mode of the functional group LD ocp is set to "Off", it not only set the behavior of all logical nodes in LD ocp to "Off" but also the behavior of all logical nodes in LD gnd. Switching the mode of LD PROT will affect the behavior of all logical devices and logical nodes belonging to the functional group LD PROT, i.e. all logical nodes in LD PROT, LD ocp, and LD gnd and LD phs.

Such hierarchical management of the mode and behavior allows a very efficient control of the different functions and sub-functions implemented in a multifunctional IED. This is designed in particular to enable testing at different levels.

The above described inheritance of mode does not apply to the inheritance of the "on" mode as shown in Table 1. "on" is configured at the logical node and logical device level, thus specifying which logical nodes and logical devices are to be used. The reason is that after performing a test when mode has been set to "test" which is inherited as a behavior by all logical devices and logical nodes with mode setting of "on", when we return the mode setting to "on" we do not want all nested logical devices and logical nodes to switch to "on".

4.2.5 Processing of information

Information is transmitted between a publishing function and a subscribing function. The publishing function is expected to convey additional information, such as data quality, etc. This information of the value is necessary for the correct understanding and processing of the value by the subscribing function. Different data attributes can be used as the inputs for the subscribing function which define how to handle the value in an application specific way.

If the test bit in the quality attribute of a data object is different from the testing behavior (Beh) of the subscribing function, the application deals with the input in a way which reflects the definitions in Table 2.

As a matter of interoperability, functions must be provided with an implementation of the data quality processing rules as defined in IEC 61850-7-4. Only if all functions participating in a scheme are processing data quality with the same understanding, an effective isolation and testing of a function can be reached. The processing of data quality is illustrated in Figure 7.

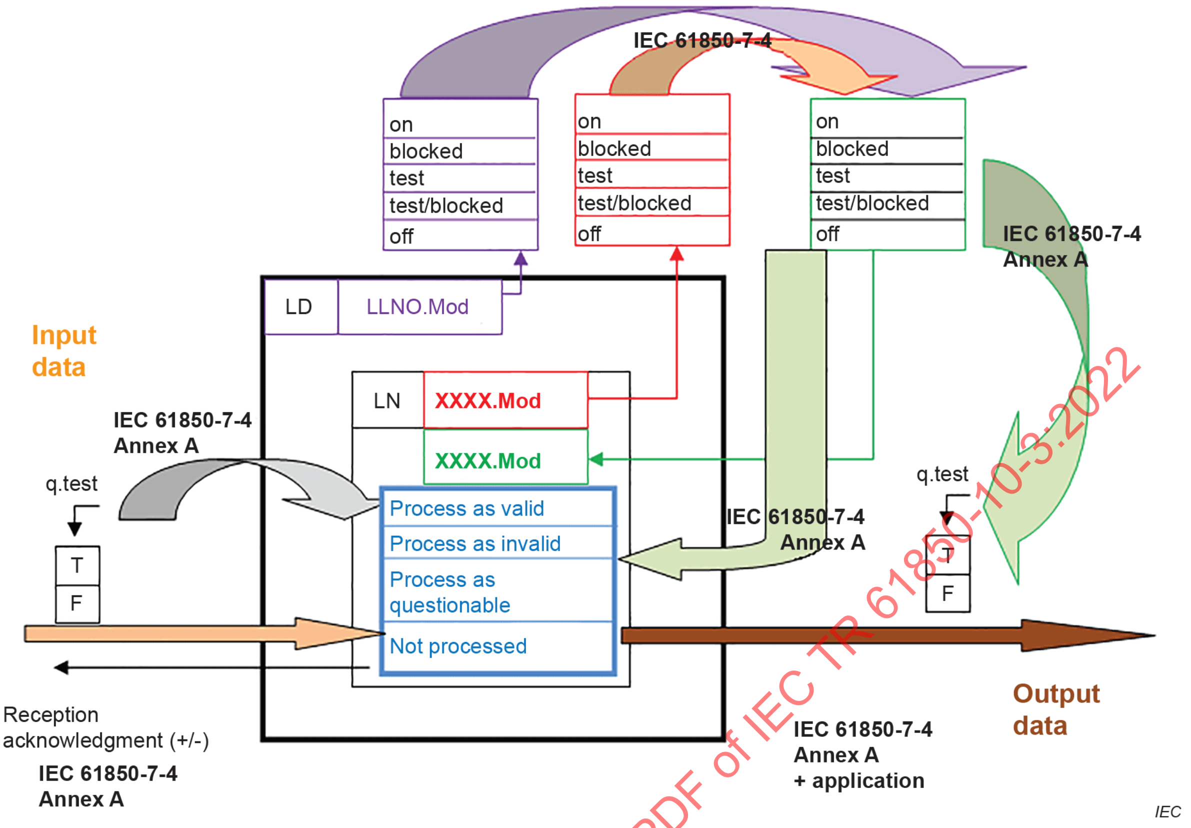

Figure 7 – Processing of the data by a LN depending on the LN behaviour and the quality attribute of input data

For a function which is 'on' or 'blocked', the user expects that its processing is not affected by information published by another function under test. Commands marked as 'test' are not considered for processing by functions operating normally. Therefore, a function in 'on' or 'blocked' state must be configured to react properly when an input data with q.test set to TRUE.

Properly can mean:

- use instead a defaulted good value
- ignore that value (keep last value)
- block the function.

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 for these tests, these inputs have to be processed accordingly.

A function which is set to 'test' or to 'test/blocked' processes "as valid" messages with q.test = FALSE and messages with q.test = TRUE (cf. Table 2), q.validity = GOOD assumed. This characteristic has an important impact on the test methodology. Table 2 summarizes the processing principles expressed in various chapters of the standard. These principles are needed to secure the interoperability of functions in the way the user expects applications to work.

The 'invalid' indication is typically known in conjunction with measurement values, but not limited to. Stronger than with an indication 'questionable' where a processing of the value is conceivable (depending on the configuration of the dedicated input processing for an application), 'invalid' unambiguously indicates that a value is not to be used. In the subscribing function, the communication services takes note that information was received, but the application does not consider the value for its processing. For a better understanding why a value is ranked 'invalid' or 'questionable', detailed quality identifiers are provided. Overflow, Out of Range, Bad Reference, Oscillatory and Failure lead to an indication 'invalid', Out of Range, Bad Reference, Oscillatory, Old data, Inconsistent and Inaccurate lead to an indication 'questionable'. The subscribing function can evaluate the detailed quality identifiers to derive the most appropriate way of processing of the information. The behaviour of the subscribing functions upon reception of invalid or questionable data should be included in the test scope.

Table 2 – Table A.2 of IEC 61850-7-4:2010/AMD1:2020, Annex A summarizes the processing principles

MODE/BEHAVIOUR	On	Blocked	Test	Test/blocked	Off
Function behind LN	ON	ON	ON	ON	OFF
Output to the Process (Switchgear) via a non-IEC 61850 link for example wire (typical for X..., Y... and GGIO LNs)	YES	NO	YES	NO	NO
Output of FC ST, MX (issued independently from Beh)	Value is relevant q is relevant	Value is relevant q is relevant	Value is relevant q.test=true	Value is relevant q.test=true	Value is relevant q.validity=invalid
Response to (Normal) Command from Client (a+ / a− acknoledgement)	a+ pos. ack.	a+ pos. ack.	a− neg. ack.	a− neg. ack.	a− neg. ack.
Response to TEST Command from Client (a+ / a− acknoledgement)	a− neg. ack.	a− neg. ack.	a+ pos. ack.	a+ pos. ack.	a− neg. ack.
Incoming data with validity=good AND test=false AND operatorBlocked=false	Processed as valid	Processed as valid	Processed as valid	Processed as valid	Not processed
Incoming data with validity=questionable AND test=false AND operatorBlocked=true	Processed as questionable	Processed as questionable	Processed as questionable	Processed as questionable	Not processed
Incoming data with validity=good AND test=true AND operatorBlocked=false	Processed as invalid	Processed as invalid	Processed as valid	Processed as valid	Not processed
Incoming data with validity=questionable AND test=true AND operatorBlocked=true	Processed as invalid	Processed as invalid	Processed as questionable	Processed as questionable	Not processed
Incoming data with validity=invalid AND test=don't care AND operatorBlocked=don't care	Processed as invalid	Processed as invalid	Processed as invalid	Processed as invalid	Not processed
Non-IEC 61850 binary (relay, contact) inputs and analogue (instrument transformer) inputs	Processed	Processed	Processed	Processed	Not processed

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It is worth noting that more than one quality indication may be set to TRUE at the same time.

A dataset using Functional Constraint Data Attributes (FCDA) should also include the quality information associated to a status value or measurement value. The Function Common Data (FCD) includes this information in their structure.

4.2.6 Blocking of information

NOTE This subclause does not treat potential blocking of data change or commands for operation reasons (such as the local/remote control authority or block open or block close of breakers).

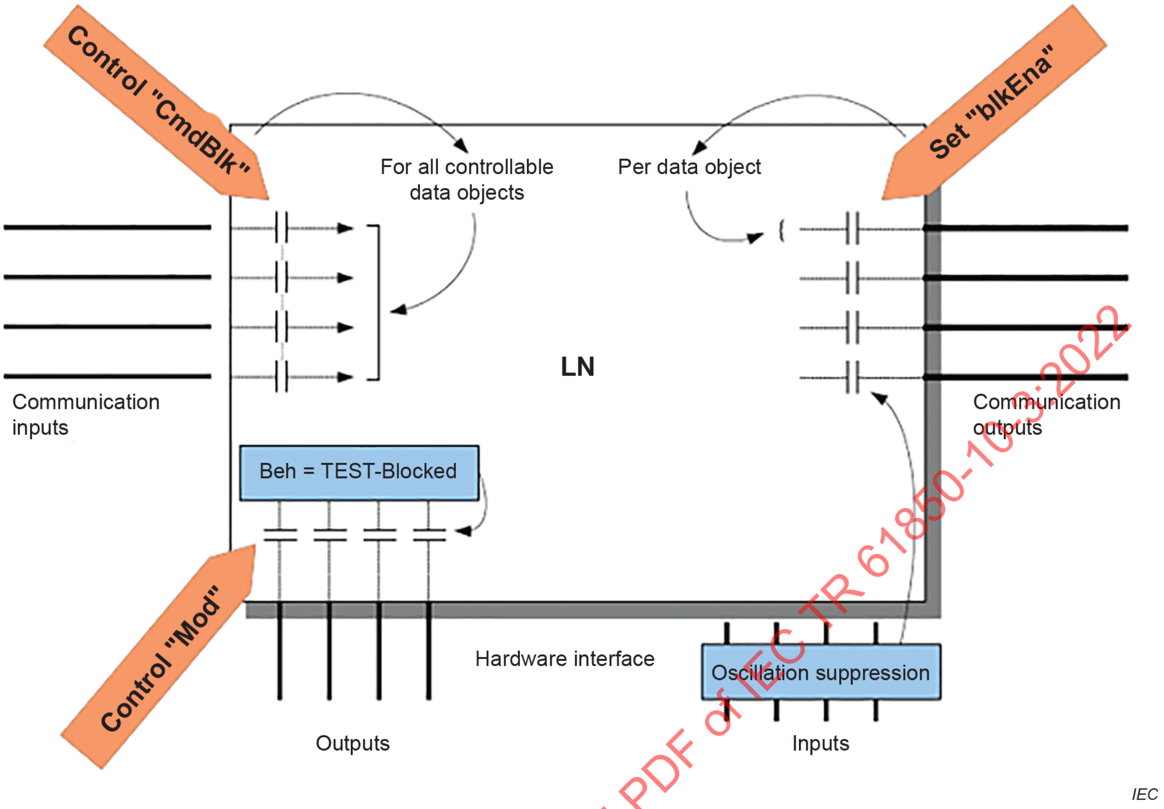

Figure 8 – Data used for logical node inputs/outputs blocking: IEC 61850-7-1:2011, Figure 39)

4.2.6.1 General

In Figure 8 the different possibilities to intervene into a given communication scheme of functions are shown. The activation of <u>physical outputs</u> (contacts, analogue ports) of functions which have a direct interaction with the process can be blocked by setting the function to 'blocked' or 'test/blocked' status using the control service on the controllable object 'Mod'. The status evaluation of <u>physical inputs</u> can be influenced by an oscillation suppression feature, if implemented in the application. This feature is defined by the configuration. The updating of a communication output can be blocked by an operator.

4.2.6.2 Blocking of incoming commands

The acceptance of commands may be prohibited by activating 'CmdBlk' (data object optionally present in any controllable LN). This blocking affects all controllable objects (i.e. with CDC of type 'controls' as defined in IEC 61850-7-3:2010, 7.5) of the Logical Node in one, except for the data objects Mod and CmdBlk, which are always accessible. If 'CmdBlk' is activated, control sequences and action triggers of all controllable data objects in this function have been blocked.

In case of effective control blocking the latest valid input is considered for the internal treatment of the LN.

Application example: This feature can be used to prevent from inadvertent triggering of a function (e.g. commanding of a switchgear). The function processes the input data normally and publishes the output data normally.

4.2.6.3 Blocking process outputs

An operator or an application may be able to freeze the further update of a data value. The value shall be the information that was acquired before the blocking by setting the (optional) attribute 'blkEna' of the concerned data 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 issuing of this data is frozen and the indications 'operatorBlocked' and 'oldData' are set to the associated data quality, as the value is no longer updated.

This feature is not to be mixed up with the Logical Node modes 'blocked' or 'test/blocked' which each affect the process outputs of a function, while 'blkEna' has effect on data level.

4.2.7 Changing the information source (input reference) for testing

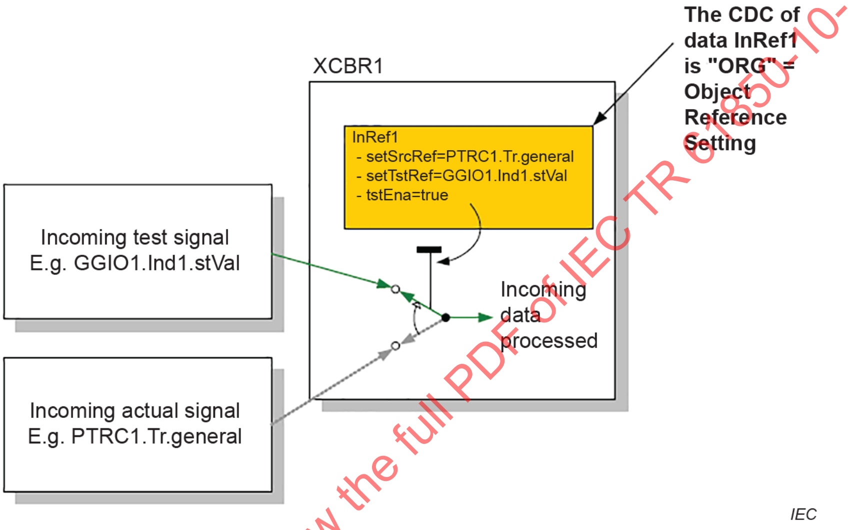

Figure 9 – Example of input signals used for testing (IEC 61850-7-1:2011, Figure 41)

The input signals to a LN may be switched between process signals from other functions and tests signals from functions dedicated for testing (even from testing devices) defined through the data object 'InRef' (an online representation of ExtRef) as shown conceptually in Figure 9. This does not depend on the Behaviour of the Logical Node and the data is processed and published according to the Behaviour.

Data attribute 'setSrcRef' specifies the object reference to the input that is normally used as input while 'setTstRef'[3] 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 (independently from the LN behavior, even if the LN behavior is not 'test' or 'test/blocked').

The use of this dedicated input as indicated through 'setTstRef' for testing is not automatic when the LN is forced to go in 'test' mode. This shall be individually set, for each of the concerned data.

A function LN can have multiple instances of 'InRef' for multiple inputs.

By means of switching over the input reference from the process signal, which may be not accessible or cannot be modified, to a signal which can be easily modified, an application can be isolated on the input side from the process and fed with test signals (value and data quality information). This feature requires having an extra function at hand which allows a controlled

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[3] Presence of the attribute ‘setTstRef’ in the ORG CDC (the one used by ‘InRef’) is optional.

generation (e.g. from a front panel pushbutton or test equipment with physical or communications interface) of these signals. In case this function is hosted in a device external to the IED under test, the data flow shall be prepared (e.g. GOOSE subscription) in the device configuration. 'InRef' is applicable to all types of Data Objects including Sampled Values.

This feature should not be mixed up with the use of the Simulation mode (cf. 4.1.1) which affects the entire LD (see 4.1.1) and is limited to GOOSE or sampled values communication, while 'tstEna' has effect on the information sourcing of a single input. It can be used for the testing of an individual LN, while the rest of the IED is in a normal operating mode.

Concerning signals subscribed by LD under test, but not instrumental for some tests (e.g. SF_6 pressure of CB, etc.), ideally, the test system should be capable to generate all these input signals and the LN should all be defined with an individual 'tstEna' for every single input (Figure10) This has to be included in the system design in the engineering phase and requires modelling of the test equipment as an IEC 61850 server with the required by the testing use cases LNs.

This enables an "automatic" configuration of the test set depending on the characteristics of the feeder and requires support of 'setTstRef' in SCL.

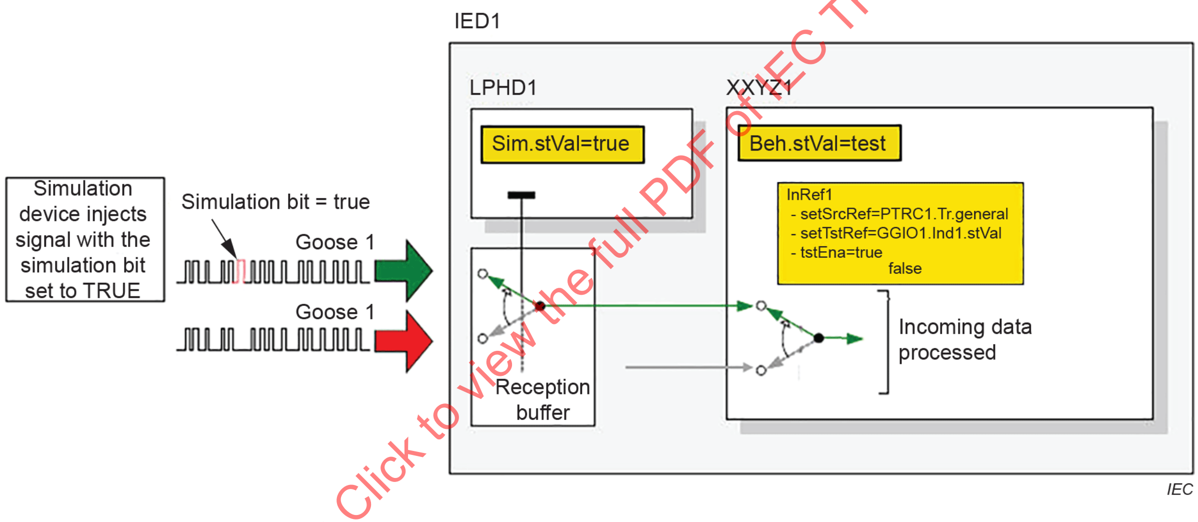

Figure 10 – Use of InRef for LN test

4.2.8 Substitution of information

IEC 61850 allows user intervention to deliberately replace a process information by a user defined one. This so-called substitution can be applied for a selection of both binary and analogue data classes. Not only the value, but also the associated data quality information can be substituted. Since this is applied under normal operating conditions, it is not related to testing. Substituted data shall not be used for test purposes.

4.2.9 Use of testing related features

The testing related features described above can be used depending on the type of test and the function (basic or distributed) being tested.

One of the most important applications of the testing features defined in the standard is the virtual isolation in energized substations. In order to help the industry migrate to the testing of IEC 61850 based digital substations, it is necessary to compare the physical isolation of conventional hard wired systems with the virtual isolation in IEC 61850 based systems.

In conventional substations the isolation is achieved typically using test switches. The test switch isolates the test object from the substation environment, while at the same time allows the connection of the test system to the test object. The test is performed based on the definitions of the function boundary of the test object from the design of the system. This is done in a specific order:

1) Isolate test object from the substation environment
2) Connect the test system to the test object
3) Execute the test plan through analog and binary signals simulation
4) Disconnect the test system to the test object
5) Restore the connection of the test object to the substation environment

Verification of the physical isolation should be performed when possible. The same applies for the restoration after the completion of the test.

In some cases it may be necessary to restore the pre-test values of specific parameters.

The use of the testing-related features in IEC 61850 allows the implementation of a similar isolation procedure. This can be implemented in the following way:

1) Isolate test object from the substation environment by putting it in test or test/blocked mode
2) Connect the test system to the test object by setting Sim = TRUE in LPHD
3) Execute the test plan by publishing sampled values and GOOSE messages with Simulation = TRUE
4) Disconnect the test system from the test object by setting Sim = FALSE in LPHD
5) Restore the connection of the test object to the substation environment by setting the mode to on

Verification of the virtual isolation in this case is much easier, because it is limited to checking the value of the test bit in the quality attribute being equal to TRUE.

The definitions of the function boundary of the test object in the case of IEC 61850 based systems is determined based on the use of the test related features in the standard, i.e. the values of Mod, and thus can be defined at the time of testing.

Verification of the virtual restoration in this case is much easier, because it is limited to checking the value of the test bit in the quality attribute being equal to FALSE.

Table 3 shows the mode and the simulation use for the different types of tests.

Table 3 – Applicable modes for different types of tests

Type of test	on	test	test/blocked	blocked	Simulation
Conformance	X	X	X	X	X
Type	X	X	X	X	X
Certification	X	X	X	X	X
Interoperability	X	X	X	X	X
Factory Acceptance	X	X	X	X	X
Installation	X	-	-	-	-
Commissioning	X	-	-	-	-
Interface	X	-	-	-	-
Site Acceptance	X	X	X	X	X
Maintenance	-	X	X	X	X

5 Testing of Protection, Automation and Control Devices and Systems

5.1 General

Testing of substation automation products and systems are part of quality systems like ISO 9001. Stages of quality assurance are shown in Figure 11. This document does not further describe the responsibility of manufacturers, unless the manufacturer is also a system integrator responsible for the fulfillment of end-user (utility) requirements. For a description of manufacturers systems tests and type tests of their products, see IEC 61850-4:2011.

The user of an IEC 61850 substation automation system shall ensure that the system integrator delivers a fully functional system that meets all requirements as defined in the design specification, as well as that the system is maintained according to the specifications throughout its lifecycle.

Systems integrators perform tests on the automation system to ensure correct implementation and configuration during off-site (FAT) and on-site (SAT) project stages. This document is a guide for functional testing during these stages with specific focus on the site commissioning. In Figure 11 the stages have been marked with a dashed square.

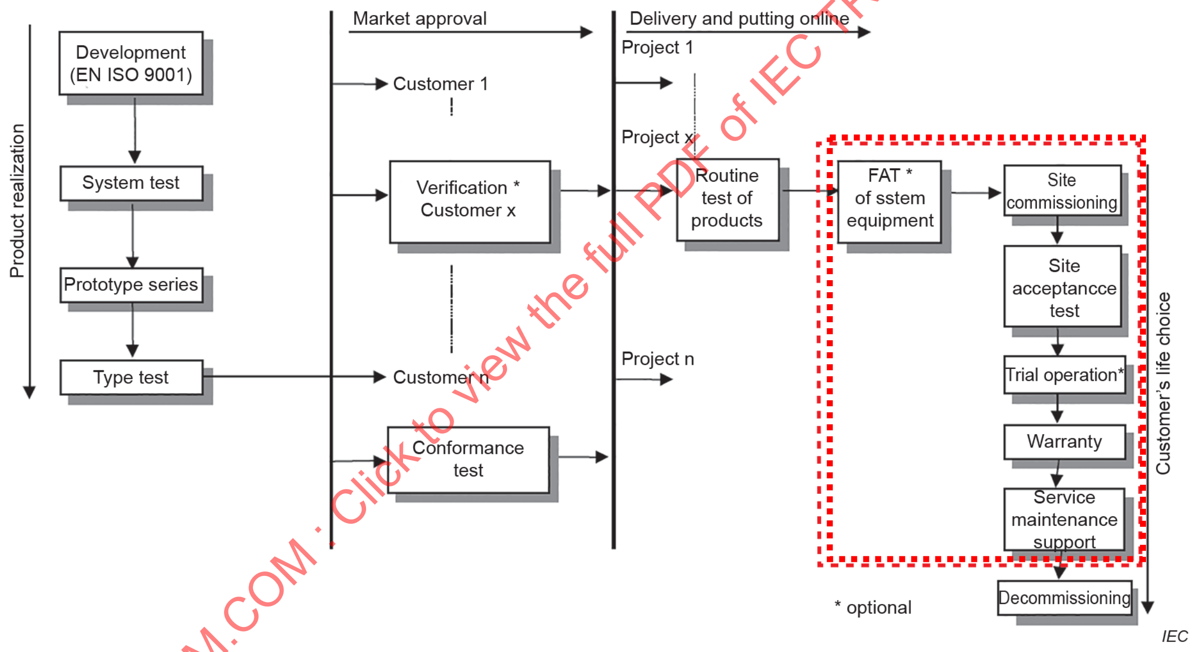

Figure 11 – Quality assurance stages of IEC 61850-4:2011

The factory acceptance test (FAT) serves to validate and verify a system and its functions from the customer's point of view. According to IEC 61850-4:2011 the factory acceptance test is optional. The main purpose of acceptance test of the system on site (SAT) is to show the correct installation and connection of all system components and to ensure functionality proofing and validation according to customer contractual technical requirements.It shall be carried out on the completely installed equipment in individual steps

Figure 12 gives the four stages of process – network control center quality assurance. As defined in IEC 61850-4:2011 these are:

a) process – bay control level;

b) bay control level – station control level;

c) station control level – network control center(s);

d) process – network control center(s).

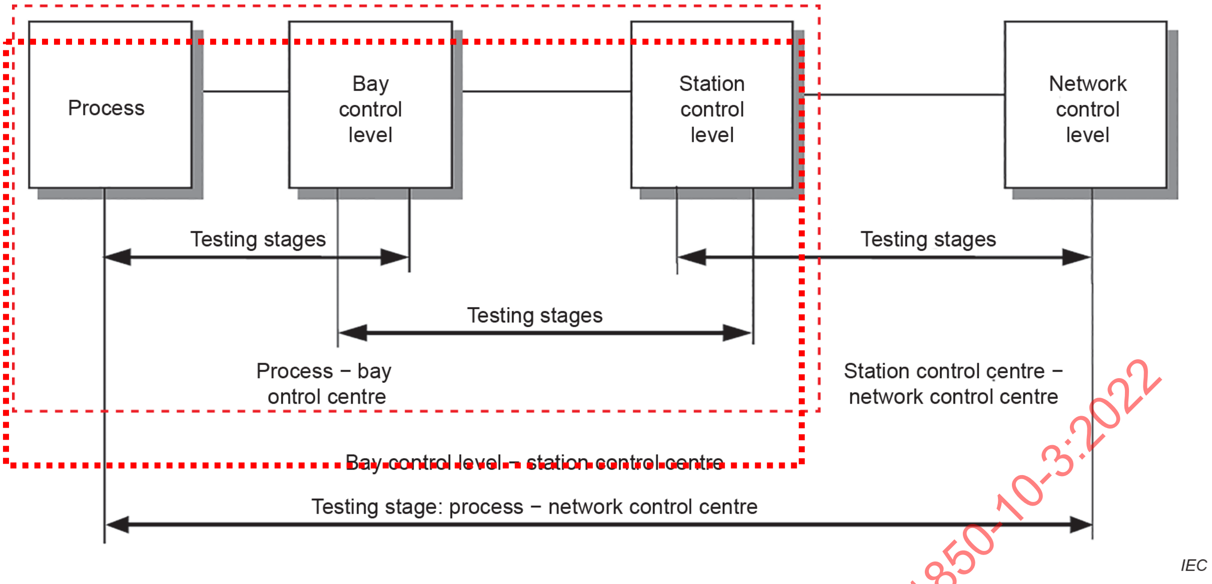

Figure 12 – Testing stages for site acceptance test as defined in IEC 61850-4:2011

Commissioning may be performed by the power utilities own personnel or in the case of a turnkey delivery be the responsibility of the system integrator. Testers normally start with unit / component level testing before they do bay level testing.

The station level testing is normally split into the testing of the process-related system level functions (e.g. bus zone / circuit breaker fail protection) before the interface related station level functions (e.g. SCADA HMI / Gateway) are being tested. The system level testing may be undertaken with a simplified Ethernet network rather than the final network design. There may be requirements for a test harness to e.g. test the SCADA HMI as a unit before releasing it for system level testing. This could be done by using an IED simulator.

5.2 Test system requirements

The test system shall have the capability to support specific requirements defined in IEC 61850-4:2011, 7.2. It should also support the following features:

- Simulation of analog signals (currents and voltages)
- Simulation of binary signals
- Simulation of sampled values (IEC 61850-9-2 or IEC 61869-9)
- Simulation of GOOSE
- Subscription to sampled values (IEC 61850-9-2 or IEC 61869-9)
- Subscription to GOOSE
- Client capability
- Monitoring of binary or other signals from the process
- Assessment of results
- Documentation of results
- Role based access
- IEC 61850-9-3 based time synchronization or SNTP based
- IEC 61850-6 based test system configuration
- File transfer

The test system should support automated testing of individual functional elements, IEDs or distributed applications. Distributed applications include protection schemes within the substation (for example breaker failure protection), as well as between substations (for example POTT scheme).

The test system should also support simulation and all modes, depending on the requirements of the specific test.

6 Test methods, practices and needs

6.1 General

This clause intends to provide the system integrators and asset owners/operators with a methodology to decompose their systems into building blocks. Currently there is no standardized method for testing IEC 61850 based systems. IEEE Std C37.233 [a]-2009 "Guide for Power System Protection Testing" has dedicated sections regarding testing of IEC 61850 based systems but focuses on the use of the edition 1.0 GOOSE test bit that is no longer used for the same purpose in IEC 61850-7-2:2010. There are many architecture options and permutations of a substation automation system. Test methodologies correspondingly vary from one utility to another. A methodical test approach is essential to ensure that the desired test coverage can be achieved when verifying and validating a system solution.

In this clause the commonly used V-model is proposed to allow a system integrator to have a more methodical approach to the verification and validation of a substation solution by breaking the system into different building blocks and detailing the interface requirements for each building block. This is especially important as some of the traditional testing boundaries are changing with the introduction of IEC 61850 (e.g. as hard-wired interfaces are being converted into fiber optic interfaces on both substation and process level. The V-Model helps to structure the test plans and test specification according to the systems hierarchy and to test the components and subsystems before they are being released for an integration/system or acceptance test.

Test cases often missed during the initial testing include, but are not limited to:

- System behavior under abnormal system condition
- Maintenance or fault rectification on in-service system
- Adding an extension to an in-service system
- Decommissioning of an in-service system

This clause introduces the recommended methodology to be used for the development and testing of complex engineering solutions. The method allows for a decomposition of a system into its basic building blocks based on the system's components, design and architecture. The model can be used to define the testing process and requirements for each building block of the entire system and then verify the solutions fulfilment of these requirements.

6.2 Testing requirements for IEC 61850 based systems

The main purpose of testing by a system integrator or asset owner / operator is to verify and validate the design, components and architecture of the solution against a set of requirements. This testing process does not normally include the conformance testing (see IEC 61850-10) or type testing (see IEC 61850-4) of individual IEDs but may include some interoperability testing between different products. Generally the testing process allows for the testing of all applicable use cases / requirements from the viewpoint of the designer, operator, asset owner / operator of the solution.

6.3 The V-Model

6.3.1 General

Substation Automation systems have the potential to be complex engineering solutions that require multiple levels of testing to verify and validate that the components, architecture and design against a set of requirements. The V-Model shown in Figure 13 is a common method used in the system engineering domain to decompose a complex engineering solution into its basic building blocks and to structure the requirements and test cases for the entire system according to the system's hierarchy.

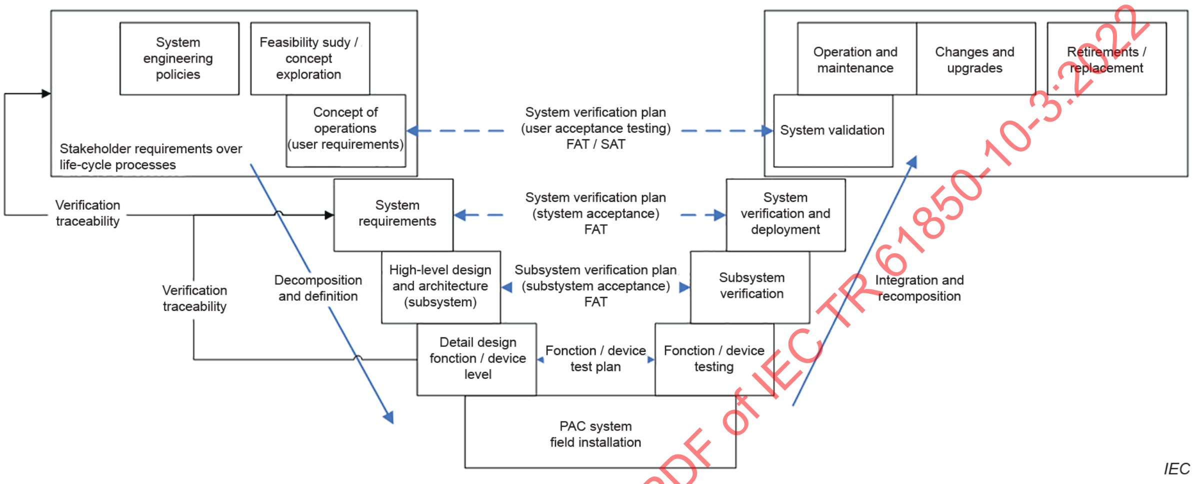

Figure 13 – V-Model used for system engineering

A substation automation system consists of several subsystems (e.g. protection and control, SCADA, Ethernet network). Subsystems are logical or physical aggregates made out of several units (e.g. single IED or function). Each unit and system / subsystem has interfaces to other components of the system. Interfaces can be mechanical, electrical or logical.

FAT and SAT testing fall into the category of acceptance testing. Acceptance testing is a process to obtain confirmation that a system meets mutually agreed-upon requirements. In many cases FAT test specification contain requirements for different levels of the system hierarchy and the acceptance test requires the execution of test cases on unit, subsystem and system level.

6.3.2 Unit testing

Unit level testing is a method by which individual devices or functions are tested to determine if they are fit for purpose. A unit is the smallest testable part of an application. A unit may be an individual function or IED with all its interfaces. Unit tests are created by designers or testers. Ideally, each test case is independent from the others. Unit tests are typically developed and run by the system integrator to ensure that the unit meets its design requirements and behaves as intended. Its implementation can vary from being manual (pencil and paper) to being formalized as part of an automated test e.g. test plan/script.

The goal of unit testing is to isolate each part of the device or function and show that the individual parts are correct. A unit test provides a strict, written test specification that the unit must satisfy. As a result, it provides several benefits. Unit tests find problems early in the development cycle of the SAS solution.

Unit testing may reduce uncertainty in the units themselves and can be used in a bottom-up testing style approach. By testing the parts of a function or unit first and then testing the sum of its parts, integration testing becomes much easier. An elaborate hierarchy of unit tests does not equal integration testing. Integration with peripheral units should be included in integration tests, but not in unit tests. Integration testing typically still relies heavily on humans testing manually; high-level or global-scope testing can be difficult to automate, such that manual testing often appears faster and cheaper. An example of a unit test is provided in 8.2.1 where an IEC 61850 based Protection IED is being unit tested using a Protection Test set called Test Device to inject stimuli into the DUT and to monitor the test results.

From the point of view of IEC 61850, unit testing is the testing of different function elements represented by Logical Nodes.

6.3.3 Integration or subsystem testing

Integration or subsystem testing is the phase in which individual units are combined and tested as a system or subsystem. It occurs after unit testing and before validation testing. Integration testing takes as its input IEDs or functions that have been unit tested, groups them in larger aggregates, applies tests defined in an integration test plan to those aggregates, and delivers as its output the integrated subsystem ready for system testing.

The purpose of integration testing is to verify functional, performance, and reliability requirements placed on major design items e.g. bus zone protection scheme. Test cases are constructed to test that all functions and components within the subsystem interact correctly, for example across the Ethernet network, and this is done after unit testing. 8.2.2 illustrates an example for the testing of a distributed protection scheme.

Examples of subsystems in a SAS

- SAS Ethernet network
- Bay level protection system e.g. feeder, transformer, coupler
- System level protection system e.g. bus zone, circuit breaker fail
- System level automation system e.g. station interlocking, voltage regulation

6.3.4 System testing

System testing is testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements. System testing falls within the scope of black box testing, and as such, should require no knowledge of the inner design of the subsystems and its components.

As a rule, system testing takes, as its input, all of the "integrated" components that have successfully passed integration testing and also the system itself integrated with any applicable hardware system(s). The purpose of integration testing is to detect any inconsistencies between the units that are integrated together (called assemblages) or between any of the assemblages and the hardware. System testing is a more limited type of testing; it seeks to detect defects both within the "inter-assemblages" and also within the system as a whole

7 Testing use cases

7.1 General

In order to help describe the methods for testing of IEC 61850 based devices and systems this report considers two testing use cases:

- Breaker Failure Protection
- Select Before Operate Breaker Control

The reason to select the above use cases is that they are both distributed applications that are implemented in a digital substation using different types of logical nodes and communications interfaces that require the use of the different testing related features in IEC 61850.

7.2 Distributed Breaker Failure Protection Scheme

7.2.1 General

Breaker Failure Protection (BFP) plays a very important role in ensuring the stability of electric power systems during short circuit faults or other abnormal conditions followed by a failure of a breaker to trip. Today in IEC 61850 based systems we use high speed communications between multifunctional Intelligent Electronic Devices (IEDs) that perform different functions within the BFP scheme.

Failure of a BFP to operate when needed or misoperation under non-critical system conditions may have a very significant impact on the stability of the electric power system or result in the unnecessary tripping of multiple loads, in both cases leading to economical losses. That is why it is so important to ensure the correct operation of BFP using proper testing and monitoring methods and technologies.

7.2.2 Use case description

7.2.2.1 Single line diagram

Figure 14 shows the single line diagram (SLD) and the different components that will be used to describe the breaker failure function use case. The naming conventions used are according to IEC 81346-2.

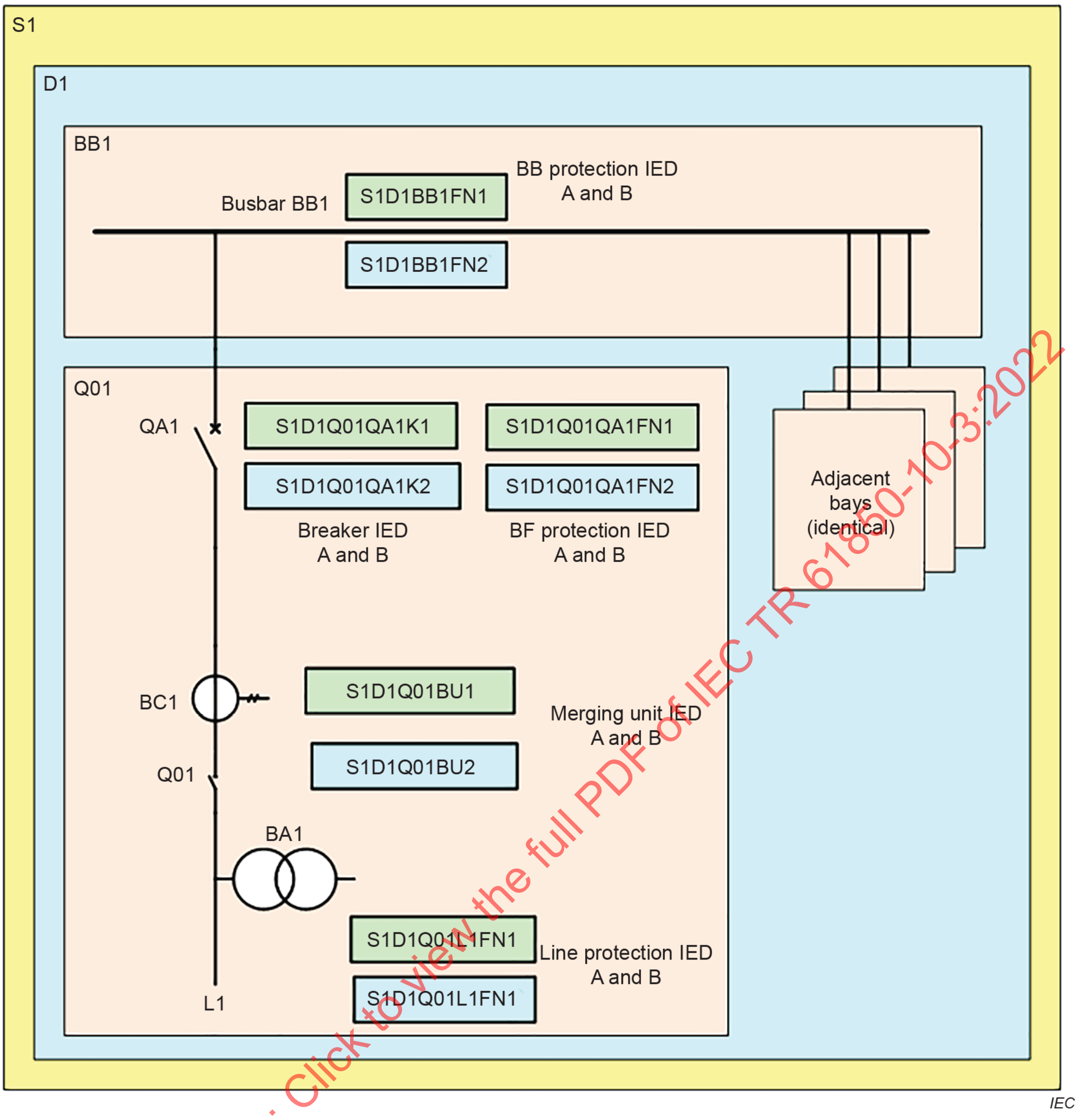

Figure 14 – Single line diagram according to IEC 81346

The SLD is composed of:

- One substation S1 that contains one voltage level D1 that contains two bays BB1 and Q01 and a series of other bays identical to bay Q01
- The bay BB1 contains one busbar BB1
- The bay Q01 contains one breaker QA1, one switch Q01, the current/voltage instrument transformers BC1 and BA1 and the departure line L1

7.2.2.2 Breaker Failure Protection Scheme Components

7.2.2.2.1 General

The breaker failure protection scheme can be implemented using different vendor or user specific principles. However, they may include several principle components:

- A function element that initiates the breaker failure protection scheme
- A function element that attempts to reduce the probability for breaker failure
- A function element that detects the breaker failure

- Function elements that clear the fault after a breaker failure

In our example use case the breaker failure protection scheme is initiated by the operation of time overcurrent protection elements represented by PTOC logical nodes through the PTRC logical nodes.

The attempts to avoid breaker failure is performed by the RBRF using re-trip.

The detection of the breaker failure is performed by the RBRF using external trip.

The tripping of breakers is performed by XCBRs.

The interface with the instrument transformers is performed by the TCTR logical nodes.

7.2.2.2.2 System components

The components of the distributed breaker failure protection scheme with redundant IEDs are shown in the nxt UML diagram in Figure 15.

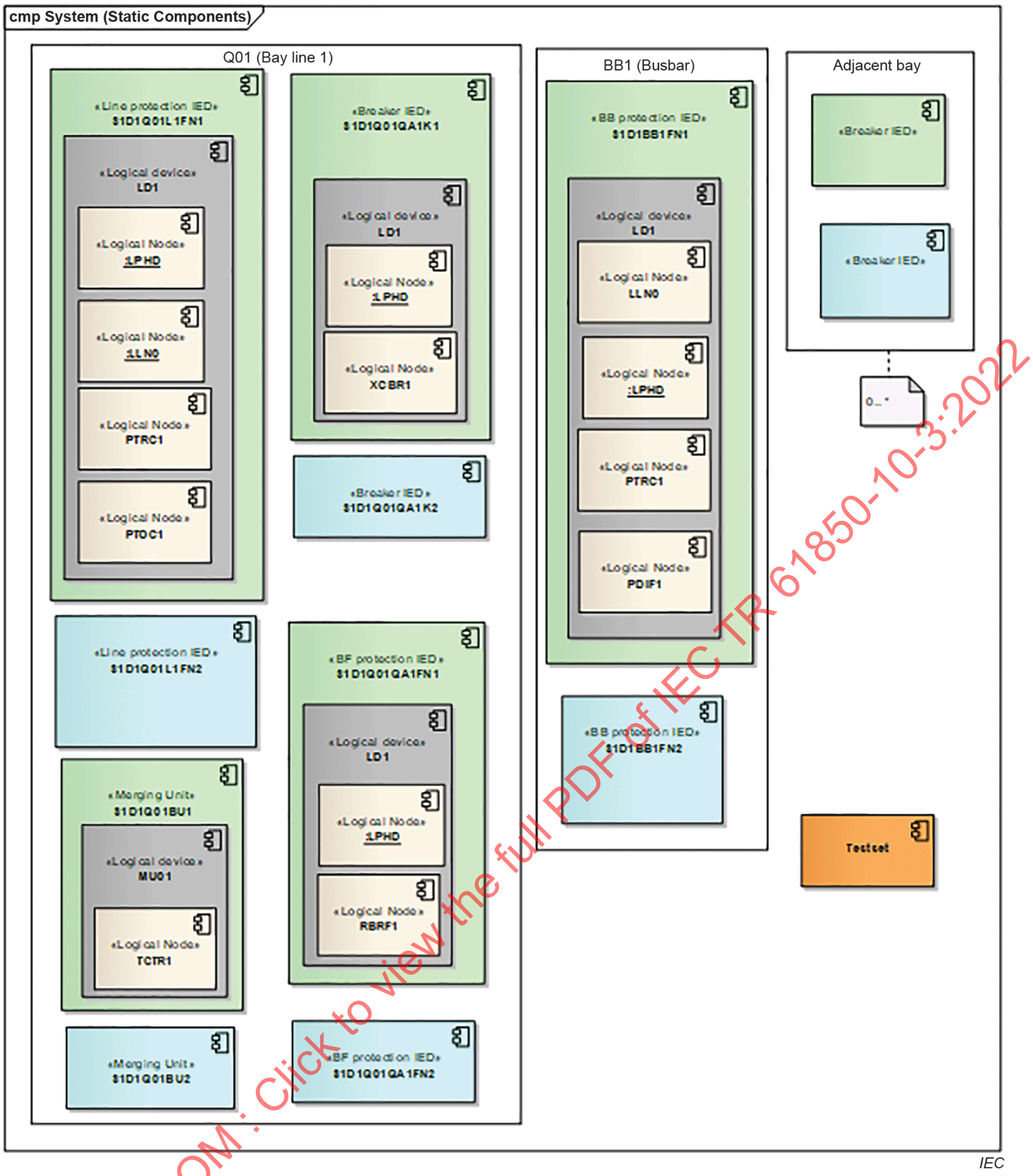

Figure 15 – System components (Static)

They are grouped per bay:

- Bay S1D1Q01
  - Two line protection IEDs: S1D1Q01L1FN1 and S1D1Q01L1FN2
  - Two breaker IEDs: S1D1Q01QA1K1 and S1D1Q01QA1K2
  - Two breaker failure protection IEDs: S1D1Q01QA1FN1 and S1D1Q01QA1FN2
  - Two merging unit IEDs: S1D1Q01BU1 and S1D1Q01BU2
- Bay S1D1BB1
  - Two busbar protection IEDs: S1D1BB1FN1 and S1D1BB1FN2
- Adjacent bays
  - Identical to bay S1D1Q01

The last component is the test set.

7.2.3 Breaker Failure Protection Scheme Interfaces

The breaker failure protection scheme includes several different types of interfaces:

- Analog interface between the instrument transformers and the stand alone merging unit
- Sampled values interface between the merging unit and the protection IEDs
- GOOSE interface between all IEDs
- Hardwired interface between the breaker controllers and the trip coils of the breakers

All the above interfaces impose different requirements for the simulation and assessment of the performance of the breaker failure protection scheme and its components.

Figure 16 shows the involved interfaces considered in the intended use case.

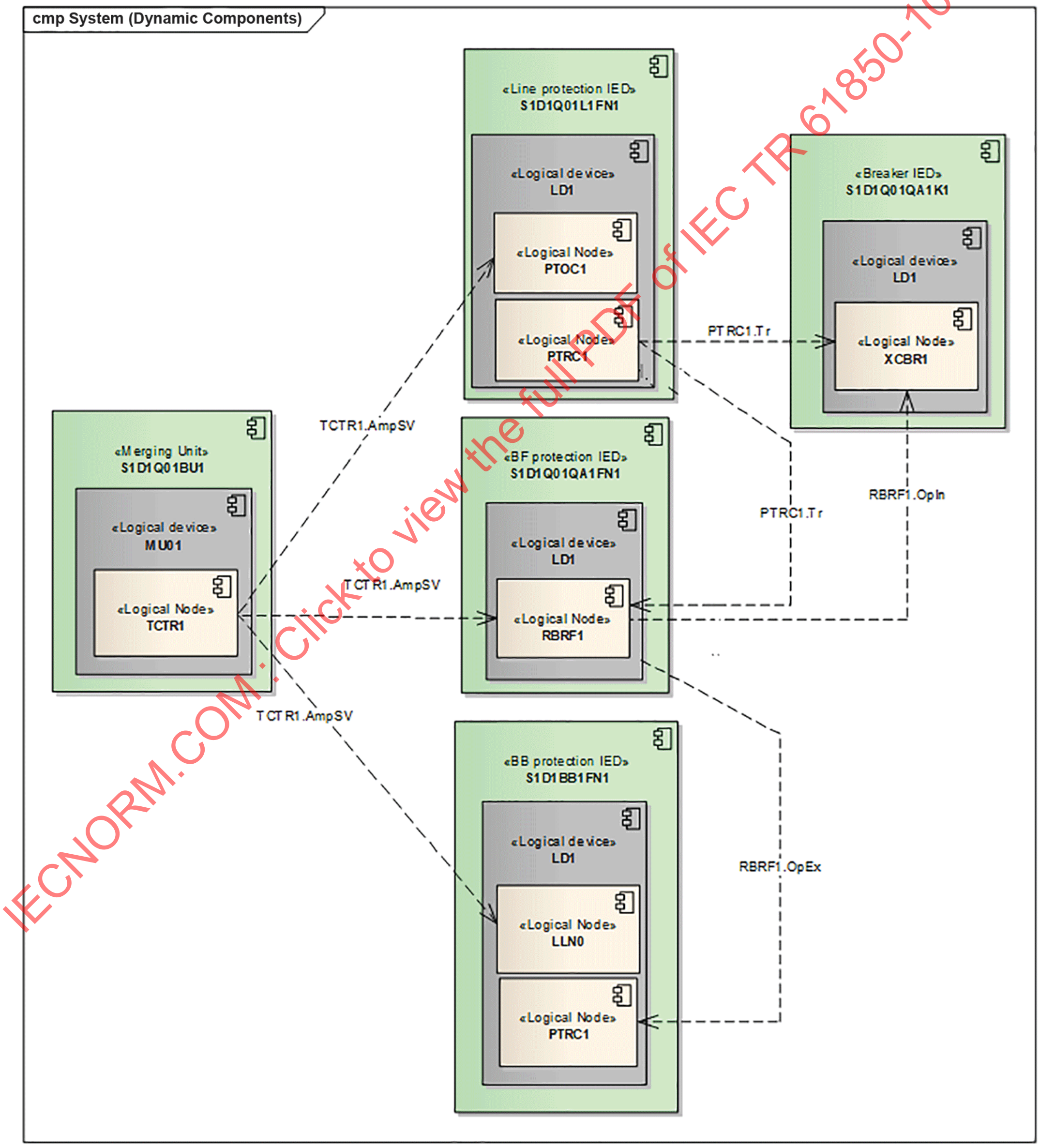

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Figure 16 – System components (Dynamic)

7.3 Distributed Select Before Operate

7.3.1 General

Controls are generic components of the substation automation systems and as such are defined to comply with all basic rules of operation in substations. Human initiated or as part of SOE they interact with different parts of PACS subsystems. Thus, controls are passing levels of checks until they reach final execution point. Most applied version of control upon the switchgear is Select Before Operate with enhanced security (SBOw) because it includes all necessary security features to provide reliable operation. Control is interacting with Interlocking functionality, Synchrocheck, Position of controlling equipment, and indirectly with switchgear, substation related blockings, protection and protection related functions. All interaction elements are not necessarily located in one physical device and as such control is presumed to be distributed function. This use case will be evaluated as SBO control service for Circuit Breaker in double busbar HV bay. Control command is issued from hierarchically elevated level (either station level or remotely from control center).

7.3.2 Select Before Operate Scheme Components

Select Before Operate scheme is defined as control service in IEC 61850-7-2. Basic components needed to fulfill control functions are:

- A function element that initiates control sequence (IHMI)
- A function element that is entitled to control switching conditions above process level (CSWI)
- A function element that models the switch with short circuit breaking capability (XCBR)

This collection can be extended with:

- A function element that models interlocking conditions (CILO)
- A function element that models synchrocheck conditions (RSYN)
- Voltage measurement provider for synchrocheck that resides in TVTR logical nodes
- A function element necessary for topological detection in order to set/reset status of CILO logical node (XSWI)
- Function elements that model switchgear and/or substation related blocking (SIMG, SARC…)

The general SBO scheme is presented in Figure 17.

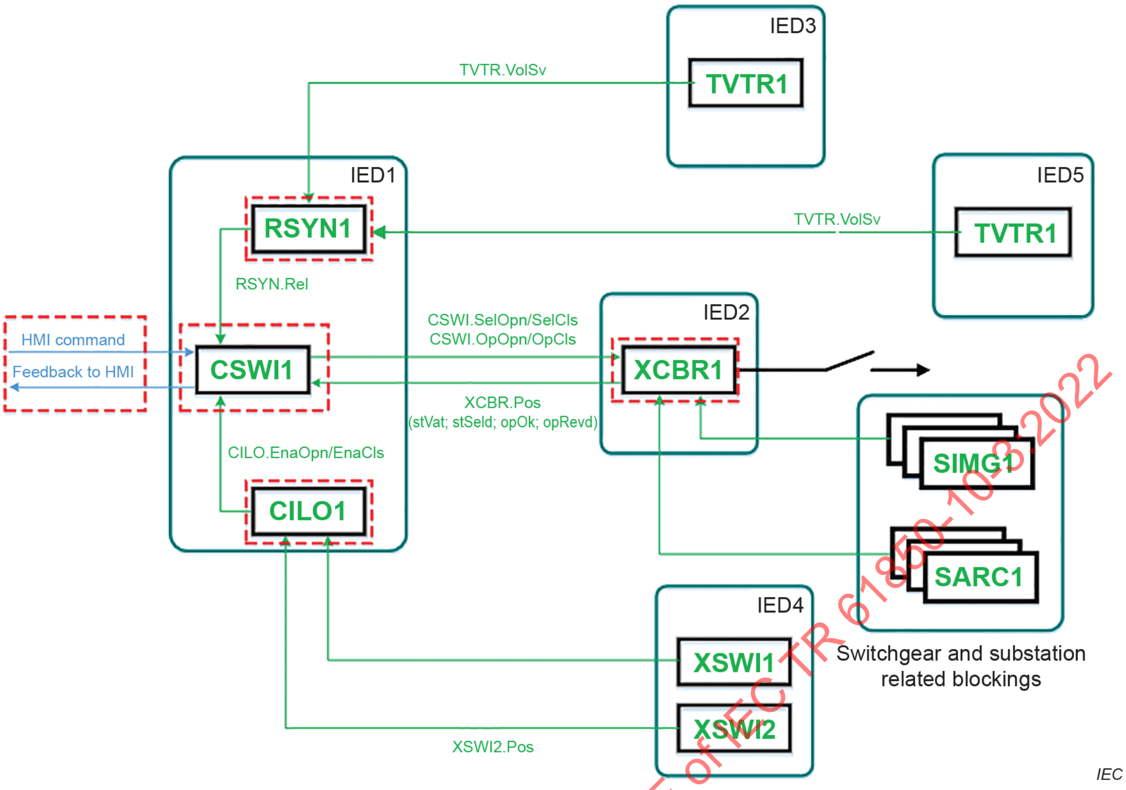

Figure 17 – Select Before Operate Scheme

The components of the Select Before Operate scheme are shown in the UML diagram in Figure 18.

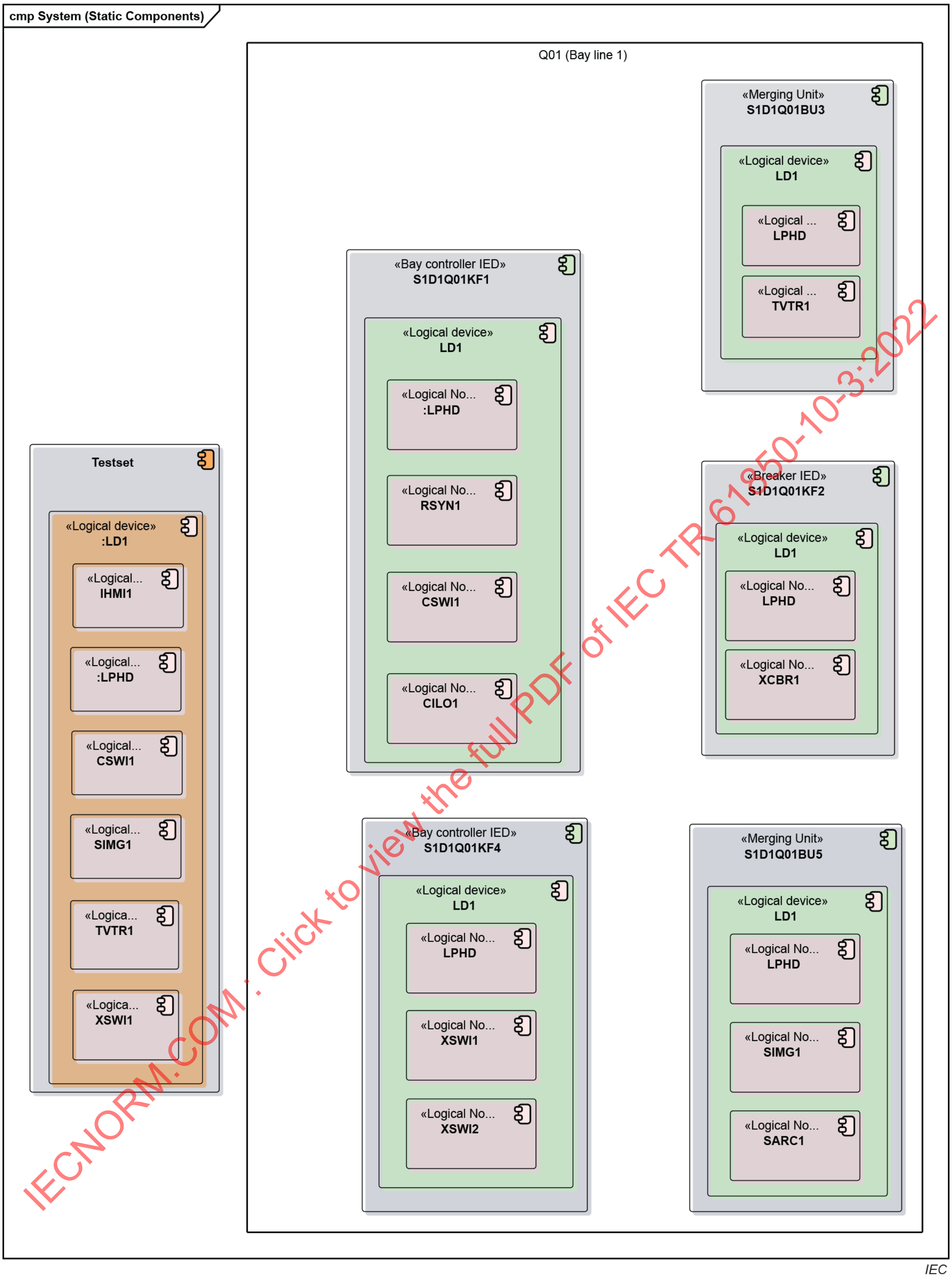

Figure 18 – Component decomposition of Select Before Operate Scheme

All components in this use case are grouped in one bay:

– Bay S1D1Q01
  - Two bay controller IEDs: S1D1Q01KF1 and S1D1Q01KF4
  - One breaker IED: S1D1Q01KF2
  - Two merging unit IEDs: S1D1Q01BU3 and S1D1Q01BU5

The last component needed for the purpose of testing is the test set.

7.3.3 Select Before Operate Scheme Interfaces

The Select Before Operate scheme (Figure 19 and Figure 20) includes several different types of interfaces:

- GOOSE interface between all IEDs
- Hardwired interface between the breaker controller and the trip coils of the breaker
- Client/Server interface (IEC 61850-8-1 MMS)
- Analogue interface between voltage instrument transformers and the stand alone merging unit
- Sampled values interface between the merging unit and the IED

All the above interfaces impose different requirements for the simulation and assessment of the performance of the Select Before Operate scheme and its components.

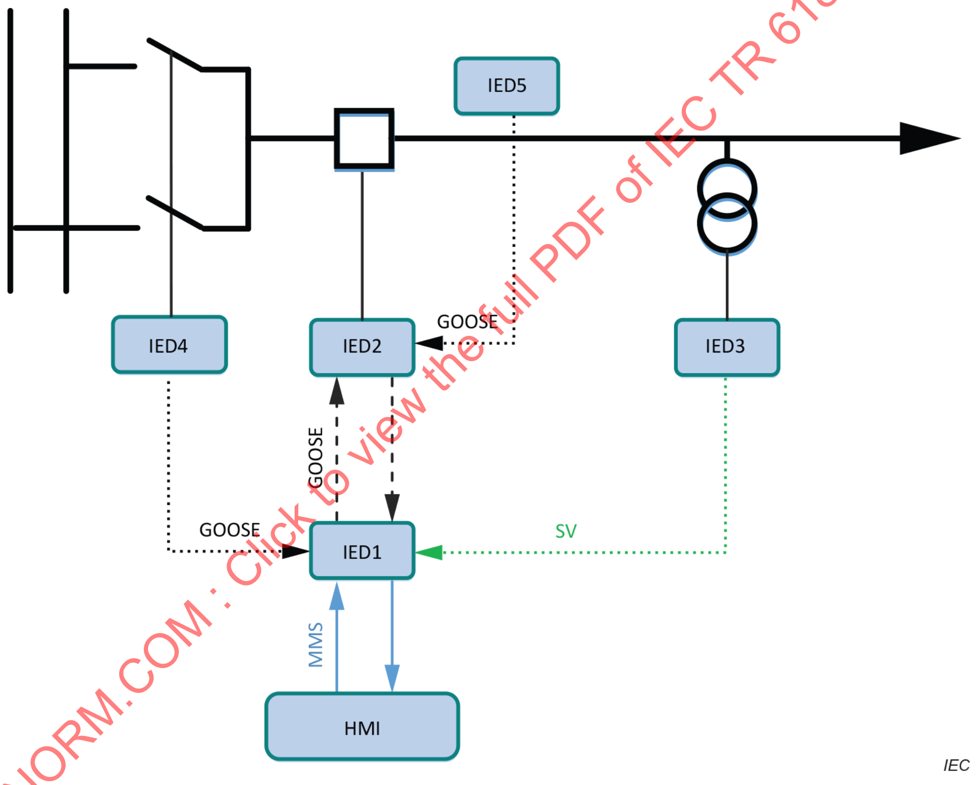

Figure 19 – Allocated interfaces for Select Before Operate Scheme – SLD

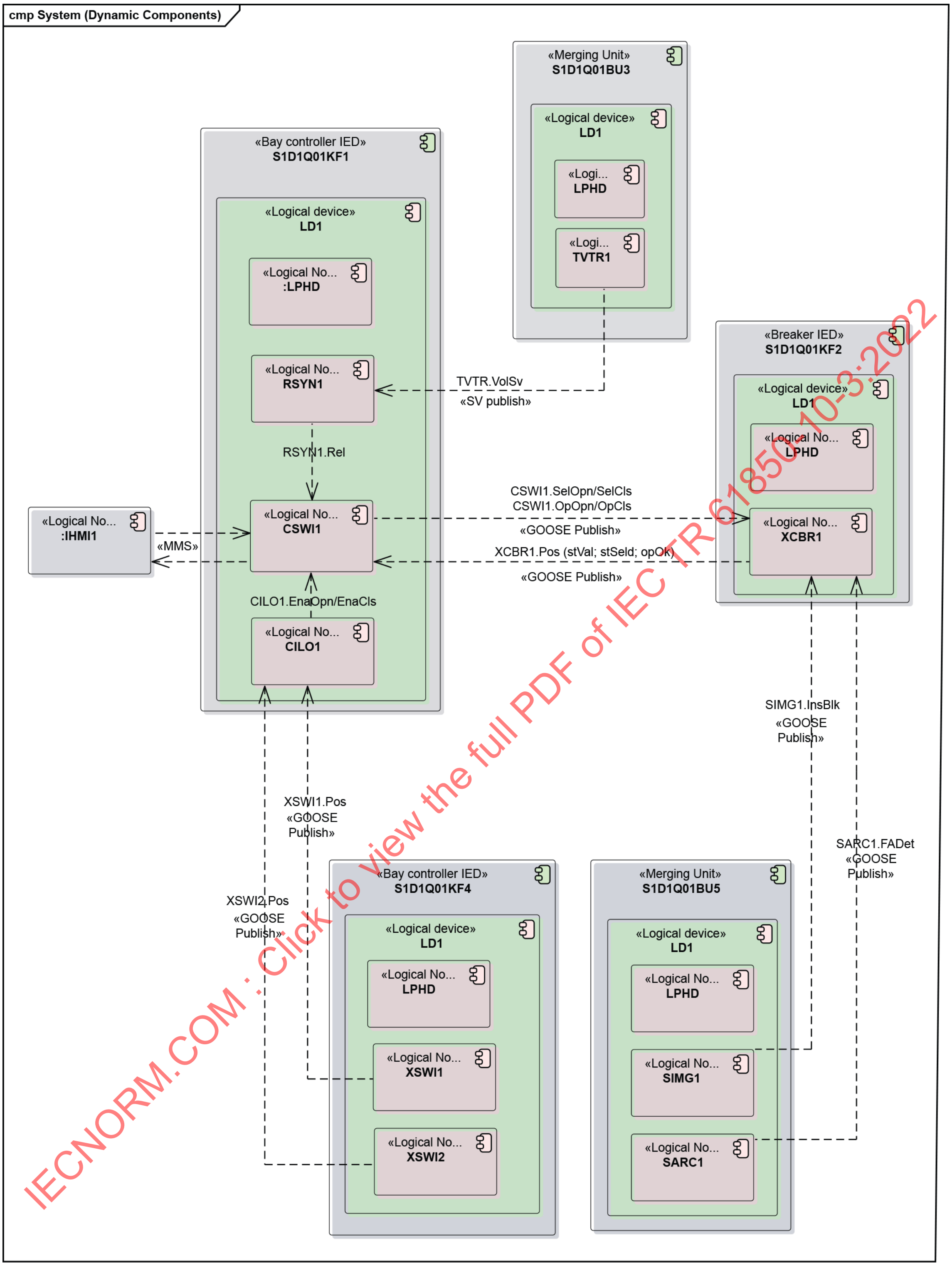

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Figure 20 – Allocated interfaces for Select Before Operate Scheme

7.3.4 Select Before Operate Scheme Behavior

Select Before Operate Scheme behaviour is explained without taking into account influence from RSYN LN (and indirectly TVTR LN), Switchgear and substation related blockings (Sxxx LN), positions of other equipment influencing CILO (XSWI1, XSWI2).

When command is initiated from HMI, control service request will start the control sequence according to the control state machine in IEC 61850-7-2.

Selection request is issued (SelVal_req()) and Control LN CSWI is performing Operative test (Interlocking,…).

If test is passed, CSWI will send GOOSE message with:

CSWI.SelOpn / SelCls.stVal=true (depending of operation initiated OPEN or CLOSE)

to Circuit Breaker LN XCBR.

When order is received by Breaker IED, opRcvd must be sent to the client.

XCBR LN is checking various conditions (hierarchical, blocking, switchgear status, health) and if all are met returns GOOSE message with:

XCBR.Pos.stSeld=true

back to CSWI, where local value will be also set to true:

CSWI.Pos.stSeld=true

and Selection positive response (SelVal_resp+()) will be returned back to Human Machine Interface LN IHMI.

There is clearance for Operation request (Oper_req()) from HMI and again interlocking test is performed within CSWI.

If test is passed, Operation positive response (Oper_resp+()) is issued back to IHMI LN.

CSWI will send GOOSE message with:

CSWI.OpOpn/OpCls.general=true

to Circuit Breaker LN XCBR.

If process returns correct response to Circuit Breaker LN, GOOSE message will be returned back to CSWI with:

XCBR.Pos.opOk=true

And local value in CSWI will be also set:

CSWI.Pos.opOk=true

When the process returns confirmation of Circuit Breaker position change it will be transmitted back as GOOSE message:

XCBR.Pos.stVal = new position

XCBR.Pos.opOk will be reset to false either after the PulseConfig or after time that is local issue.

XCBR.Pos.opOk = false

It will be returned to CSWI and local value will be also set to false:

CSWI.Pos.opOk=false

This results in resetting OpOpn/OpCls.general = false in CSWI LN.

Control state machine is having condition to reset stSeld remotely in XCBR by issuing GOOSE message with:

CSWI.SelOpn/SelCls.stVal = false.

Positive command Termination request (CmdTerm_req+()) is issued back to IHMI.

Reset of XCBR.stSeld will reinitiate CSWI.stSeld=false upon receival of GOOSE message from XCBR LN.

Explained behaviour is presented in the UML diagram in Figure 21.

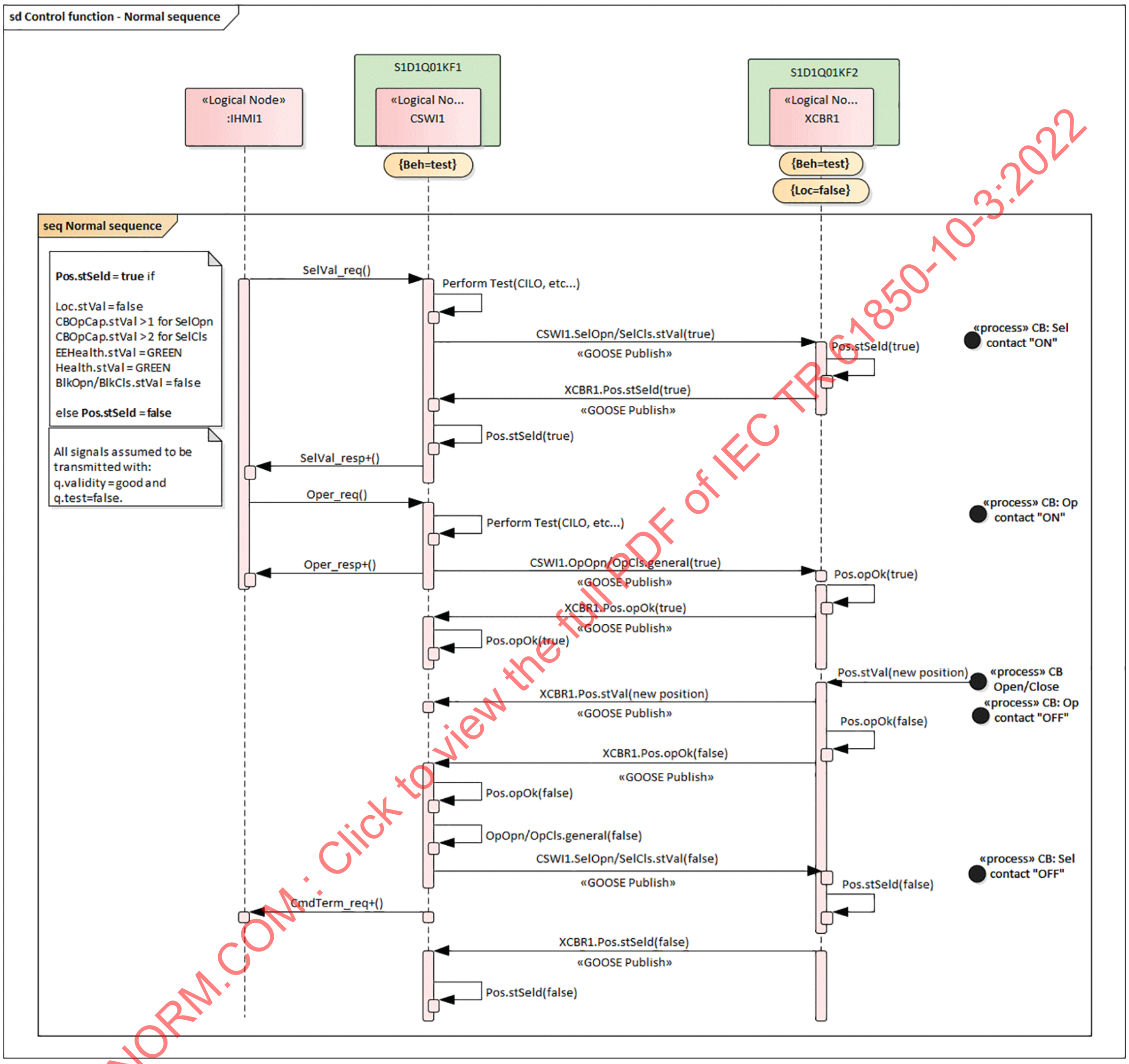

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Figure 21 – Simplified SBO scheme behaviour

7.3.5 Single line diagram

The single line diagram (SLD) used in SBO use case along with its components is presented in Figure 22 (the naming conventions are according IEC 81346-2).

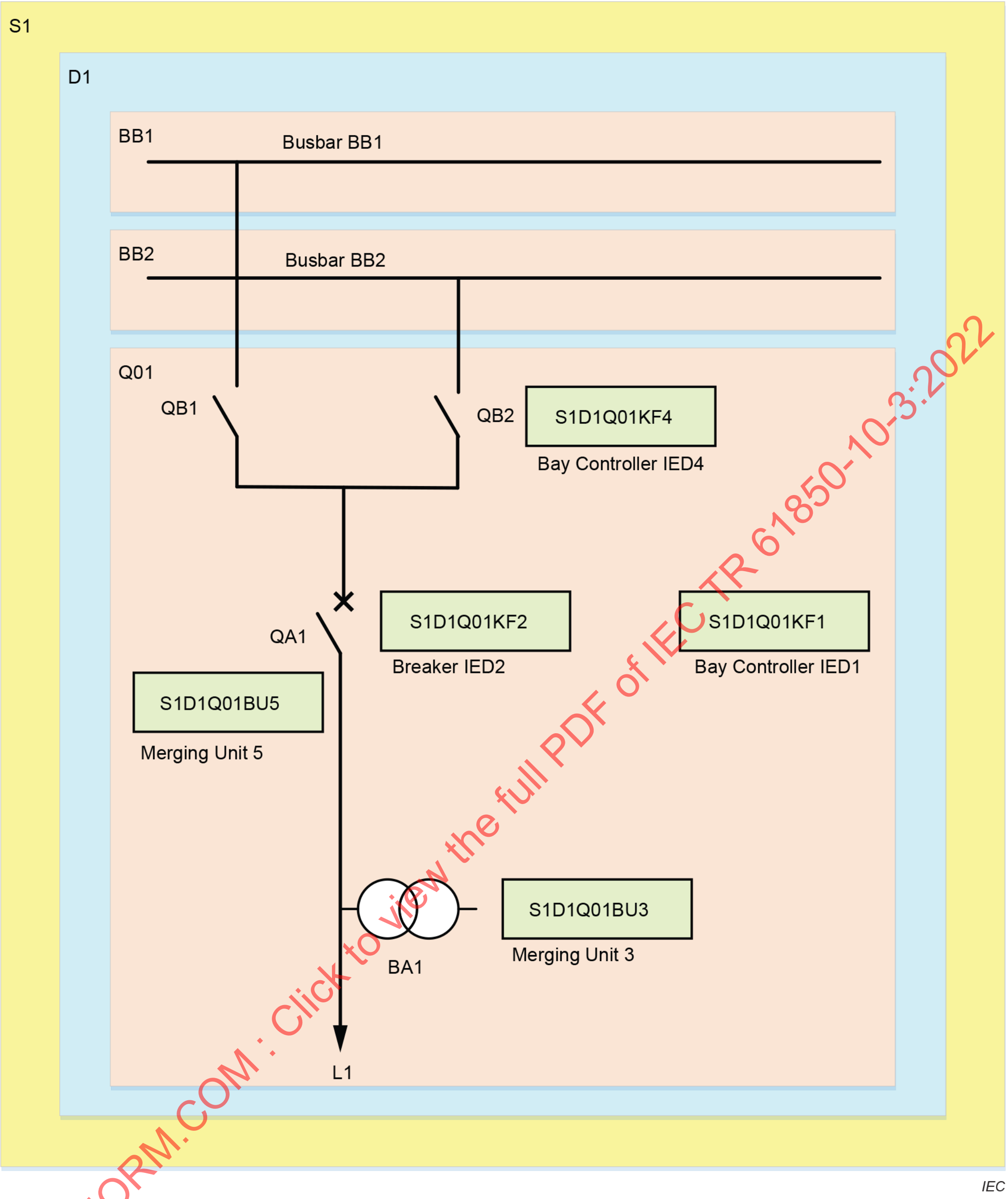

Figure 22 – Single line diagram

The SLD is composed of:

- One substation S1 that contains one voltage level D1 with two busbars bays BB1 and BB2 and bay Q01
- The bay Q01 contains one breaker QA1, two disconnectors QB1 and QB2, the voltage instrument transformer BA1 and the line L1

8 Test sequences for the use cases

8.1 Breaker failure protection testing

8.1.1 General

Subclauses 8.1.2 to 8.1.11) explain the different test sequences involved between the system components during the functional testing of the breaker failure function use case.

All the test sequences are intended to be realized by means of the network communication which does not imply that other means cannot be used, e.g. the device HMI functions.

The test sequences are described using UML sequence diagrams in the following order:

a) the normal and the fault sequences
b) the sequences used to set the test mode and the simulation state of specific functions involved
c) the distinct communication interfaces test sequences of specific functions involved
d) the end to end test sequence of the distributed breaker failure protection scheme.

8.1.2 Normal sequence

This sequence is the one prevailing when no fault is present on the primary system (Figure 23).

Prerequisites:

a) All functions (logical nodes) are in the state: Beh=on

Sequence:

a) The process values (primary system I/U of L1) are processed as normal (no fault)
b) No action (operate or trip) is in progress

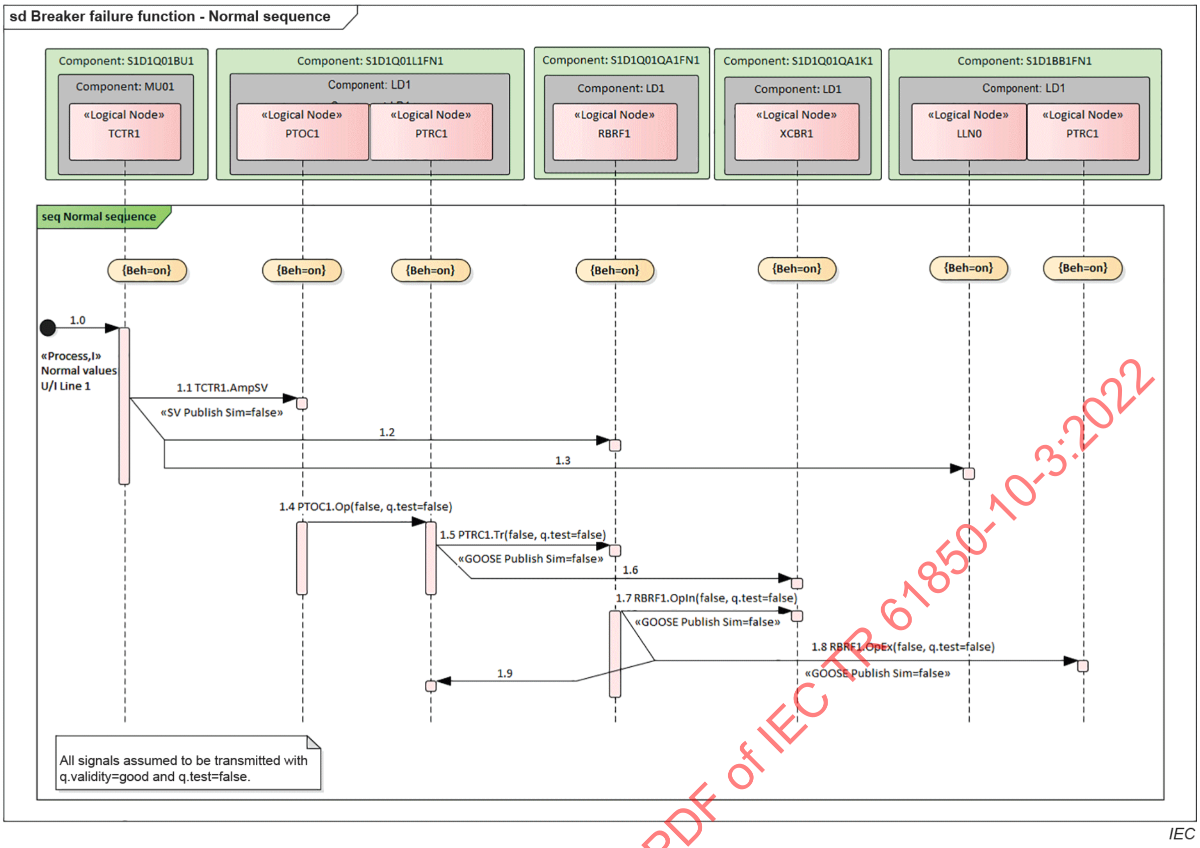

Figure 23 – Normal sequence

8.1.3 Fault sequence

This is the sequence of events when a fault occurs on the primary system (Figure 24). It includes breaker failure detection.

Prerequisites:

a) All functions (logical nodes) are in the state: Beh=on (normal sequence)

Sequence:

a) The process values (primary system I/U of L1) are processed as fault values
b) A fault is detected (message 1.4) and trip messages (1.5 and 1.7) are sent to trip the breaker QA1 and initiate the breaker failure protection (message 1.6)
c) The breaker failure protection retrip the breaker QA1 (messages 1.9 and 1.10)
d) If the fault is not cleared after a certain delay, the breaker failure protection trip the adjacent bays (messages 1.12 and 1.13) including the faulted bay (message 1.11)

NOTE The principle here is that the breaker failure function does not differentiate what function it has been initiated from. The external trip is always sent to the adjacent zones of the breaker.

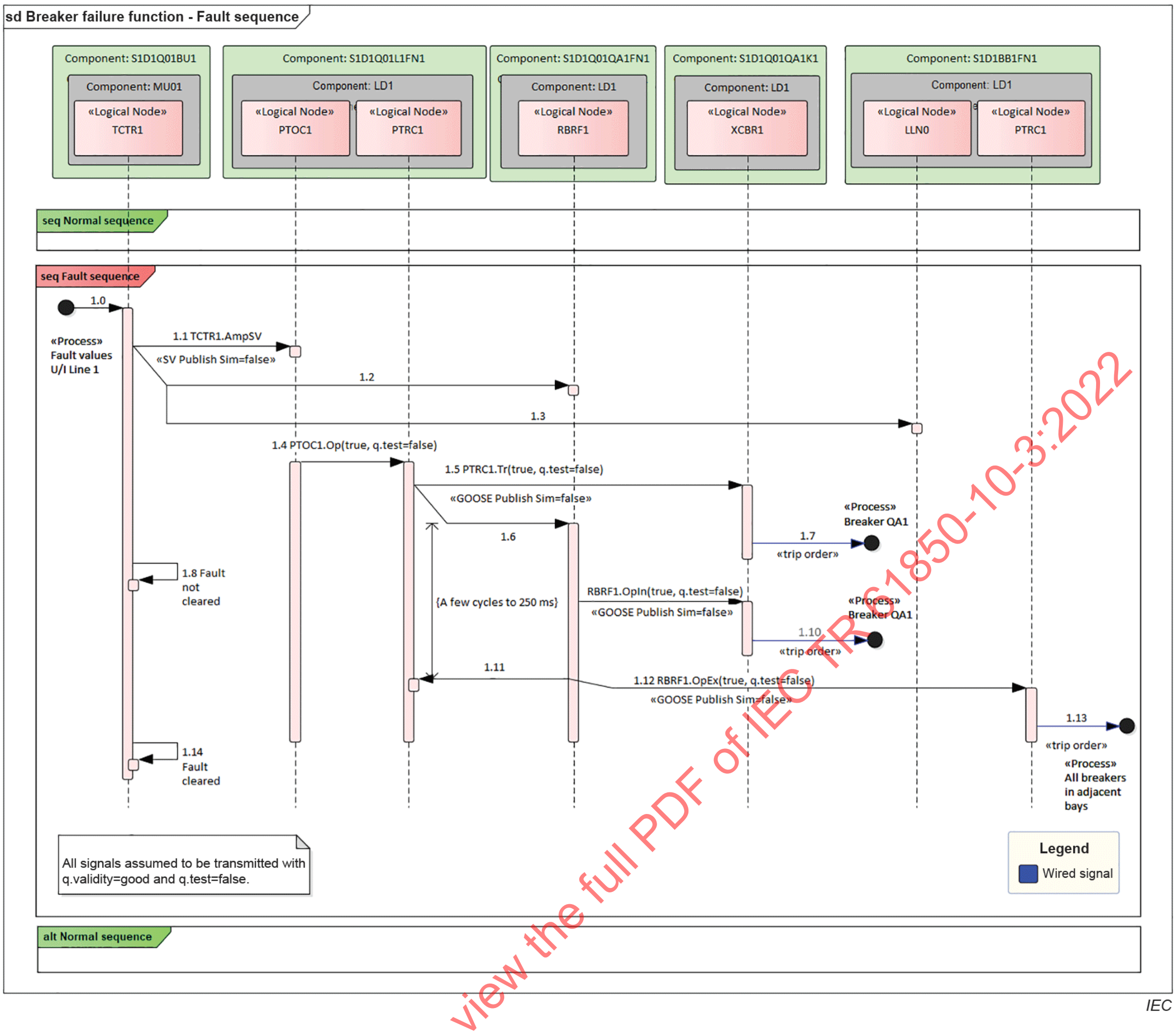

Figure 24 – Fault sequence

8.1.4 Setting the test mode and the simulation state of the line protection function

This sequence (Figure 25) is used to change the behavior (S1D1Q01L1FN1/LLN0.Beh) of the line protection function from "on" to "test" and the line protection device simulation state (S1D1Q01L1FN1/LPHD.Sim) from "false" to "true".

Prerequisites:

a) All functions (logical nodes) are in the state: Beh=on (normal sequence)

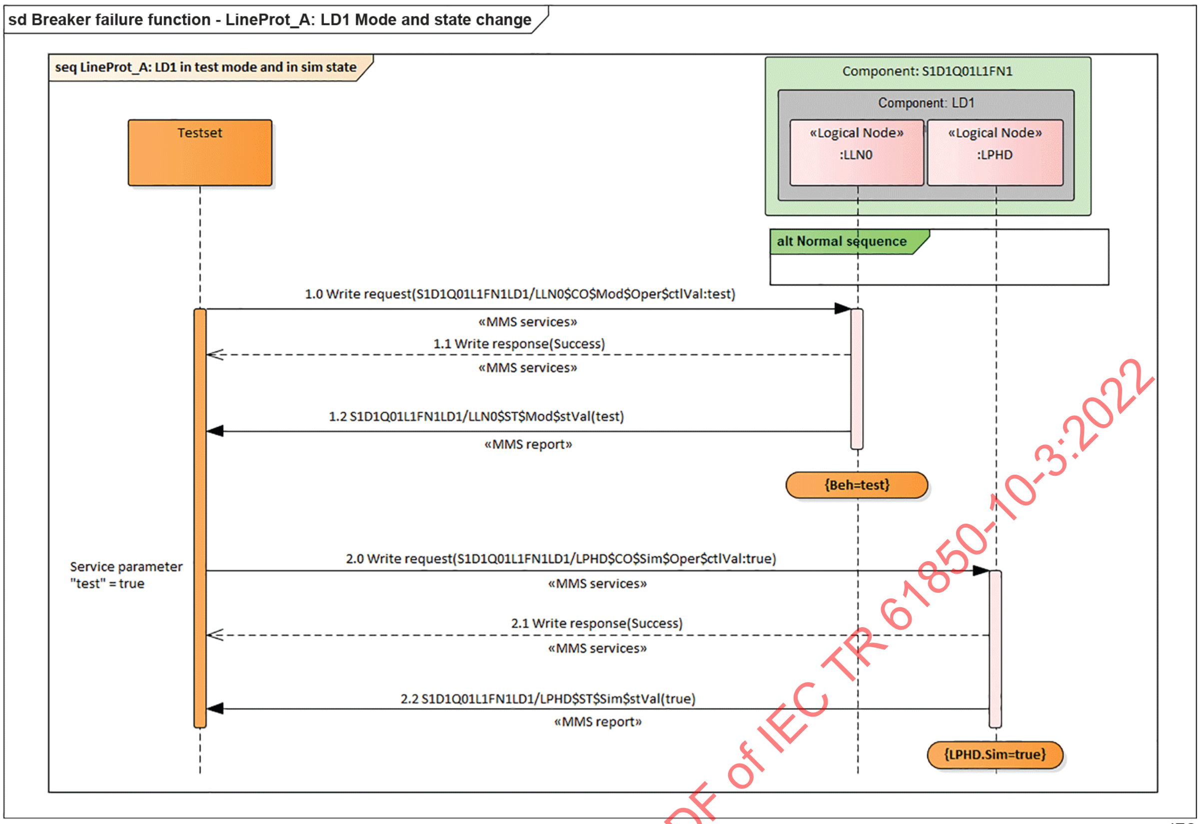

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Figure 25 – Line protection function: Setting the mode and the simulation state

Sequence:

a) The test set sends a write message (1.0) to the line protection device in order to change the mode of the function

b) The line protection device confirms to the test set the successful writing (1.1)

c) The line protection device sends a report to the test set confirming that the Beh of the function is now in test (1.2)

d) The test set sends a write message (2.0) to the line protection device in order to put the whole device in the simulation state. The service parameter "test" has the value true (see IEC 61850-7-2)

e) The line protection device confirms to the test set the successful writing (2.1)

f) The line protection device sends a report to the test set confirming that the device is now in the simulation state (2.2)

The inverse sequence is used to set back the behavior (LLN0.Beh) of the line protection function and the device simulation state to the previous values.

8.1.5 Setting the test mode and the simulation state of the breaker failure function

This sequence (Figure 26) is used to change the behavior (S1D1Q01QA1FN1/LLN0.Beh) of the breaker failure function from "on" to "test"and the breaker failure device simulation state (S1D1Q01QA1FN1/LPHD.Sim) from "false" to "true". The sequence is the same as in 8.1.4.

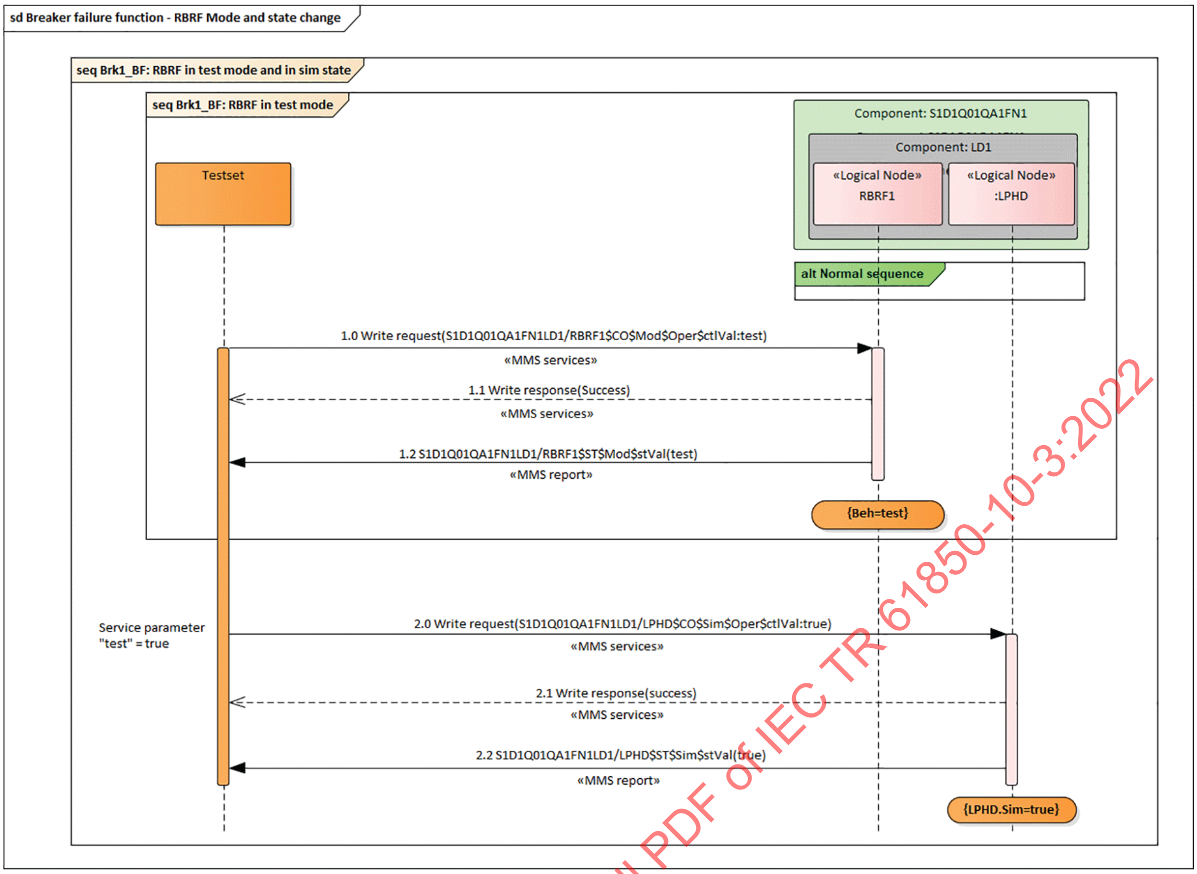

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Figure 26 – Breaker failure function: Setting the mode and the simulation state

8.1.6 Setting the test mode and the simulation state of the breaker function

This sequence (Figure 27) is used to change the behavior (S1D1Q01QA1K1/LLN0.Beh) of the breaker function from "on" to "test/blocked" and the breaker device simulation state (S1D1Q01QA1K1/LPHD.Sim) from "false" to "true".

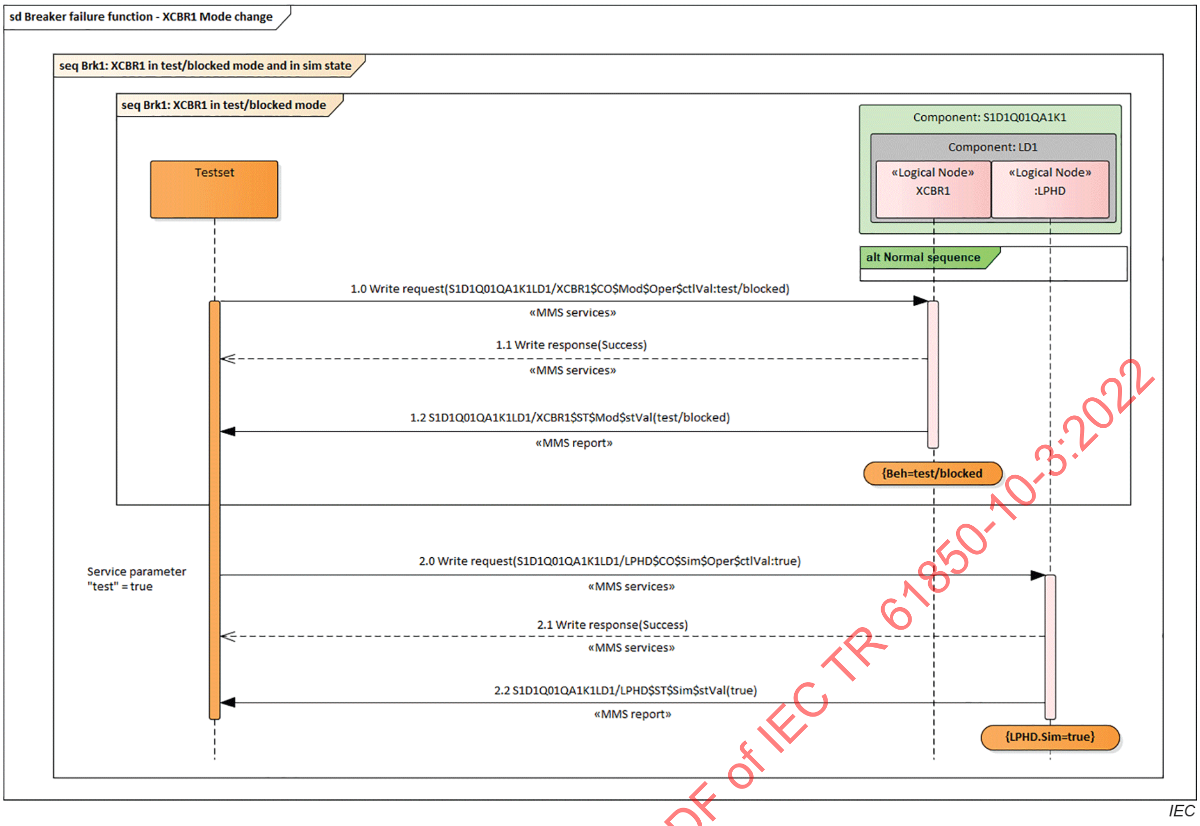

Figure 27 – Breaker function: Setting the mode and the simulation state

8.1.7 Setting the test mode of the bus bar protection function

This sequence (Figure 28) is used to change the behavior (S1D1BB1FN1/LLN0.Beh) of the bus bar protection function from "on" to "test".

Figure 28 – Bus bar protection function: Setting the mode

8.1.8 Testing the line protection IED

This sequence (Figure 29) aims at testing the line protection IED with the interfaces shown in Figure 30.

Prerequisites:

a) All functions (logical nodes) are in the state: Beh=on (normal sequence)

Sequence:

a) The test starts by setting the line protection function in the test mode and the protection line device S1D1Q01L1FN1 in the simulation state
b) The test set activates the transmission of simulated process sample values (1.1) with the following characteristics:
   1) current values are exceeding the line protection fault setting values
   2) the simulation flag S of the telegram is set to "true"
   3) the quality q of the current values is set to "test"
c) The line protection function operates (1.2)
d) The breaker failure function and the bus bar protection process the telegram as invalid (1.3 and 1.4) (see IEC 61850-7-4)
e) The line protection function sends a GOOSE trip signal (1.5 to 1.7) with q="test"
f) The breaker failure function and the breaker protection process the telegram as invalid (1.5 and 1.6) (see IEC 61850-7-4)
g) The test set acknowledges the reception of the trip signal (1.7) and deactivates the transmission of simulated process sample values (1.8)

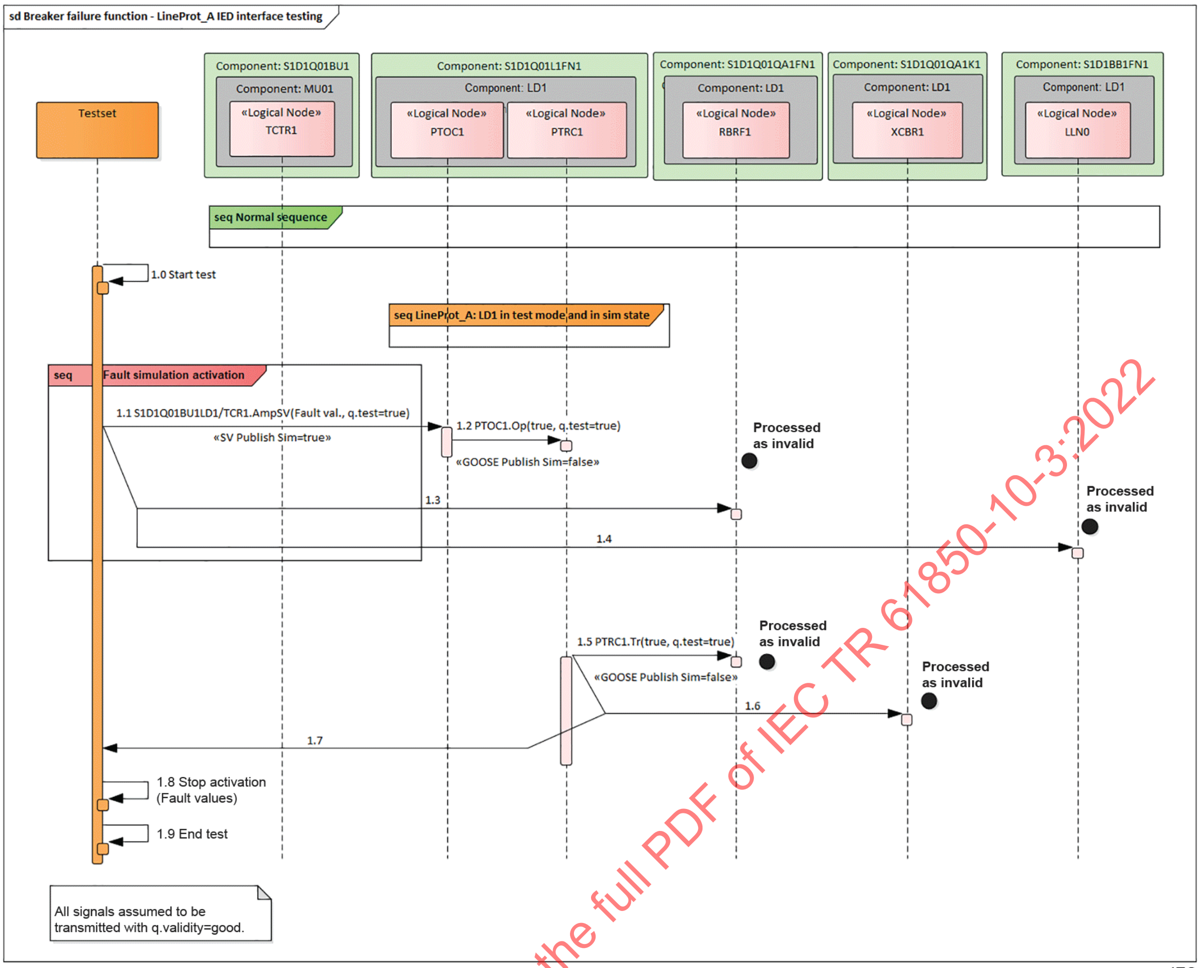

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Figure 29 – Line protection IED A interface testing

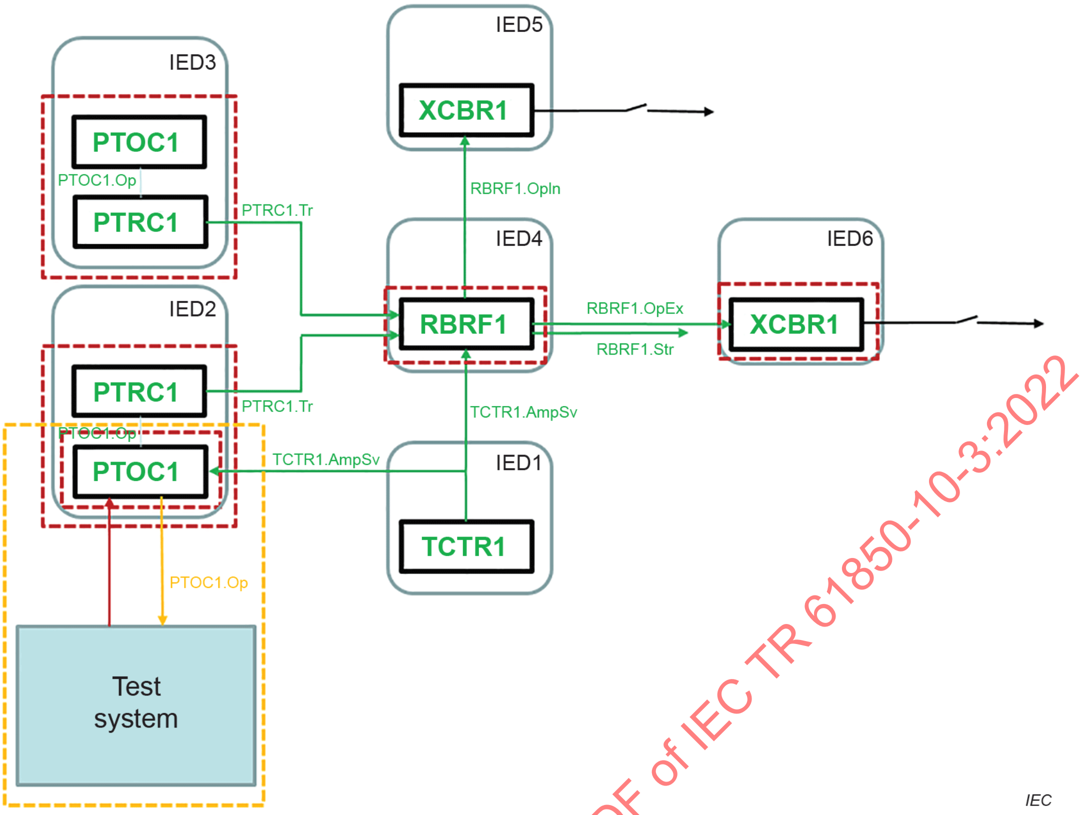

Figure 30 – Interfaces between test system and tested IED for testing of line protection function

8.1.9 Testing the breaker failure IED A interface

This sequence (Figure 31) aims at testing the breaker failure IED A interface as shown in Figure 32.

Prerequisites:

a) All functions (logical nodes) are in the state: Beh=on (normal sequence)

Sequence:

a) The test starts by setting the breaker failure function in the test mode and the breaker failure device S1D1Q01QA1FN1 in the simulation state
b) The test set activates the sequence "Fault simulation" in order to transmit simulated process sample values to the breaker failure function
c) The test set sends a GOOSE trip signal (1.1) with the following characteristics:
    1) the simulate bit S of the telegram is set to "true"
    2) the quality q of the trip signal is set to "test"
d) The test set maintains the sequence "Fault simulation" (1.2)
e) The breaker failure function sends a GOOSE internal trip signal with q="test" (1.3 and 1.4)
f) The breaker function processes the telegram as invalid (1.3) (see IEC 61850-7-4)
g) The test set acknowledges the reception of the internal trip signal (1.4)
h) The breaker failure function sends a GOOSE external trip signal (1.5 to 1.7) with q="test"
i) The bus bar protection function processes the telegram as invalid (1.5) (see IEC 61850-7-4)
j) The line protection function processes the telegram as invalid (1.6) (see IEC 61850-7-4)
k) The test set acknowledges the reception of the external trip signal (1.7)

l) End of the test (1.8 and 1.9)

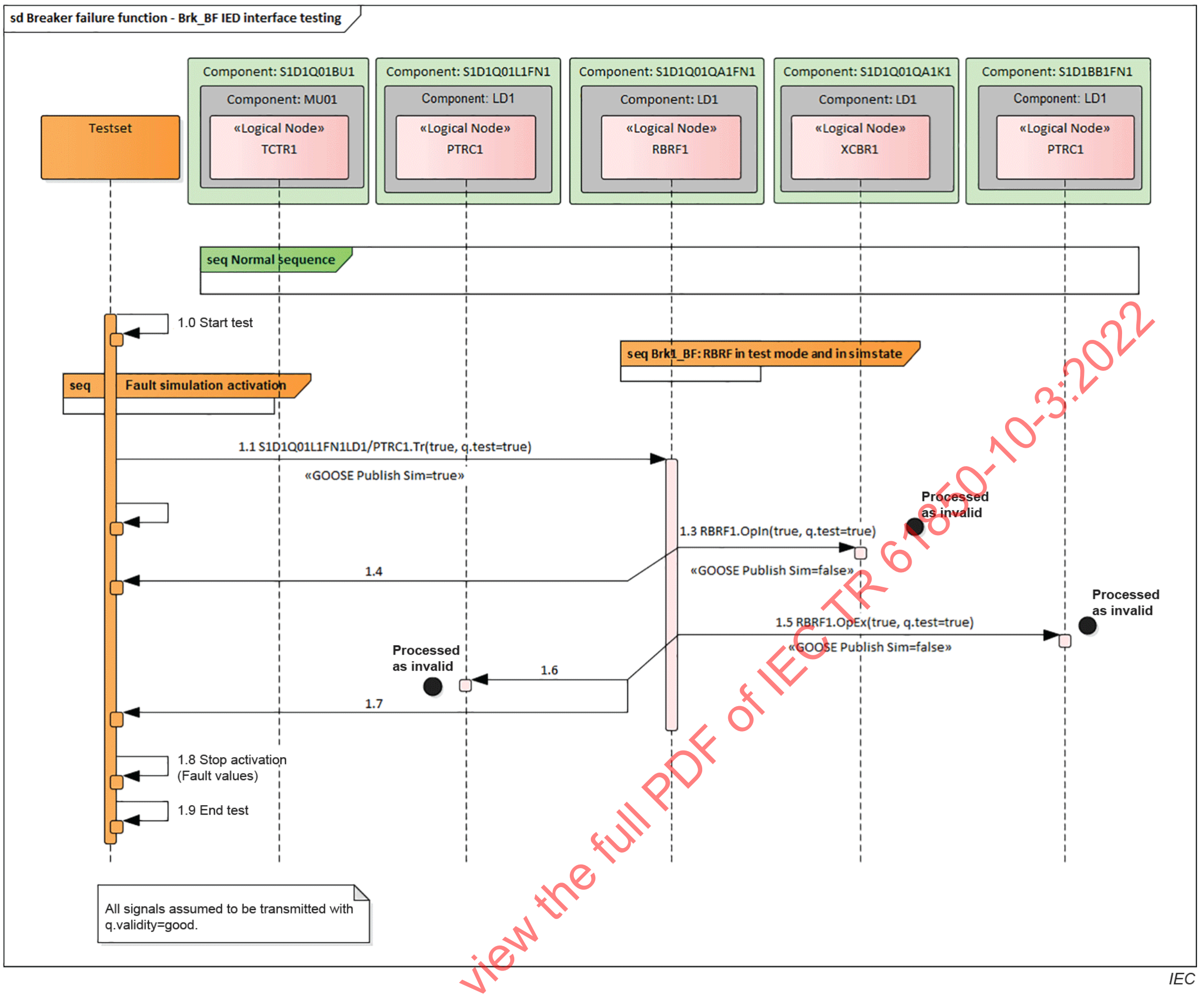

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Figure 31 – Breaker failure IED A interface testing

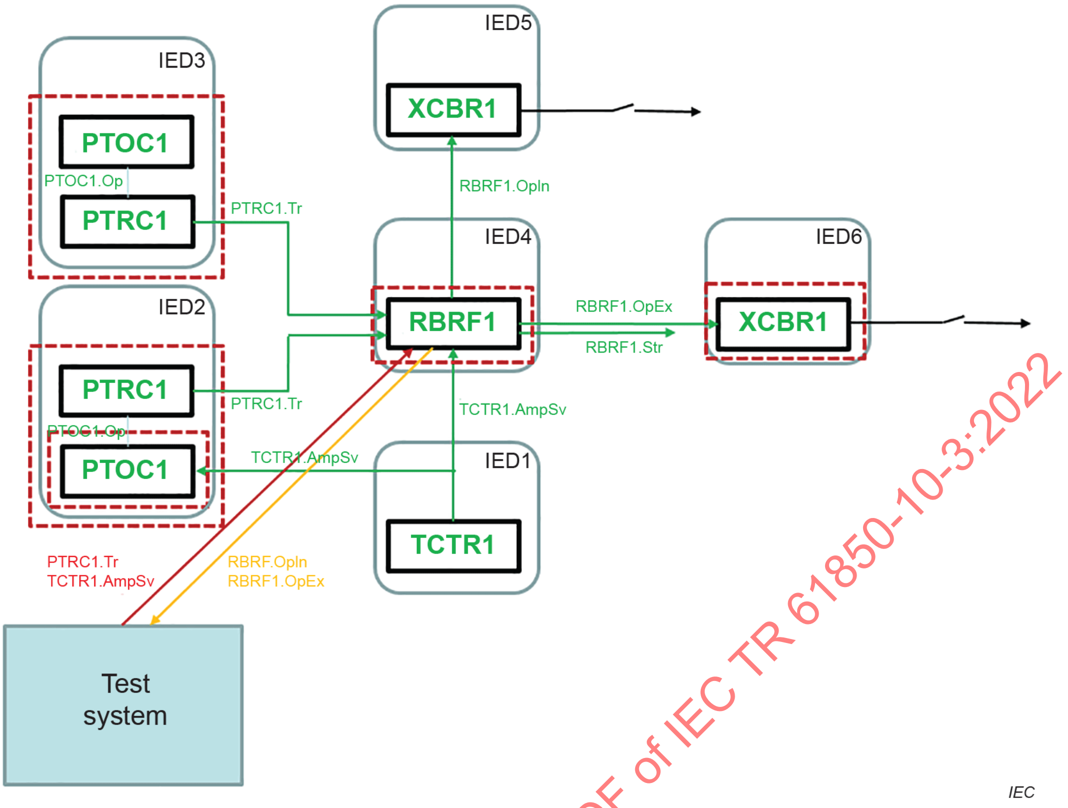

Figure 32 – Interfaces between test system and tested IED for testing of breaker failure protection function

8.1.10 Testing the breaker IED A interface

This sequence (Figure 33) aims at testing the breaker IED A interface as shown in Figure 34.

Prerequisites:

a) All functions (logical nodes) are in the state: Beh=on (normal sequence)

b) The breaker is in the closed position (XCBR1.Pos.stVal="on")

Sequence:

a) The test starts by setting the breaker function in the test mode and the breaker device S1D1Q01QA1K1 in the simulation state

b) The test set sends a GOOSE trip signal (1.1) with the following characteristics:
   1) the simulate bit S of the telegram is set to "true"
   2) the quality q of the trip signal is set to "test"

c) The breaker function processes the telegram as valid (1.1) and does not issue any output to the process (see IEC 61850-7-4)

d) The breaker function device sends a report (1.2) to the test set confirming that:
   1) the breaker is still in the closed position (no output to the process)
   2) the trip signal (1.1) has been received

NOTE 1 For the semantic of the data attributes opRcvd, opOk and tOpOk, see IEC 61850-7-3.

e) The test set sends a GOOSE internal trip signal (2.0) with the following characteristics:
   1) the simulate bit S of the telegram is set to "true"
   2) the quality q of the trip signal is set to "test"

f) The breaker function processes the telegram as valid (2.0) and does not issue any output to the process (see IEC 61850-7-4)

g) The breaker function device sends a report (2.1) to the test set confirming that:
   1) the breaker is still in the closed position (no output to the process)
   2) the trip signal (2.1) has been received

NOTE 2 For the semantic of the data attributes opRcvd, opOk and tOpOk, see IEC 61850-7-3.

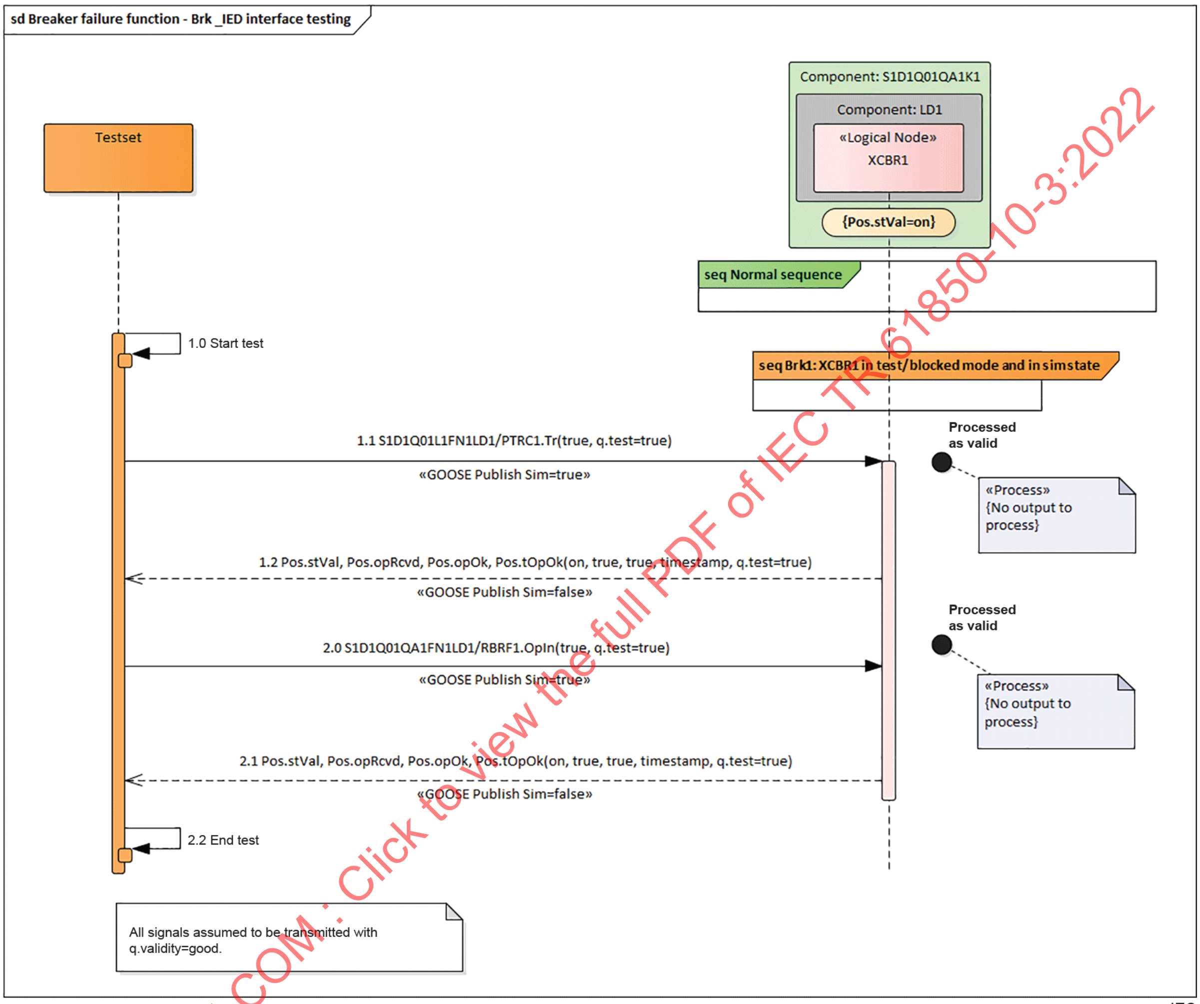

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Figure 33 – Breaker IED A interface testing

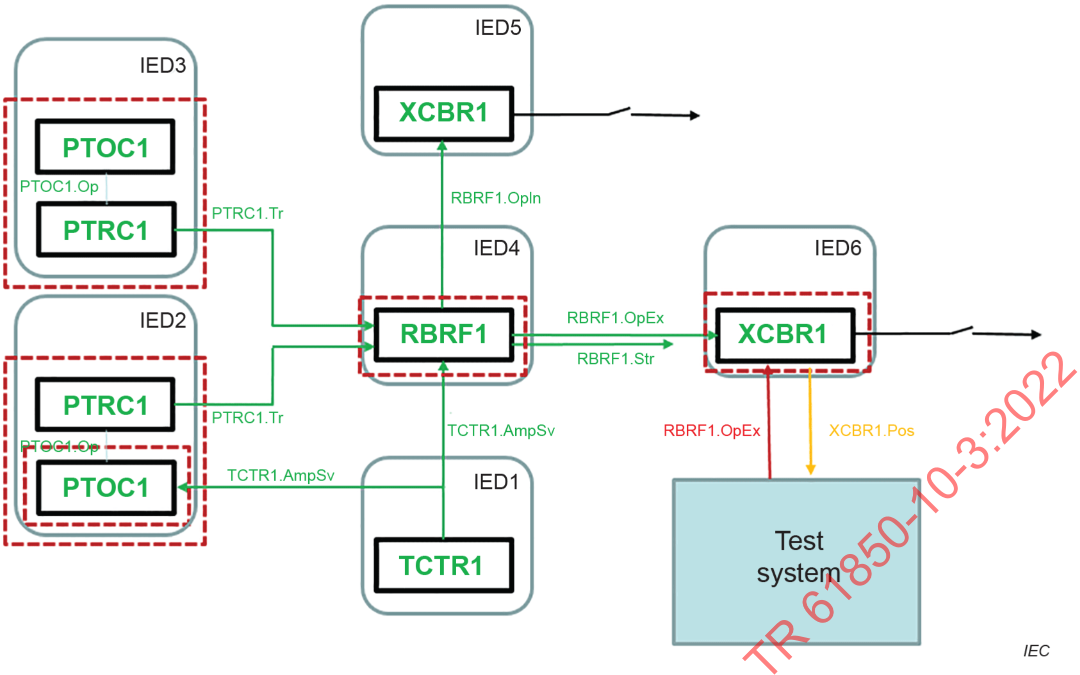

Figure 34 – Interfaces between test system and tested IED for testing of breaker control function

8.1.11 Testing the breaker failure function End-to-End

This sequence (Figure 35) aims at testing the breaker failure function from End-to-End with interfaces as shown in Figure 36.

Prerequisites:

a) All functions (logical nodes) are in the state: Beh=on (normal sequence)
b) The breaker is in the closed position (XCBR1.Pos.stVal="on")
c) The busbar breakers are in the closed or opened position

Sequence:

a) The test starts by setting all the following functions in the corresponding mode:
   1) the line protection function: test mode
   2) the breaker failure function: test mode
   3) the breaker function: test/blocked mode
   4) the bus bar protection function: test mode
   5) all the busbar breaker functions: test/blocked mode
b) The test continues with the setting of the following devices in the simulation state:
   1) the line protection device S1D1Q01L1FN1
   2) the breaker failure protection device S1D1Q01QA1FN1
   3) the breaker device S1D1Q01QA1K1
c) The test set activates the sequence "Fault simulation" in order to transmit simulated process sample values to the involved functions
d) The test set sends a GOOSE trip signal (2.0, 2.1 and 2.2) with the following characteristics:
   1) the simulate bit S of the telegram is set to "true"
   2) the quality q of the trip signal is set to "test"

e) The breaker function processes the telegram as valid (2.2) and does not issue any output to the process (see IEC 61850-7-4)
f) The breaker function device sends a report (2.3) to the test set confirming that:
    1) the breaker is still in the closed position (no output to the process)
    2) the trip signal (2.2) has been received

NOTE 1 For the semantic of the data attributes opRcvd, opOk and tOpOk, see IEC 61850-7-3.

g) The test set maintains the sequence "Fault simulation" (3.0)
h) The breaker failure function sends a GOOSE internal trip signal with q="test" (3.1 and 3.2)
i) The breaker function processes the telegram as valid (3.1) and does not issue any output to the process (see IEC 61850-7-4)
j) The test set acknowledges the reception of the internal trip signal (3.2)
k) The breaker function device sends a report (3.3) to the test set confirming that:
    1) the breaker is still in the closed position (no output to the process)
    2) the internal trip signal (3.1) has been received

NOTE 2 For the semantic of the data attributes opRcvd, opOk and tOpOk, see IEC 61850-7-3.

l) The breaker failure function sends an external trip signal (3.4 to 3.6) with q="test"
m) The bus bar protection function processes the telegram as valid (13.4) (see IEC 61850-7-4)
n) The line protection function processes the telegram as valid (3.5) (see IEC 61850-7-4)
o) The test set acknowledges the reception of the external trip signal (3.6)
p) The bus bar protection function sends a GOOSE trip signal with q="test" (3.7 and 3.8)
q) All bus bar breaker function devices send a report (3.9) to the test set confirming that:
    1) the breakers positions have not changed (no output to the process)
    2) the trip signal (3.7) has been received

NOTE 3 For the semantic of the data attributes opRcvd, opOk and tOpOk, see IEC 61850-7-3.

r) End of the test (3.10 and 3.11)

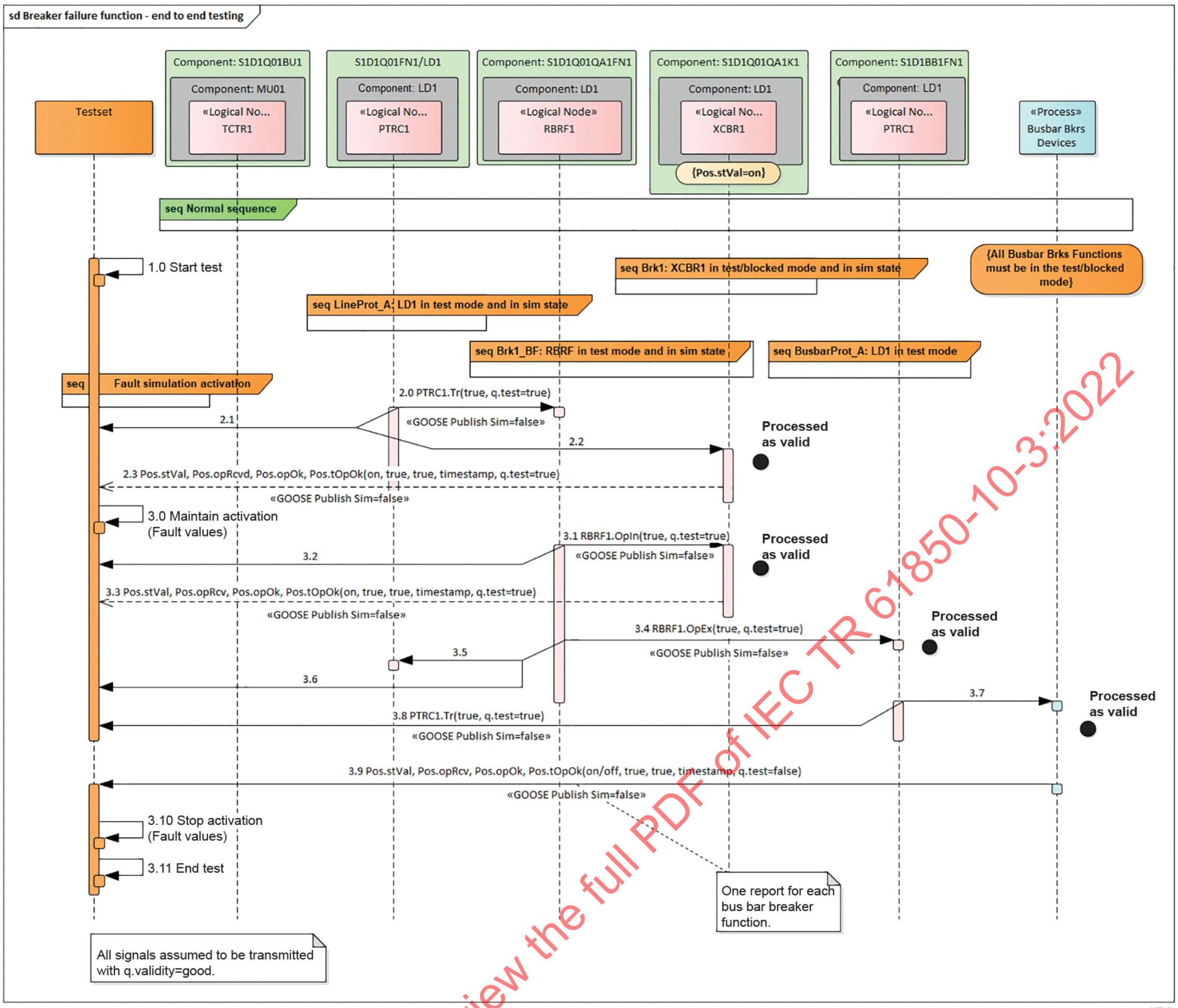

Figure 35 – Breaker failure function end to end testing

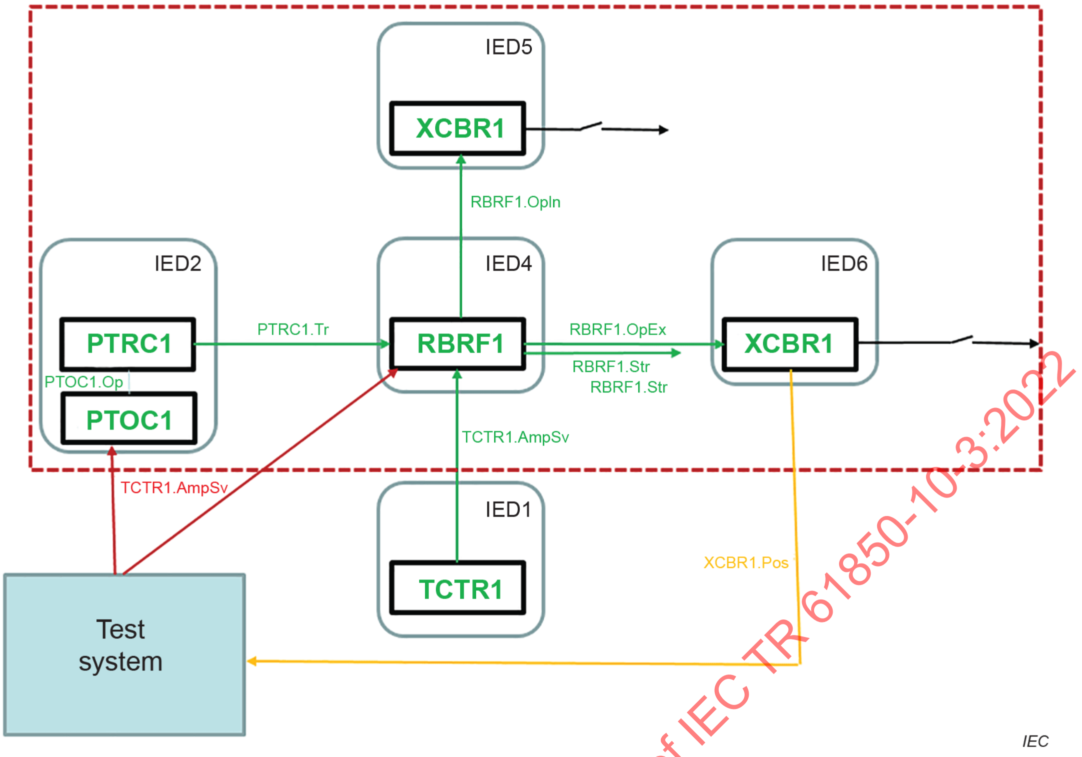

Figure 36 – Interfaces between test system and tested IEDs for End-to-End testing of breaker failure protection scheme

8.2 Select Before Operate Scheme Testing

8.2.1 General

Testing of SBO scheme can be divided into several stages.

The first set of tests includes behaviour testing of each involved system component (Logical Node) i.e. Unit test. The test system shall provide all necessary inputs and to be able to evaluate results in order to provide enough inputs for PASS/FAIL decision and diagnostics, if necessary.

Tests can be positive or negative checks.

The second set of tests is considered to test interfaces between Logical nodes.

The third set of tests is end-to-end that will test the whole path from initiation to the XCBR LN.

8.2.2 Unit testing

8.2.2.1 General

As mentioned in 6.2.1, unit testing is the testing of Logical Nodes as function elements. The main purpose is to confirm design requirements. As such these tests shall be performed in early stage of engineering i.e. during factory acceptance tests. In the case that end-to-end tests during site acceptance test or maintenance have failed then the unit test shall be repeated in order to diagnose part of the system.

8.2.2.2 TVTR testing

The testing of the TVTR (Figure 37) is part of the testing of a stand-alone merging unit that provides the stream of voltage samples used by the synchrocheck function element in the scheme.

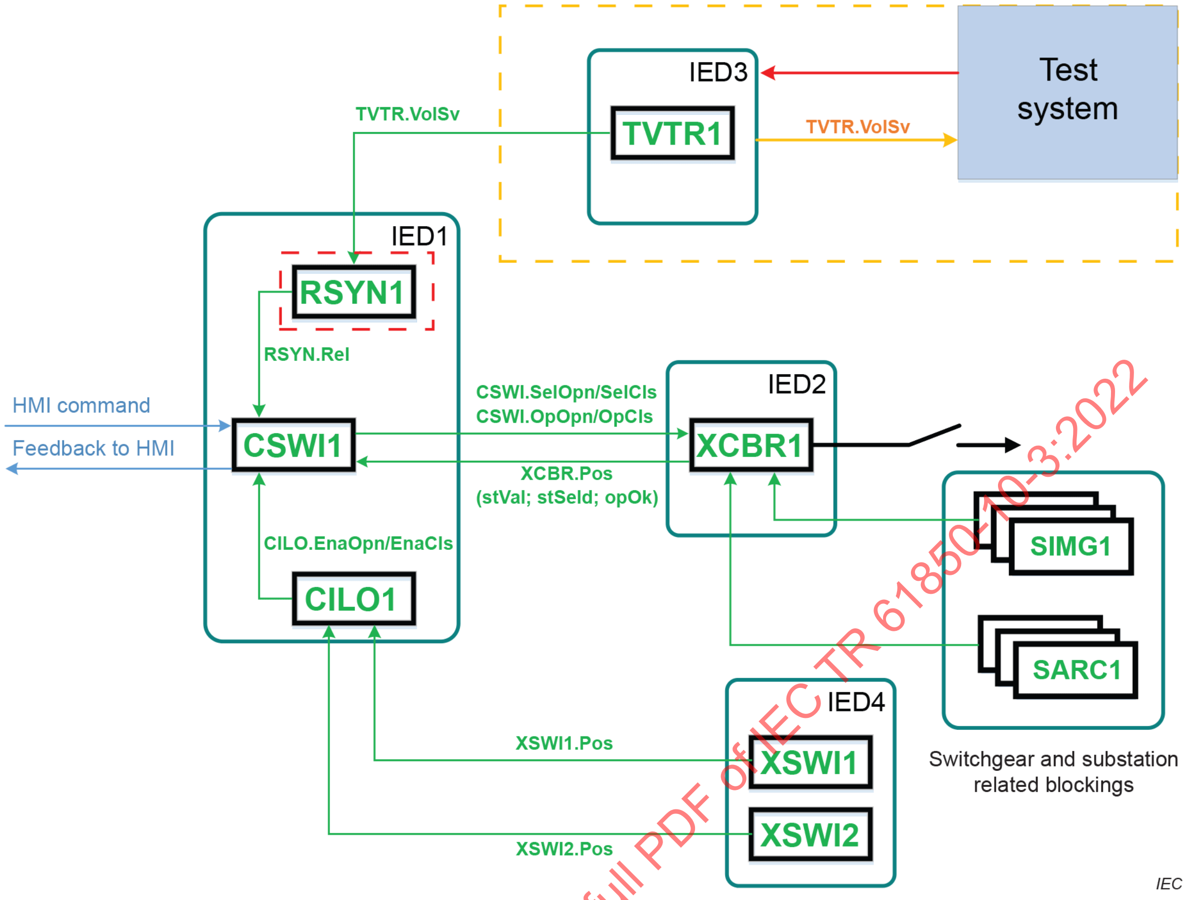

Figure 37 – Unit test of TVTR LN – simplified

Isolation during test

The TVTR testing requires an analogue interface between the test device and the merging unit.

In the cases of type testing or acceptance testing the test device analogue voltage outputs are directly connected to the merging unit voltage inputs and no isolation is required.

A test switch is required to isolate the merging unit from the substation environment. It shall be connected to the analogue voltage outputs of the test device when performing commissioning or maintenance testing for the merging unit.

Testing sequence

The following steps (Figure 38) should be followed for the merging unit testing:

1) The merging unit shall be put in "test" mode in order to ensure that no alarms will be issued when the test switch is disconnected from the substation process. This will also ensure that all IEDs subscribing to this merging unit will not operate incorrectly during the test.
2) The test device should be connected to the test switch.
3) A test case should be selected for the execution of the test.
4) The test case shall be executed and the performance of the merging unit shall be evaluated and documented.
5) After the completion of the test the test switch is removed.
6) The mode is reset to "on" to put back the merging unit back to the normal operating state.

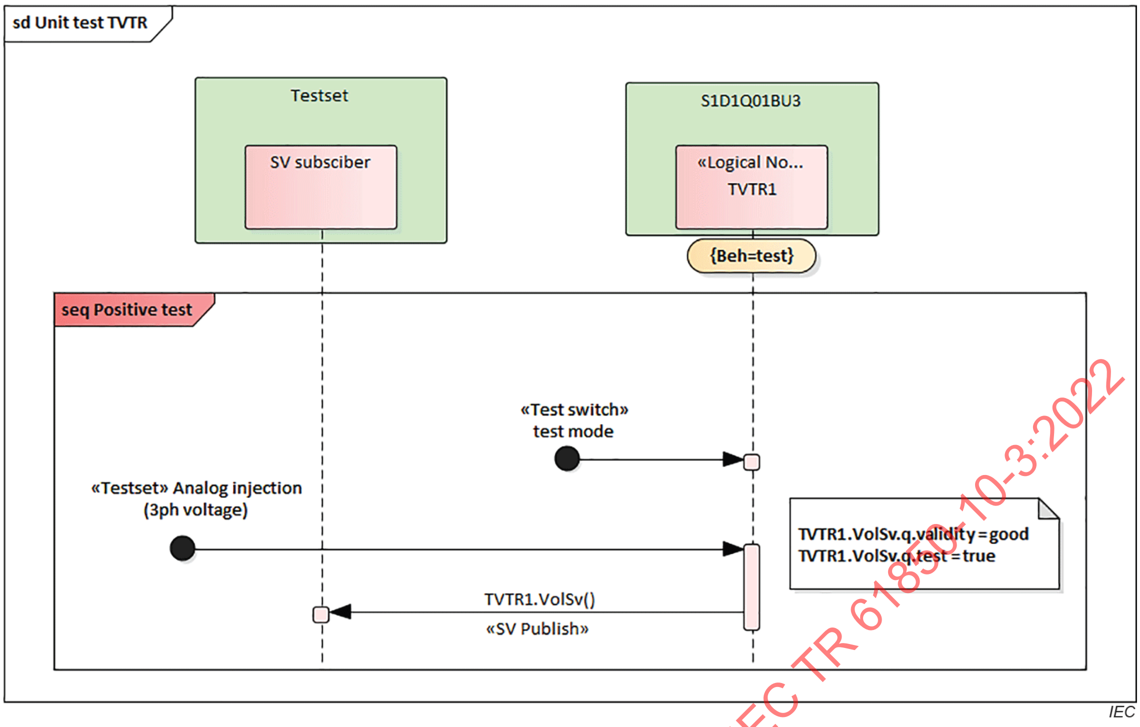

Figure 38 – Unit test of TVTR LN

Time synchronization

The test equipment and the merging unit shall be synchronized using IEC 61850-9-3 in order to be able to evaluate its performance.

Test execution

This test is intended only to ensure that the merging unit is working correctly in an energized substation. The main goal is to check if the streaming sampled values correspond to the injected signal within the specified tolerances.

Test assessment

The test assessment can be based on a comparison of the samples values with the same sequence number published by the merging unit S1D1Q01BU3/TVTR.VolSv.InstMag with the sampled values published by the test system TS/TVTR.VolSv.InstMag.

The test assessment shall also verify that all samples are transmitted with q.validity = good and q.test=true.

In the case of type and acceptance testing the value of Mod shall be TVTR.Mod=on or TVTR.Mod=test, because we need to ensure that the TVTR is performing correctly in the different modes. This will be based on checking the value of TVTR.Beh and the Test bit in the quality attribute of the sampled values TVTR.VolSv.q.test.

In the case of commissioning or maintenance testing the TVTR.Mod=test.

8.2.2.3 XCBR testing

For the testing of LN XCBR two scenarios will be evaluated:

- without interface to the process (simple open command – nominal scenario without boundary cases) – example of positive check
- with simulation of the process variables (switchgear and substation related blocking) – example of negative check

<u>Scenario 1 – no interface to the process</u>

Isolation during test

The test system (Figure 39) is needed to replace part of the control state machine that is covering IHMI and CSWI LN i.e. to simulate behaviour interaction between HMI and CSWI LN. Thus, the Test system will only interact with the tested XCBR LN. In this test case no additional checks will be performed (interlocking, synchrocheck).

In the case of type or acceptance tests no test switch is required to isolate the tested IED from the substation environment. The test system can be directly connected to Breaker IED.

For commissioning/maintenance testing, the test switch can be used to prevent operation of Circuit breaker and to diverse Breaker IED interfaces toward Test system binary inputs and outputs. In this case, the control state machine will be tested with positive feedback.

Another approach is a non-invasive test where the test assessment should be commenced by monitoring optional CSWI and XCBR data objects opRcvd and opOk while CSWI LN is in test and XCBR LN is in test/blocked mode. In this case, the control state machine can be confirmed indirectly by monitoring mentioned opOk and opRcvd. Control will be terminated with negative request (Invalid position or Request Timeout).

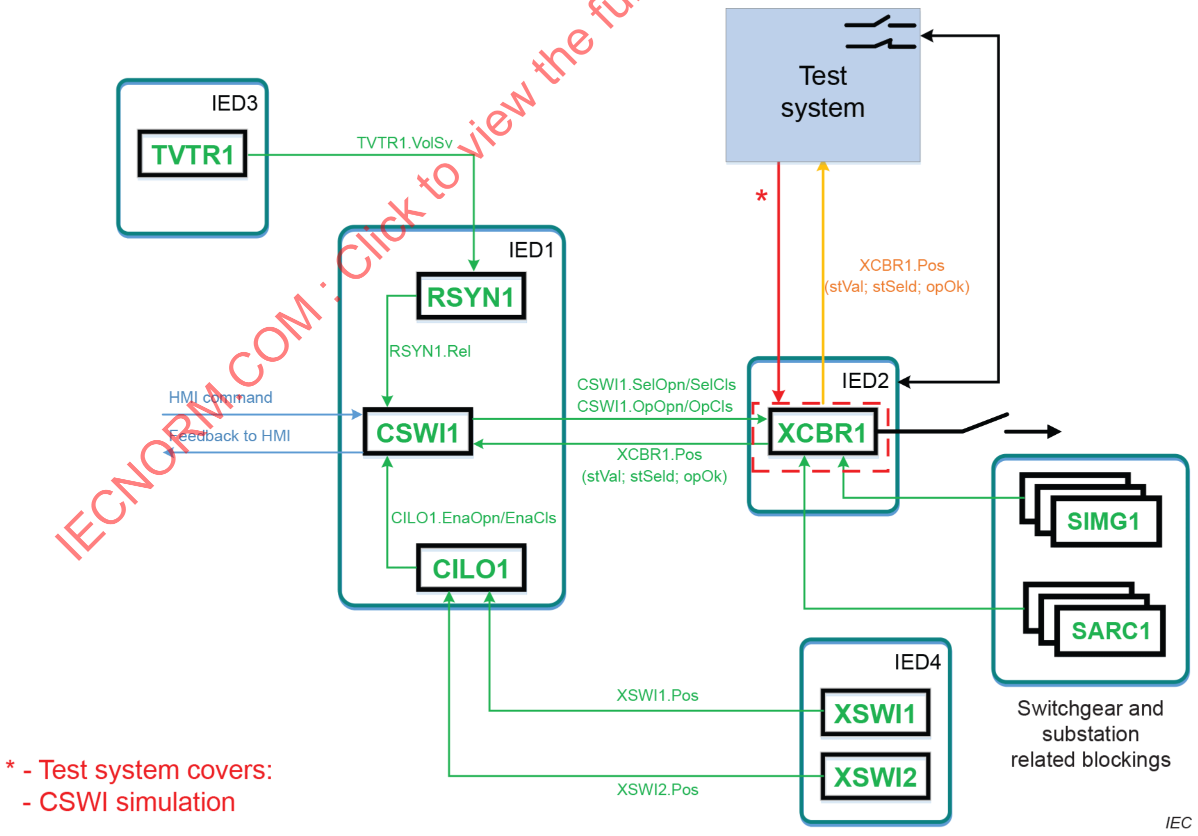

Figure 39 – Unit test of XCBR LN – Scenario 1 – simplified

Testing sequence (Figure 40):

Prerequisites:

S1D1Q01KF2/XCBR1.Beh = test,
S1D1Q01KF2/XCBR1.Loc = false,
S1D1Q01KF2/LLN0.Beh = on,
S1D1Q01KF2/LPHD1.Sim = true.
Test set – GOOSE messages (CSWI1 DO/DA) with Sim = true.

Test steps:

1 – Test system – hardwired simulation of closed/open CB position,

2 – S1D1Q01KF2 – Verification of the output from LN (XCBR1.Pos.stVal, XCBR1.Pos.q)

3 – Test system – Simulation of Selection and Operation states in CSWI1 (CSWI1.SelOpn/SelCls, CSWI1.OpOpn/OpCls, Test = true, Sim = true)

4 – S1D1Q01KF2 – Verification of closing output opening/closing contacts

5 – Test System – Simulated Circuit breaker position is changed by test system,

6 – S1D1Q01KF2 – Verification of changed output from LN (XCBR1.Pos.stVal, XCBR1.Pos.q)

Above defined test steps should be repeated with following variations:

- S1D1Q01KF2/XCBR1.Mod = on-blocked/test/test-blocked/off
- S1D1Q01KF2/LLN0.Mod = on-blocked/test/test-blocked/off
- S1D1Q01KF2/LPHD1.Sim = false

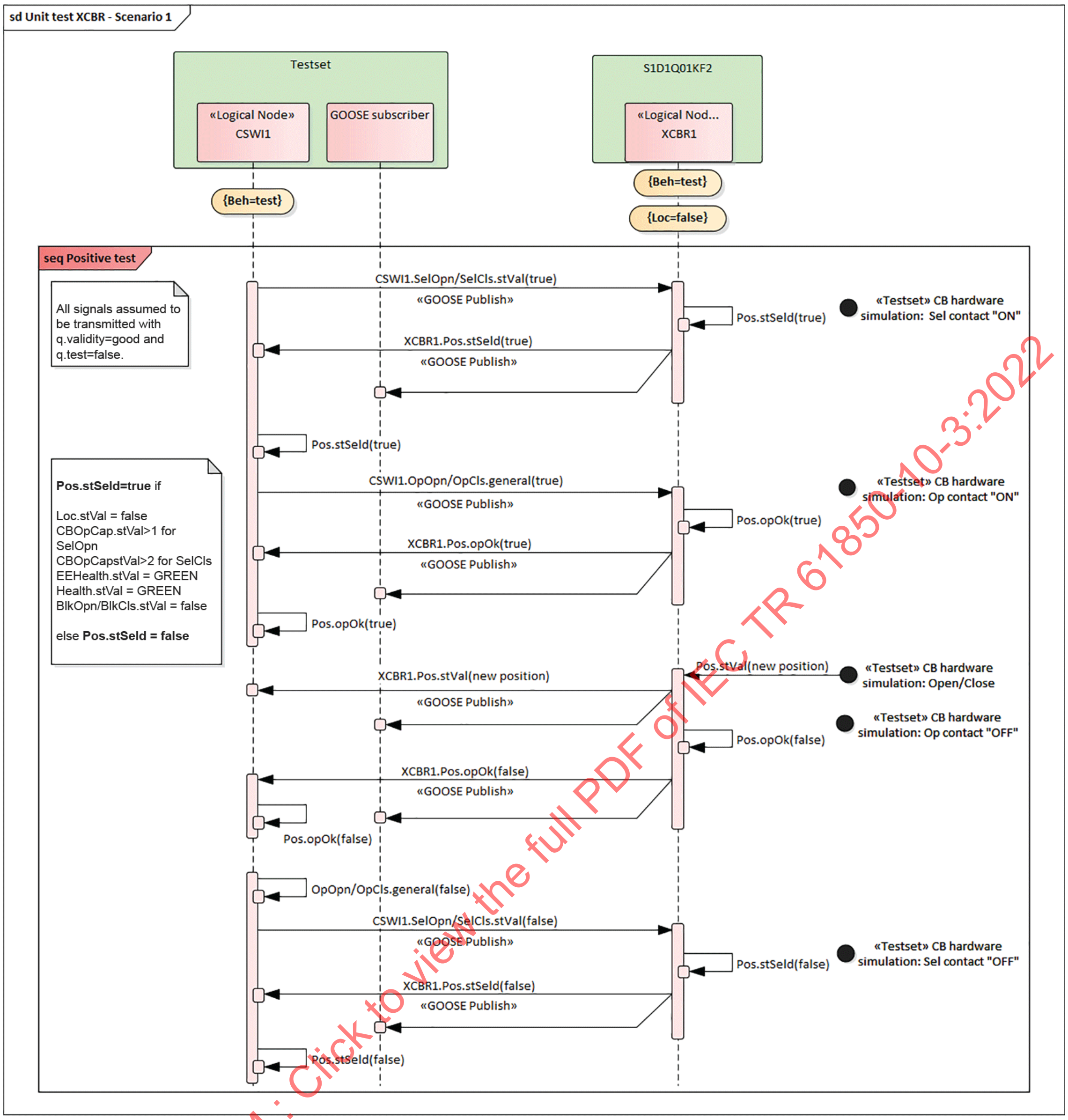

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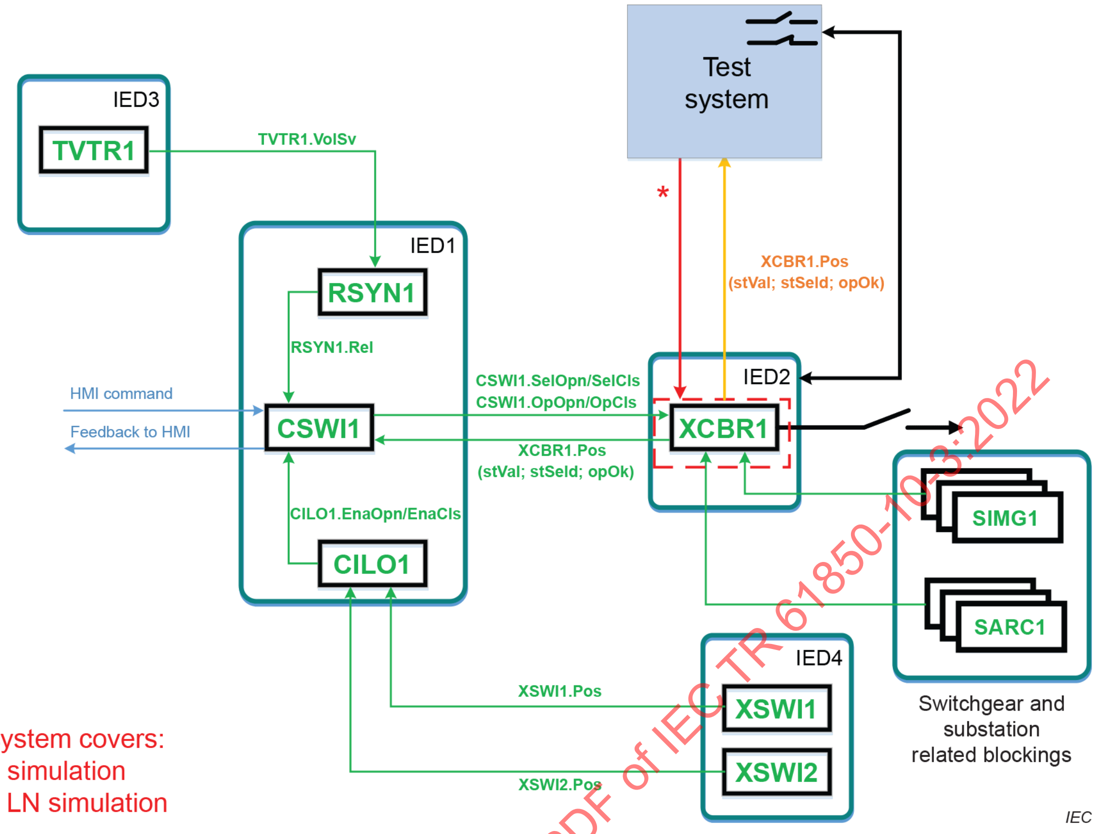
Figure 40 – Unit test of XCBR LN – Scenario 1

Scenario 2 – simulation of process variables

In this example (Figure 41), only the SF6 Gas Pressure threshold (block) is used to establish the operational capacity of the CB. In generic tests of the LN, all sensor inputs used directly or indirectly by XCBR have to be included in the tests.

Isolation during test

The same rules apply as for Scenario 1.



* - Test system covers:
  - CSWI simulation
  - SIMG LN simulation

Figure 41 – Unit test of XCBR LN – Scenario 2 – simplified

Testing sequence (Figure 42):

Prerequisites:

S1D1Q01KF2/XCBR1.Beh = test,
S1D1Q01KF2/XCBR1.Loc = false,
S1D1Q01KF2/LLN0.Beh = on,
S1D1Q01KF2/LPHD1.Sim = true,
TS/CSWI1.Beh = test,
TS/SIMG1.Beh = test,
Test set – GOOSE messages (SIMG1 DO/DA) with Sim = true.

Test steps:

1 – Test system – CB/switchgear monitoring signals SIMG1.InsBlk = TRUE published (GOOSE)
2 – S1D1Q01KF2 – Verification of the output from LN:
XCBR1.EEHealth = RED,
XCBR1.BlkOpn.stVal = true,
XCBR1.BlkOpn.q.test = false,
XCBR1.BlkCls.stVal = true,
XCBR1.BlkCls.q.test = false.
3 – Test system – Simulation of Selection and Operation states in CSWI1
(CSWI1.SelOpn/SelCls, CSWI1.OpOpn/OpCls, Test = true)
4 – S1D1Q01KF2 – Verification that there is no operation of output opening/closing contacts

The above defined test steps should be repeated with following variations:

- S1D1Q01KF2/XCBR1.Mod = on-blocked/test/test-blocked/off
- S1D1Q01KF2/LLN0.Mod = on-blocked/test/test-blocked/off
- S1D1Q01KF2/LPHD1.Sim = false

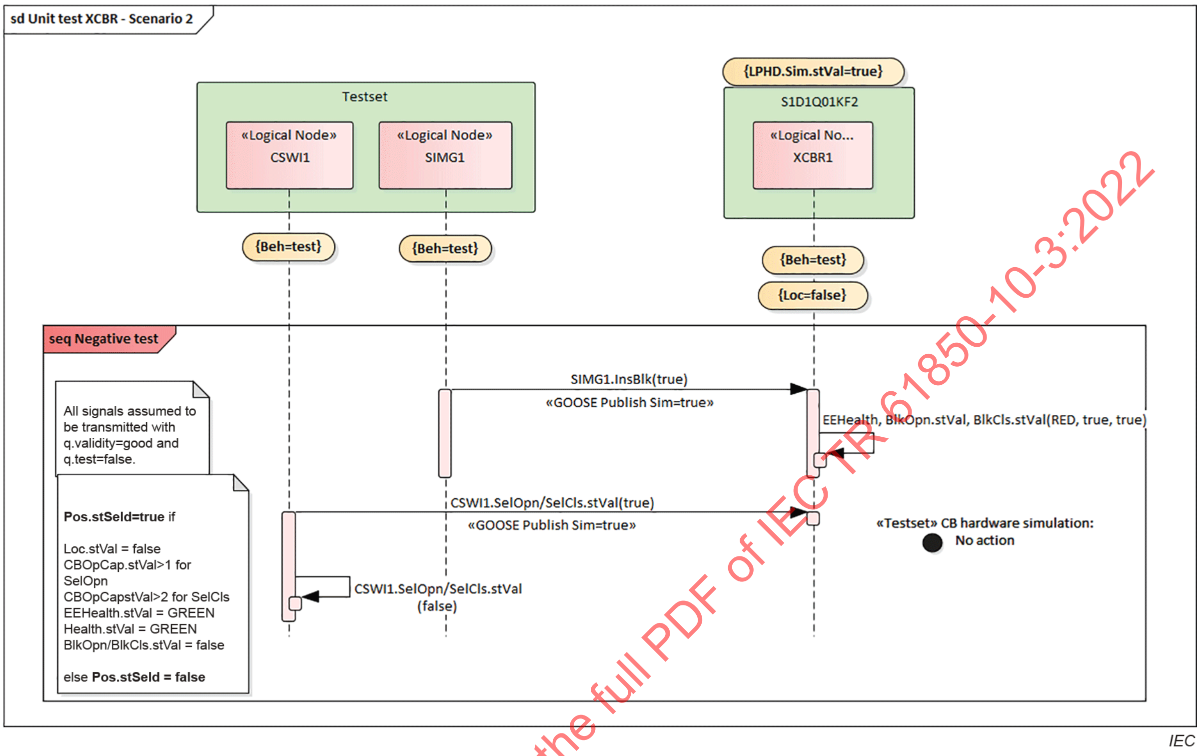


Figure 42 – Unit test of XCBR LN – Scenario 2

8.2.2.4 CILO testing

For the purpose of CILO Logical Node testing, the test system shall:

- Simulate GOOSE messages involved in interlocking logic for specific CILO Logical Node
- To be able to poll CILO LN DO/DA values OR to enable Report with Dataset with reference to CILO data objects. For the testing purpose, there could be engineered GOOSE message (Dataset with relevant CILO object) with GOOSE CB enabled only during testing.

This is a simplified example.

8.2.2.5 CSWI testing

For the purpose of CSWI Logical Node testing, the test system shall:

- Behave as an MMS client (with support for relevant control model) in order to initiate control sequence
- Emulate the behaviour of XCBR LN in order to enable execution of complete control state machine
- To be able to poll CSWI LN DO/DA values OR to enable Report with Dataset with reference to CSWI data objects. For the testing purpose, there could be engineered GOOSE message (Dataset with relevant CILO object) with GOOSE CB enabled only during testing.
- To enable report with reference to Control service tracking.

This is a simplified example.

To be done with test/blocked.

8.2.3 Subsystem (Interface) testing

8.2.3.1 CSWI – XCBR testing

This interface test (Figure 43) shall show correct interaction between CSWI LN and XCBR LN by simulating HMI command and response of process (CB position). Simulation will be done by Test system.

The test system has a GOOSE subscribe support that is used to asses results of LN communication (signal exchange between CSWI and XCBR using GOOSE messages). This is necessary in case of diagnostics.

In this test case no additional checks will be performed (interlocking, synchrocheck).

Isolation during test

The test system is needed to replace part of control state machine that is covering IHMI1. In this test case no additional checks will be performed (interlocking, synchrocheck).

In case of type or acceptance tests no test switch is required to isolate the tested IEDs from the substation environment. Test system can be directly connected to Bay Controller and Breaker IED.

For commissioning/maintenance testing, test switch can be used to prevent operation of Circuit breaker and to diverse Breaker IED interfaces toward Test system binary inputs and outputs.

For non-invasive test, test assessment should be commenced by monitoring optional CSWI and XCBR data objects opRcvd and opOk while CSWI LN is in test and XCBR LN is in test/blocked mode. Control will be terminated with negative request (Blocked by mode).

Testing sequence:

Prerequisites:

S1D1Q01KF1/CSWI1.Beh = test,

S1D1Q01KF1/LLN0.Beh = on,

S1D1Q01KF2/XCBR1.Beh = test,

S1D1Q01KF2/XCBR1.Loc = false,

S1D1Q01KF2/LLN0.Beh = on,

Test steps:

1 – Test system – hardwired simulation of closed/open CB position

2 – S1D1Q01KF2 – Verification of the output from LN (XCBR1.Pos.stVal, XCBR1.Pos.q)

3 – Test system – Simulation of Selection and Operation command requests (Client requests simulation)

4 – Test system – Verification of published GOOSE messages from CSWI1 and XCBR1 with corresponding information (as shown on Figure)

5 – S1D1Q01KF2 – Verification of closing output opening/closing contacts

6 – Test system – Simulated Circuit breaker position is changed by Test system,

7 – S1D1Q01KF2 – Verification of change of output from LN (XCBR1.Pos.stVal, XCBR1.Pos.q)

Above defined test steps should be repeated with following variations:

- S1D1Q01KF1/XCBR1.Mod = on-blocked/test/test-blocked/off
- S1D1Q01KF1/LLN0.Mod = on-blocked/test/test-blocked/off
- S1D1Q01KF1/CSWI1.Mod = on-blocked/test/test-blocked/off
- S1D1Q01KF1/LLN0.Mod = on-blocked/test/test-blocked/off

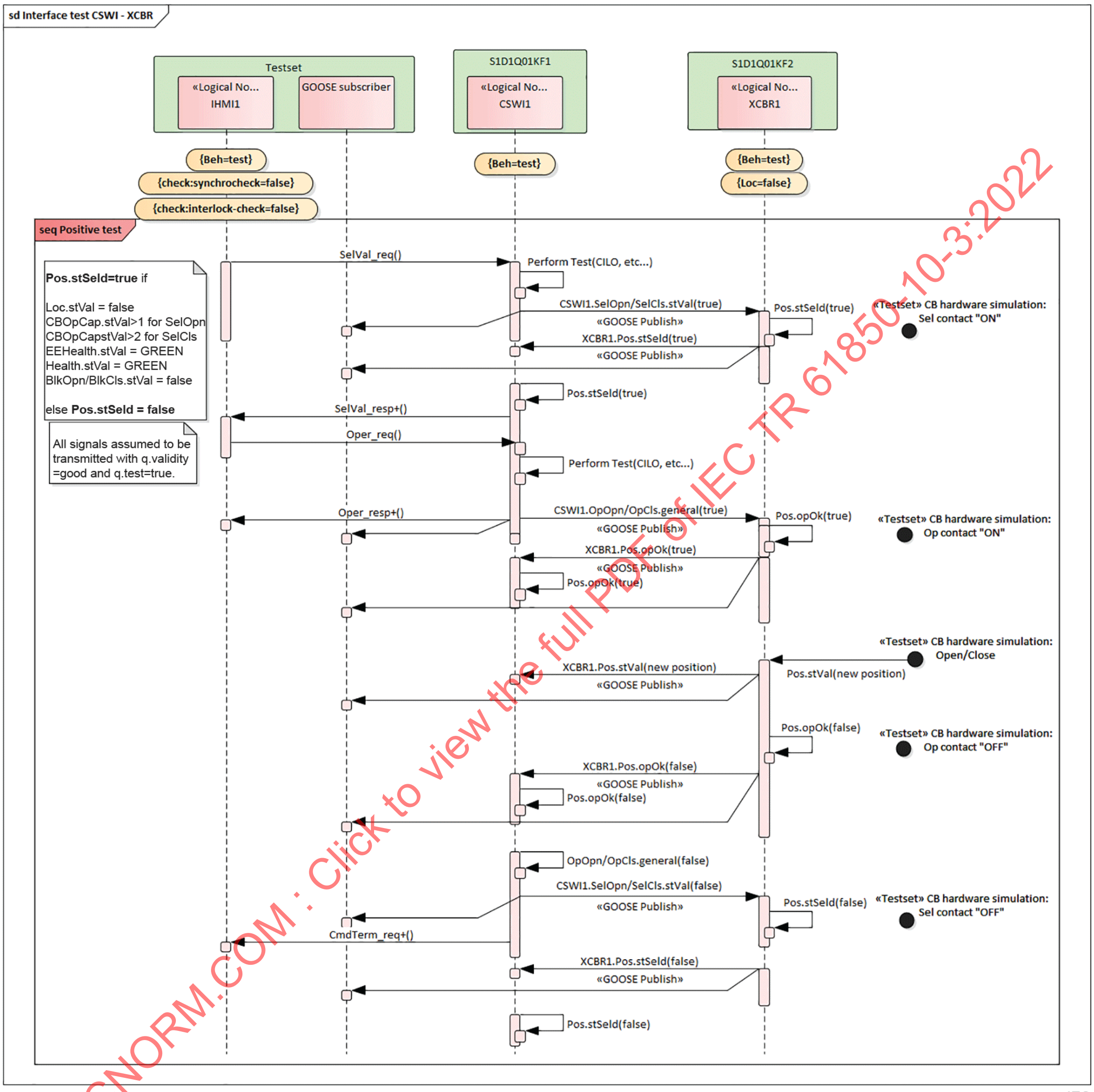


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Figure 43 – Interface test of CSWI – XCBR LNs

8.2.4 System (End-to-End) testing

8.2.4.1 General

These types of tests are to be performed in case of FAT, SAT or maintenance. Depending on the mentioned cases, the test prerequisites have to be accommodated.

Let us assume for end-to-end test that process inputs of SBO scheme have to be either taken from a real source (for example, voltage measurement or switchgear monitoring) or simulated by a Test system. In the case that physical operation (in case of energized power system that is under test) is prohibited, the test engineer/operator shall deploy specific IEC 61850 testing features that will help him to prove the test requirements.