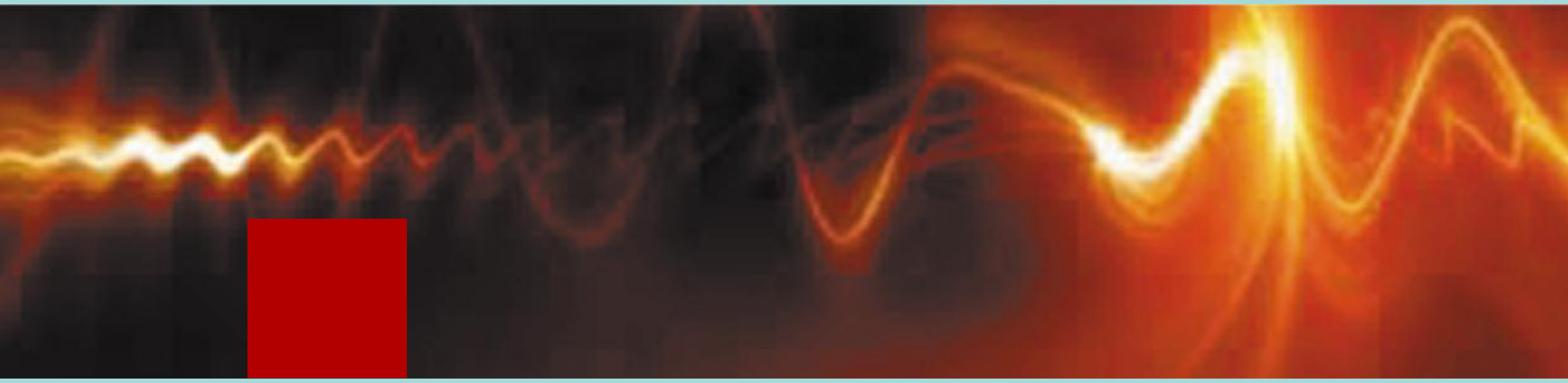

Research Project InterOP

Investigating Interoperability of IEC 61850 Devices of Different Suppliers

Functional Specification for Testing

FGH

Forschungsgemeinschaft
für Elektrische Anlagen
und Stromwirtschaft e.V.

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Postal Address:
Postfach 81 01 69
68201 Mannheim
Germany

Shipping Address:
Hallenweg 40
68219 Mannheim (Rheinau)
Germany

Phone: +49 (0)6 21 / 80 47 – 100
Fax: +49 (0)6 21 / 80 47 – 112
E-Mail: fgh@fgh-ma.de
Internet: www.fgh-ma.de

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1 General

1.1 Scope

One central goal of the standard IEC 61850 is to provide comprehensive interoperability in substation automation systems between control, protection and station level devices of different suppliers. Several experiences and papers recently presented at various conferences have shown that this objective is not yet fully reached and is a limiting factor for the freedom of commerce, the freedom of the customers to choose their equipment and the efficiency of systems.
In order to investigate the challenges that emerge from the requirement to provide interoperability, to support standardization activities and to derive guidelines and recommendations to ease future engineering processes the research project InterOP has been initiated defining, executing and analysing concrete test cases of IEC 61850 devices in a co-operative research effort.
This document presents the functional specification featuring the following defined test cases in the sections 2 – 13:

- Control blocking
- MMS file transfer
- Switching by SBO with interlocking
- Reverse blocking
- Autoreclosure coordination
- Busbar voltage replica
- Switching with synchrocheck function
- Substation supervision
- Earthfault detection
- Frequency relay function
- Automatic neutral current regulator (Petersen coil regulator)
- Automatic OLTC controller

Each test case section contains:

- the test case description including a system overview,
- the configuration of IEDs,
- the use cases and
- the requirements concerning interfaces and performance.

The functional specification is based on typical applications and examples found in substations of large electric grids. Therefore, parts of the DKE IEC 61850 substation model are considered [DKE_MODEL]. To guarantee the benefit for all users of IEC 61850 technology, interested parties have been invited to review and comment the functional specification.

The functional specification forms the base for setting up the test specification. While the functional specification gives an abstract description of the test case functionality the test specification depicts the test case setup concerning IEDs and the interaction to further equipment and describes in detail the information flow between devices. The tests defined within the test specification will be executed at FGH e.V. facility in Mannheim, Germany.
All interoperability tests are based on IEC 61850 Edition 1 while the results will potentially serve as valuable input for further editions of the standard and guidelines for using it. The scope is in no way limited to the German market or the InterOP project participants and all test cases use common and typical scenarios found in substations. FGH e.V. will publish a detailed report summarizing all achieved results and recommendations dealing with interoperability issues. The report will be sent to standardization committees, working groups and other official bodies related to IEC 61850 and will be available for free for all interested parties at FGH e.V.

1.2 Abbreviations and Definitions

Table 1-1 Abbreviations

Abbreviation	Explanation
AI	Analogue Input
AR	Autoreclosure
ATCC	Automatic Tap-Change Controller
AVR	Automatic Voltage Regulator (IED functionality relates to ATCC)
AW	Alarm / Warning Indication
BI	Binary input
BO	Binary Output
BVR	Busbar voltage replica
CB	Current Breaker
COMTRADE	IEEE Standard Format for Transient Data Exchange
DO	Data Object
FTP	File Transfer Protocol
GOOSE	Generic object oriented substation events
I>	First Over current stage
I>>	Second Over current stage
IED	Intelligent Electronic Device
IETF	Internet Engineering Task Force
Iop	Operating current stage
LD	Logical Device
LN	Logical Node
MMS	Manufacturing Message Specification
OLTC	On-Load Tap changer
PICS	Protocol Implementation Conformance Statement
PIXIT	Protocol Implementation Extra Information
SBO	Select before operate
U_{12}	Synchronisation voltage / Reference voltage
Uo	Zero sequence voltage
Z1	Impedance zone 1 stage

1.3 References to Standards and Definitions

Table 1-2 References to Standards and Definitions

[IEC61850-5] IEC 61850-5: Communication Networks and Systems in Substations. Part 5: Communication requirements for functions and device models (2003)

[IEC61850-7-1] IEC 61850-7-1: Communication Networks and Systems in Substations. Part 7-1: Basic communication structure for substations and feeder equipment – Principles and models (2003).

[IEC61850-7-2] IEC 61850-7-2: Communication Networks and Systems in Substations. Part 7-2: Basic communication structure for substations and feeder equipment – Abstract communication service interface (ACSI) (2003)

[IEC61850-7-3] IEC 61850-7-3: Communication Networks and Systems in Substations. Part 7-3: Basic communication structure for substations and feeder equipment – Common Data Classes (2003)

[IEC61850-7-4] IEC 61850-7-4: Communication Networks and Systems in Substations. Part 7-4: Basic communication structure for substations and feeder equipment – Compatible logical node classes and data classes (2003)

[DKE_MODEL] DKE952.0.1: Modelling Guideline and Sample Modelling using SCL (2008, Version 1.0.)

[DKE_APPLICATIONS] DKE952.0.1: Applications using the Services of IEC61850. (2008, Version 1.0.)

2 Test Case - Control Blocking

2.1 Description

2.1.1 General

This section describes the functions of the substation when conditions exist that block control operations. Control operations are user generated requests originating in an IEC61850 client for a specific IEC61850 server (an IED) to perform a control operation, such as reset LEDs or control the circuit breaker. The most complex control operation is to close the circuit breaker which has many checks and conditions and may also be modelled as an SBO control which gives more possibilities for blocking functions. Control service using Direct Control will not be tested.

The blocking functions described in this section apply to 2 clients selecting and operating two IEDs between them according to the functionality required. Figure 2-1 illustrates the concept.

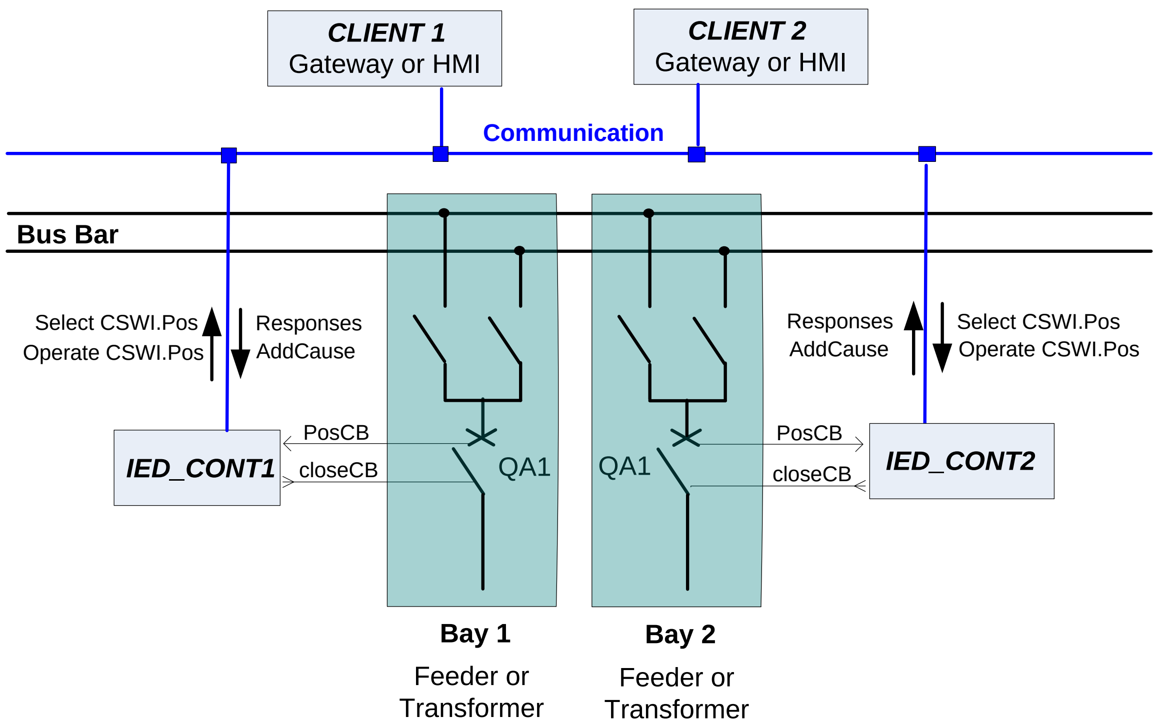


Figure 2-1 Control Blocking – System Overview

In this overview two separate bays are shown with controlling IEDs which control the manual (remote) closing of the circuit breakers. These IEDs are controlled from 2 separate clients, where either client can select and operate the circuit breaker control on any IED.

2.1.2 Blocking Conditions

2.1.2.1 Blocking Condition Reasons

Control operations are blocked for a variety of reasons. These can be subdivided into the following distinct areas:

- Interlocking: The control request is blocked because the status of other equipment in the substation prevents it.
- Synchrocheck: The control request is blocked because synchronism conditions are not met, e.g. voltage magnitude difference on either side of the connection to be made is outside limits.
- Equipment: The control request is blocked because the mode or other condition of the IED prevents it.
- Selection: The control request is blocked because another client has already selected the same control.
- Operation: An operate request may be blocked if an SBO control was not previously selected, or was previously selected by a different client.
- Uniqueness (1-out-of-n logic): The control request is blocked because another IED in the bay or substation is currently processing a control request.

Of these, the interlocking and the synchrocheck reasons are already covered by sections 4 and 8 of this document. The remaining reasons are covered in this section and are described below.

2.1.2.2 Control Blocking Responses

When the control request is blocked an AddCause parameter accompanying the negative response is used to identify the reason for the block. Table 2-1 shows all blocking conditions and indicates the AddCause that accompanies the response returned if the IED blocks the control. This table is not the full list of all AddCause values, just those related to control request blocking conditions outlined above.

Table 2-1 AddCause Values and Reasons

AddCause Value	Reason
Blocked-by-switching-hierarchy	Operation is blocked due to IED not accepting remote commands
Select-failed	Control already selected
Parameter-change-in-execution	Settings update (on another interface possibly) is in progress
Blocked-by-Mode	Mode of switchgear does not allow switching (IED in test mode)
Blocked-by-process	External condition blocks switchgear action (EEHealth of XCBR/XSWI = “Alarm”)
Command-already-in-execution	Control action is already running
Blocked-by-health	CB blocked by internal reason. (Health attribute of XCBR/XSWI = “Alarm”)
1-of-n-control	Control on another IED is in progress
Object-not-selected[1]	Control was not selected prior to operation

Note: In the case where more than one blocking condition exists the order in which the IED applies the checks is vendor specific. Thus if several blocking conditions exist, no assumptions can be made that any particular blocked response applicable to the conditions present will be output. In addition, certain blocking responses may never be generated if the IED applies other checks first that would also cause the control to be rejected. An example of this is the blocked responses for selection which may never be generated if the IED performs a 1-out-of-n logic check first which could also cause the control request to be blocked.

[1] This AddCause is listed in part 8-1 Table 77 but is not listed in part 7-2 where all other AddCause ACSI values are listed.

2.1.3 Equipment

2.1.3.1 IED Mode

The mode that an IED is set to could have an impact on control request acceptance. Three modes can cause a control request to be blocked

- Local Mode: IED does not accept remote commands
- Test Mode: IED does not accept commands that do not have test bits set
- Settings mode: IED is busy with settings changes from another source

In an ideal substation the fact that an IED is operating in local mode should prevent the station computer from issuing control requests if the IED has output indications to inform the station computer that it has changed mode. By a similar means an IED in test mode should indicate this to any other interested parties which will then only send controls appropriate to testing and commissioning activities. However, an IED should be capable of rejecting control requests in these modes irrespective of whether it has output indications or not.

2.1.3.2 Switchgear Health

If the switchgear is in a faulty state or its health is affected by some condition then control requests to operate the switchgear cannot be accepted and must be blocked. This is dependant on the switchgear health and condition being an input to the IED. Two health indications exist:

- Internal Health – Conditions in the IED indicate that the circuit breaker is unhealthy, for example an operation count has exceeded a limit.

- External Health – Condition of the switchgear indicates that it is not healthy. This will depend on the type of switchgear, typical example would be low pressure in a gas-insulated device.

2.1.4 Selection

Blocking of a control should occur if the control is already busy by a request from another client. This occurs under two conditions:

- An SBO control is already selected by another client
- A Direct Operate control has been operated by another client which is still being processed by the IED

In each case the IED must reject the control request with a suitable negative response.

2.1.5 Operation

Blocking of an SBO control operation should occur if the control selection is incorrect: This is caused by:

- The SBO control is not selected
- The SBO control is already selected by a different client to the one issuing the operate request

In each case the IED must reject the control request with a suitable negative response.

2.1.6 Uniqueness (1-out-of-n logic)

As a further level of protection the bay and/or substation may implement a scheme which prevents more than 1 IED handling a control request at a time within the bay/substation. In this scheme an IED will block a control request if it has received indications from other IEDs within the same bay or substation that they are handling a control request already. In order to allow the best range of control blocking functionality the scheme used will be bay based. This will allow selection and operation of controls in different bays to proceed without being blocked by 1-out-of-n logic. Thus, in the system diagram above, IED_CONT1 will block attempts to select or operate a control if a control is already selected or operated on IED_CONT2, whereas IED_CONT3 will still allow a control to select or operate even if one is already selected or operating on IED_CONT1/IED_CONT2.

2.2 Configuration

1. All the functions defined in this section require the data object ‘Pos’ in logical node XCBR in all control IEDs identified to be configured as an SBO Control.
2. The select timeout values for the ‘Pos’ SBO controls need to be configured to as long as possible to facilitate some of the functions described, particularly for multi-client or multi-IED functions, otherwise incorrect AddCause values may be generated by the IED if it has timed-out any select condition.

2.3 Use Cases

2.3.1 Equipment Conditions

Many of the use cases associated with this functionality have the same goal which is that the control request is blocked by a preset equipment condition and the appropriate AddCause value is returned. The use case defined below (Blocked by switching hierarchy) is an example use case to illustrate one specific equipment condition. The table (Table 2-2) below indicates the other conditions and AddCause values that result. These are not included as specific use cases.

Table 2-2 Equipment Conditions Details

Blocking Condition	AddCause	Preset Condition Achievement
IED_CONT1 in settings update mode	Parameter-change-in-execution	From another interface of IED_CONTROL1 (e.g. Front Panel) start changing settings then apply the use case trigger without exiting the settings process.
Switchgear QA1 external health	Blocked-by-process	Configure switchgear to an external unhealthy condition (EEHealth attribute of relevant XCBR or XSWI LN should indicate ‘Alarm’)
Switchgear QA1 unhealthy	Blocked-by-health	Configure IED_CONT1 to achieve a Health status of Alarm in the relevant switchgear LN (XCBR or XSWI)
IED_CONT1 in test mode	Blocked-by-Mode	Switch IED_CONT1 into test mode.

2.3.1.1 Blocked by switching hierarchy [UC CB001]

Use case name:	Control Commands blocked by an equipment blocking condition
Use case id:	UC CB001
Version:	1.00
Goal:	Control request on circuit breaker QA1 in Bay 1 is blocked due to switching hierarchy, circuit breaker remains open
Summary:	IED processes Control request and rejects it with suitable AddCause value. Circuit breaker does not close and remains open.
Actors:	User, IED_CONT1, CLIENT1

Preconditions:	**Pr1**	Circuit breaker QA1 has open status
	Pr2	IED_CONT1 is in normal operation mode, no output operation (Protection function or switching operation) is running
	Pr3	IED_CONT1 is configured to Local Mode (i.e. remote control of Circuit Breaker is disabled|)
Triggers:	**T1**	Close circuit breaker QA1 in Bay 1 requested by user from CLIENT1
Course of events:	**C1**	CLIENT1 sends select request to IED_CONT1
	C2	IED_CONT1 rejects select request with response- and AddCause value Blocked-by-switching-hierarchy
	C3	CLIENT1 displays failure to User
Postconditions:	**Po1**	Circuit breaker QA1 in Bay 1 has open status
	Po2	IED_CONT1 is in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

2.3.2 Selection Condition

This condition is illustrated by three separate use cases, one which shows the behaviour of a client attempting to select a control already selected by another client. The second shows a client attempting to Operate a control selected by another client. The third use case describes a client Operating a control not previously selected.

2.3.2.1 Select blocked by selection [UC CB002]

Use case name:		Control request blocked due to already being selected by another client
Use case id:		[UC CB002]
Version:		1.00
Goal:		Control request on circuit breaker QA1 in Bay 1 is blocked, circuit breaker remains open
Summary:		IED processes Control request and rejects it with suitable AddCause value. Circuit breaker does not close and remains open.
Actors:		IED_CONT1, CLIENT1, CLIENT2
Preconditions:	**Pr1**	Circuit breaker QA1 in Bay 1 has open status
	Pr2	IED_CONT1 and IED_CONT2 are in normal operation mode, no output operation (Protection function or switching operation) is running
	Pr3	None of the conditions specified in Table 2-2 apply
	Pr4	IED_CONT1 is configured in Remote mode
Triggers:	**T1**	Close circuit breaker QA1 in Bay 1 requested by user from CLIENT1
Course of events:	**C1**	USER on CLIENT1 sends control request to select Circuit Breaker QA1 control on IED_CONT1
	C2	IED_CONT1 accepts select and replies with a positive response
	C3	User on CLIENT2 sends control request to select Circuit Breaker QA1 in Bay 1 control on IED_CONT1
	C4	IED_CONT1 blocks request from CLIENT2 with AddCause ‘Select-failed’
	C5	CLIENT1 sends control request to deselect Circuit Breaker QA1 in Bay 1 control on IED_CONT1
	C6	IED1 accepts deselect and replies with a positive response
Postconditions:	**Po1**	Bay 1 circuit breaker QA1 has open status
	Po2	IED _CONT1 and IED_CONT2 are in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

2.3.2.2 Operate blocked by Selection [UC CB003]

Use case name:	Control operate request blocked due to already being selected by another client
Use case id:	[UC CB003]
Version:	1.00
Goal:	Control operate request on circuit breaker QA1 in Bay 1 is blocked, circuit breaker remains open
Summary:	IED processes Control request and rejects it with suitable AddCause value. Circuit breaker does not close and remains open.
Actors:	IED_CONT1, CLIENT1, CLIENT2

Preconditions:	**Pr1**	Circuit breaker QA1 in Bay 1 has open status
	Pr2	IED_CONT1 is in normal operation mode, no output operation (Protection function or switching operation) is running
	Pr3	None of the conditions specified in Table 2-2 apply
	Pr4	IED_CONT1 is configured in Remote mode
Triggers:	**T1**	Select circuit breaker QA1 in Bay 1 requested by user from CLIENT1
Course of events:	**C1**	USER on CLIENT1 sends select request to select Circuit Breaker QA1 control on IED_CONT1
	C2	IED_CONT1 accepts select and replies with a positive response
	C3	User on CLIENT2 sends Operate request to close Circuit Breaker QA1 in Bay 1 control on IED_CONT1
	C4	IED_CONT1 blocks request from CLIENT2 with AddCause 'Object-not-selected'
	C5	CLIENT1 sends control request to operate Circuit Breaker QA1 in Bay 1control on IED_CONT1
	C6	IED1 accepts request, performs operation and replies with a positive response
Postconditions:	**Po1**	Bay1 circuit breaker QA1 has closed status
	Po2	IED_CONT1 is in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

2.3.2.3 Control Not Selected [UC CB004]

Use case name:	Control request blocked due to not being selected	
Use case id:	[UC CB004]	
Version:	1.00	
Goal:	Control opearte request on circuit breaker QA1 in Bay 1 is blocked, circuit breaker remains open	
Summary:	IED processes Control operate request and rejects it with suitable AddCause value. Circuit breaker does not close and remains open.	
Actors:	IED_CONT1, CLIENT1	
Preconditions:	**Pr1**	Circuit breaker QA1 in Bay 1 has open status
	Pr2	IED_CONT1 is in normal operation mode, no output operation (Protection function or switching operation) is running
	Pr3	None of the conditions specified in Table 2-2 apply
	Pr4	IED_CONT1 is configured in Remote mode
Triggers:	**T1**	Close (operate) circuit breaker QA1 in Bay 1 requested by user from CLIENT1
Course of events:	**C1**	USER on CLIENT1 sends control request to operate Circuit Breaker QA1 control on IED_CONT1
	C2	IED_CONT1 blocks request from CLIENT1 with AddCause 'Object-not-selected'
Postconditions:	**Po1**	Bay1 circuit breaker QA1 has open status
	Po2	IED_CONT1 is in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

2.3.3 1-out-of-n Logic Condition [UC CB005]

This use case describes the function of trying to select two controls on different IEDs where a 1-out-of-n logic scheme is in place.

Use case name:	Control request blocked due to 1-out-of-n logic	
Use case id:	[UC CB005]	
Version:	1.00	
Goal:	Control request is blocked when control selected on another IED in the same bay	
Summary:	After a control is selected on the first IED, Second IED processes Control request and rejects it with suitable AddCause value, but then accepts it when control released on first IED	
Actors:	IED_CONT1, IED_CONT2, CLIENT1, CLIENT2	
Preconditions:	**Pr1**	Circuit breakers QA1 in Bay 1 and Bay 2 have open status
	Pr2	IED_CONT1 and IED_CONT2 are in normal operation mode, no output operation (protection function or switching operation) is running
	Pr3	None of the conditions specified in Table 2-2 apply in either bay
	Pr4	IED_CONT1 and IED_CONT2 are configured in Remote mode
Triggers:	**T1**	User on Client1 selects CB QA1 in Bay1
Course of events:	**C1**	CLIENT1 sends control request to select Circuit Breaker QA1 on IED_CONT 1
	C2	IED_CONT 1 accepts select and replies with a positive response
	C3	User on CLIENT2 sends control request to select QA1 in Bay 2 to IED_CONT2
	C4	IED_CONT2 blocks request with AddCause '1-out-of-n logic'
	C5	CLIENT1 sends control request to deselect Circuit Breaker QA1 of Bay 1 to IED_CONT1
	C6	IED_CONT1 accepts deselect and replies with a positive response
	C7	User on CLIENT2 sends control request to select QA1 in Bay 2 to IED_CONT2
	C8	IED_CONT2 accepts request and replies with a positive response
	C9	CLIENT2 sends control request to deselect Circuit Breaker QA1 of Bay 2 to IED_CONT2
	C10	IED_CONT2 accepts deselect and replies with a positive response
Postconditions:	**Po1**	Bay 1 and Bay 2 circuit breakers QA1 have open status
	Po2	IED is in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

2.4 Requirements

2.4.1 Interfaces

All interfaces are using standard IEC61850 control requests and responses as defined in [IEC61850-7-2].
The following tables define type and quantity of interfaces per IED. This definition is the base for system design and system engineering – defining type and quantity of interaction between process and system components in principle.
Table 2-3 defines the interface between process and IEDs.
Table 2-4 defines IEC 61850 based client server communication between IEDs.

Table 2-3 Control Blocking – Process interface

Data	IED_CONT1	IED_CONT2
Position of circuit breaker QA1	BI	
Position of circuit breaker QA1		BI
Control output to circuit breaker QA1	BO	
Control output to circuit breaker QA1		BO

Table 2-4 Control Blocking – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 data				IED_CONT1	IED_CONT2	CLIENT1	CLIENT2
	IED_LD	LN	Data	CDC				
IED_CONT1 CB QA1 Position	<IED_CONT1><LD>	CSWI	Pos	DPC	Server reporting		Client	Client
IED_CONT2 CB QA1 Position	<IED_CONT2><LD>	CSWI	Pos	DPC		Server reporting	Client	Client

2.4.2 Performance Requirements

The time requirements are uncritical. Response times below 1 second are sufficient if the switching operation is triggered by a user.

3 Test Case - MMS File Transfer

3.1 Description

3.1.1 Overview

This section describes the functions of the substation when disturbance records are extracted as COMTRADE files over MMS file transfer (see Figure 3-1). The File Transfer Protocol (FTP), as defined by the Internet Engineering Task Force (IETF), is not supported by this test.
There are two functional areas which have to be analysed for file transfer.

- The directory structure of the server device has to be recognized by the client considering the used directory separators, the file naming format and maximum filename length for disturbance files.
- The file transfer itself with checking of the integrity of the extracted files but without analysing the content of the file (no COMTRADE format checking).

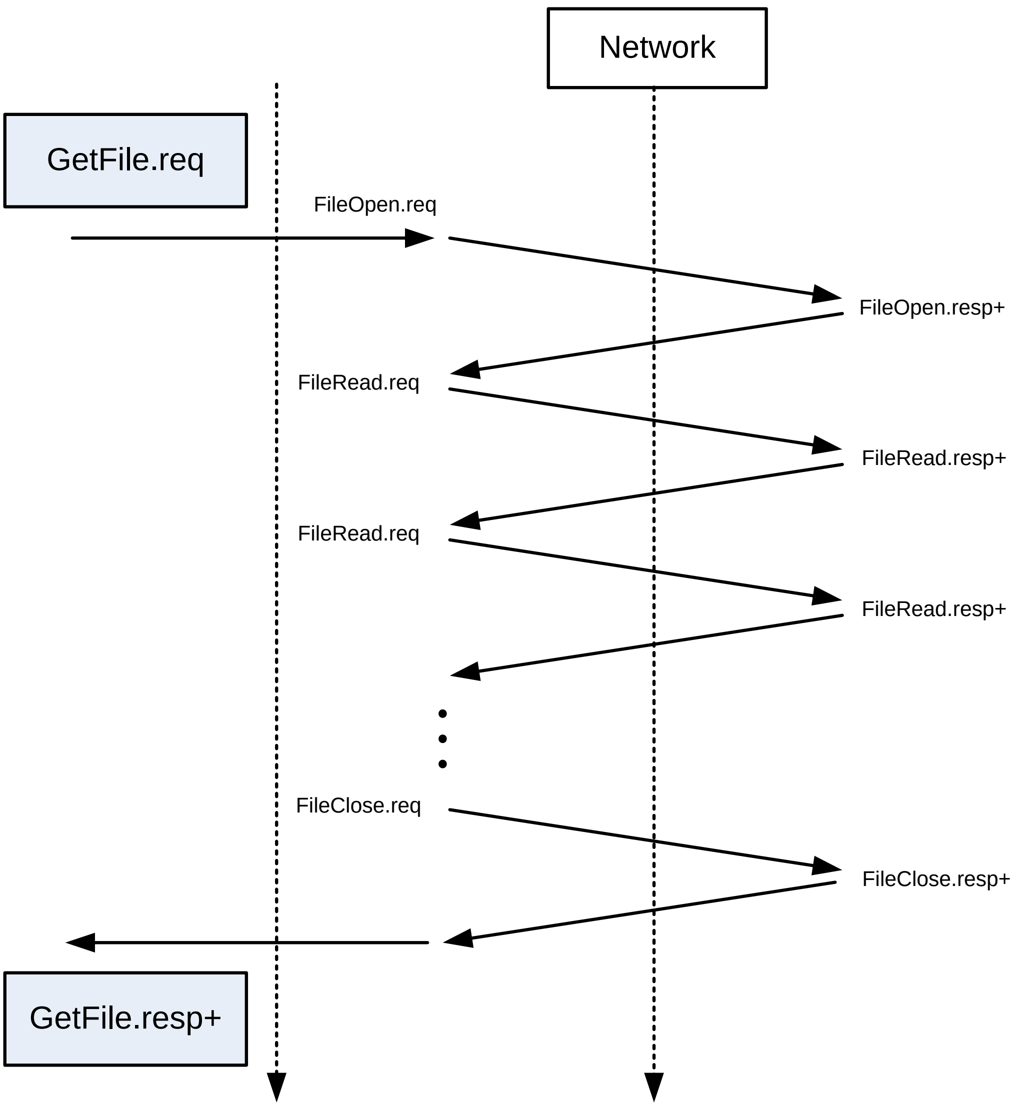


Figure 3-1 MMS File Transfer – Message Sequence

Figure 3-2 illustrates the communication between one client and one server concerning file download. The situation if more than one client or server are requesting simultaneous file services is not handled by the test cases.

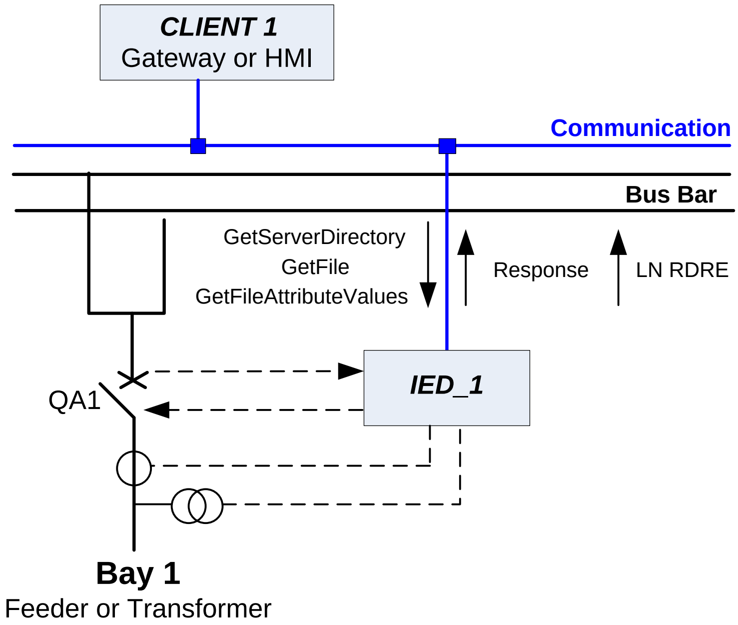


Figure 3-2 MMS File Transfer – System Overview

3.1.2 Vendor Variability

Vendors may implement file directory and file naming in different ways as there are only some requirements in the standard which must be met. Also it is expected that these aspects should be described in the PIXIT of the device.
The use cases and tests can then be adjusted at a later stage when the variability of the equipment is known. This should be available through documents produced by the vendors, especially the PIXIT and the PICS documents.

3.1.3 File transfer definitions in IEC61850 Standard

File Directory
IEC61850 Part 8-1 Section 23.1 defines that COMTRADE files shall be contained within a file directory called "COMTRADE". The COMTRADE specification specifies the use of three different suffixes (e.g. hdr, cfg, and dat).
A server, that contains logical devices, shall have as one of its root directories a directory named "LD". Below the LD root shall be a set of directory names that represent the logical devices within the server.

MMS File Transfer
[IEC61850-7-2] Section 6.1 and 20.2 define the services for MMS file transfer. The support for the services GetServerDirectory (6-1), GetFile (20.2.1) and GetFileAttributeValues (20.2.4) is mandatory. The support for the services SetFile and DeleteFile are optional. Optional services are not part of the described test cases.

Logical Node RDRE
[IEC61850-7-4] Section 5.5.2 defines the logical node RDRE which mainly describes the disturbance recorder function (together with RADR and RBDR if present in the data model) in the server device. The mandatory data objects 'RcdMade' and 'FltNum' are normally used by clients to initiate a file transfer for a new disturbance record and to synchronise the information content between client and server.

3.2 Configuration

1. All the functions defined in this section require the data object 'RcdMade' in logical node RDRE in the data model of the IED. This LN is mandatory for disturbance transmission.
2. The device parameters are set by a tool prepared from vendor. No special settings are required.

3.3 Use Cases

3.3.1 Read the server directory structure [UC FT1]

Use case name:	Read the server directory structure
Use case id:	[UC FT1]
Version:	1.00
Goal:	Analyse directory structure
Summary:	IED responds with the directory structure.
Actors:	User, IED1 (GetServerDirectory services), Client

Preconditions:	**Pr1**	IED is in normal operation mode and contains at least one fault record generated by a trigger condition
Triggers:	**T1**	Trigger for a new fault by an analog process simulator, binary input or front panel.
Course of events:	**C1**	Client requests GetServerDirectory(FILE) with correct parameters and for each responded directory a new GetServerDirectory(FILE) is generated.
	C2	IED1 responds with the directory structure.
Postconditions:	**Po1**	none
Notes:		The returned directory structure must meet the client's requirements. A directory with the name COMTRADE must exist corresponding to the PIXIT description.

3.3.2 Read the list of disturbance files [UC FT2]

Use case name:	Read the list of disturbance files
Use case id:	[UC FT2]
Version:	1.00
Goal:	Analyse directory structure and file naming.
Summary:	IED responds with the list of files in the COMTRADE directory.
Actors:	User, IED1 (GetServerDirectory and GetFileAttributeValues services), Client

Preconditions:	**Pr1**	IED is in normal operation mode and contains at least one fault record generated by a trigger condition
Triggers:	**T1**	Trigger for a new fault by an analog process simulator, binary input or front panel.
Course of events:	**C1**	Client requests GetServerDirectory(FILE) for the COMTRADE directory.
	C2	For each responded file a GetFileAttributeValues request is issued.
	C3	IED1 responds with the directory file list and file attributes.
Postconditions:	**Po1**	None
Notes:		The returned file list and the file naming must meet the client's requirements and description in the PIXIT.

3.3.3 User requested upload of COMTRADE files [UC FT3]

Use case name:	User requested upload of COMTRADE files
Use case id:	[UC FT3]
Version:	1.00
Goal:	Analyse file integrity
Summary:	IED responds with the file data.
Actors:	User, IED1 (GetFile service), Client

Preconditions:	**Pr1**	IED is in normal operation mode and contains at least one fault record generated by a trigger condition
Triggers:	**T1**	Trigger for a new fault by an analog process simulator, binary input or front panel.
Course of events:	**C1**	Client requests GetFile service with correct parameters.
	C2	IED1 responds with the file content.
Postconditions:	**Po1**	At least two new files were received during file transfer on client side.
	Po2	IED is in normal operation mode, the disturbance records list is unchanged.
Notes:		The integrity of the files must be evaluated by comparing the content with the expected results. For example COMTRADE records can be visualized by a COMTRADE viewer. If possible to obtain the same record by readout on the front port of the device the two outcomes can be compared.

3.3.4 Automatic upload of new disturbance files initiated by RcdMade (RDRE) [UC FT4]

Use case name:	Automatic upload of new of new disturbance files initiated by RcdMade (RDRE)
Use case id:	[UC FT4]
Version:	1.00
Goal:	Analyse file integrity.
Summary:	IED responds with the file data.
Actors:	User, IED1 (GetFile service), Client

Preconditions:	**Pr1**	IED is in normal operation mode and contains no fault records.
Triggers:	**T1**	Trigger for a new fault by an analog process simulator, binary input or front panel.
Course of events:	**C1**	Server generates a new disturbance record by a trigger condition.
	C2	Server generates a report for the RcdMade signal.
	C3	Client requests GetFile() with correct parameters
	C4	IED1 responds with the file content.
Postconditions:	**Po1**	At least two new files were received during file transfer on client side.
	Po2	IED is in normal operation mode, the disturbance records list is unchanged.
Notes:		The integrity of the files must be evaluated by comparing the content with the expected results. This test can be run only if the client reacts to the RcdMade or FltNum data objects.

3.3.5 Readout of files with interruption of communication during file transfer [UC FT5]

Use case name:	Readout of files with interruption of communication during file transfer
Use case id:	[UC FT5]
Version:	1.00
Goal:	Analyse file integrity. Discard files that are not completely transmitted.
Summary:	IED responds with the file data.
Actors:	User, IED1 (GetFile service), Client

Preconditions:	**Pr1**	IED is in normal operation mode and contains at least one stored fault record generated by a trigger condition.
Triggers:	**T1**	Trigger for a new fault by an analog process simulator, binary input or front panel.
Course of events:	**C1**	Client requests GetFile() with correct parameters.
	C2	IED1 responds with the file content.
	C3	Interruption of the physical connection on the server device before file transmission is completed.
	C4	After reconnection the file transfer has to be repeated.
Postconditions:	**Po1**	At least two new files were received during file transfer on client side.
	Po2	IED is in normal operation mode, the disturbance records list is unchanged.
Notes:		The integrity of the files must be evaluated by comparing the content with the expected results. For example COMTRADE records can be visualized by a COMTRADE viewer. After reconnection of the client the file transfer should be repeated. Although on client side there should be only one valid file corresponding to the device data.

3.4 Requirements

3.4.1 Interfaces

As Client/Server interfaces the reports from the LN RDRE are used.

The following tables define type and quantity of interfaces per IED. This definition is the base for system design and system engineering – defining type and quantity of interaction between process and system components in principle.
Table 3-1 defines the interface between process and IEDs.
Table 3-2 defines IEC 61850 based client server communication between IEDs.

Table 3-1 MMS File Transfer – Process interface

Data	IED_1
Current input 3phase BE1	AI
Voltage input 3phase BE5	AI

Table 3-2 MMS File Transfer – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 data				IED_1	IED_Station
	IED_LD	LN	Data	CDC		
IED_1 RcdStr	<IED_1><LD>	RDRE	RcdStr	SPS	Server reporting	Client
IED_1 RcdMade	<IED_1><LD>	RDRE	RcdMade	SPS	Server reporting	Client
IED_1 FltNum	<IED_1><LD>	RDRE	FltNum	INS	Server reporting	Client

- RcdMadeIndication that the file is ready to be downloaded
- FltNum Fault number which corresponds to the file
- RcdStr Indication that a new file is in progress to be build

3.4.2 Performance Requirements

Time performance is not evaluated and uncritical.

4 Test Case - Switching by SBO with interlocking

4.1 Description

4.1.1 General

The interlocking function is used to check switching devices control availability.
The decision whether a switchgear actuation is blocked or released requires evaluating logical links from the topological environment of the device to be actuated and of relevant process information.
The logical node for interlocking (LN CILO) is used to indicate the interlocking results held by each Switch Controller (LN CSWI).
The interlocking function itself determines the status of its data and thus permits the closing/opening of the device when TRUE. The control service checks this value before it controls "Close/On"/"Open/Off" a switch at the selection and execution phases.

Figure 4-1 shows the principal procedure of interlocking in a bay when a command is given. Upon receipt of a switching command the control logic checks if the intended control can be released (CILO). The interlocking logic provides the release or blockade information. When calculating the interlocking result not only the field-internal status and release information but also information of other bay units is considered.
Moreover, the interlocking logic provides other bay units with the calculated status and release information. In case of release the command is issued to the process, in case of blockade no command is issued.

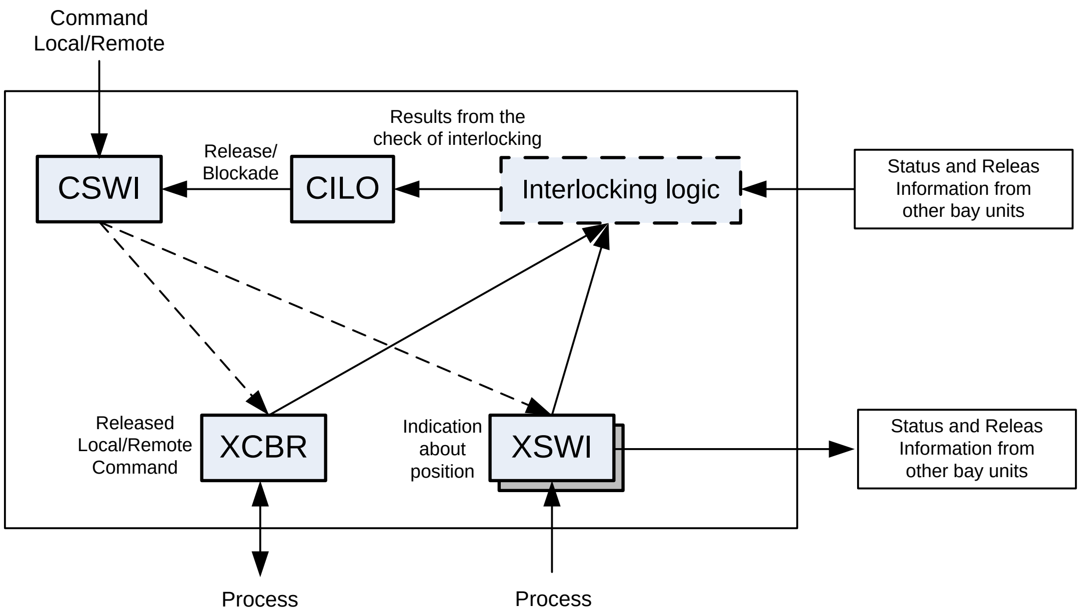


Figure 4-1 Switching by SBO with interlocking – Basic interlocking procedure in a bay unit

General operation of switching by SBO with interlocking is shown by Figure 4-2.

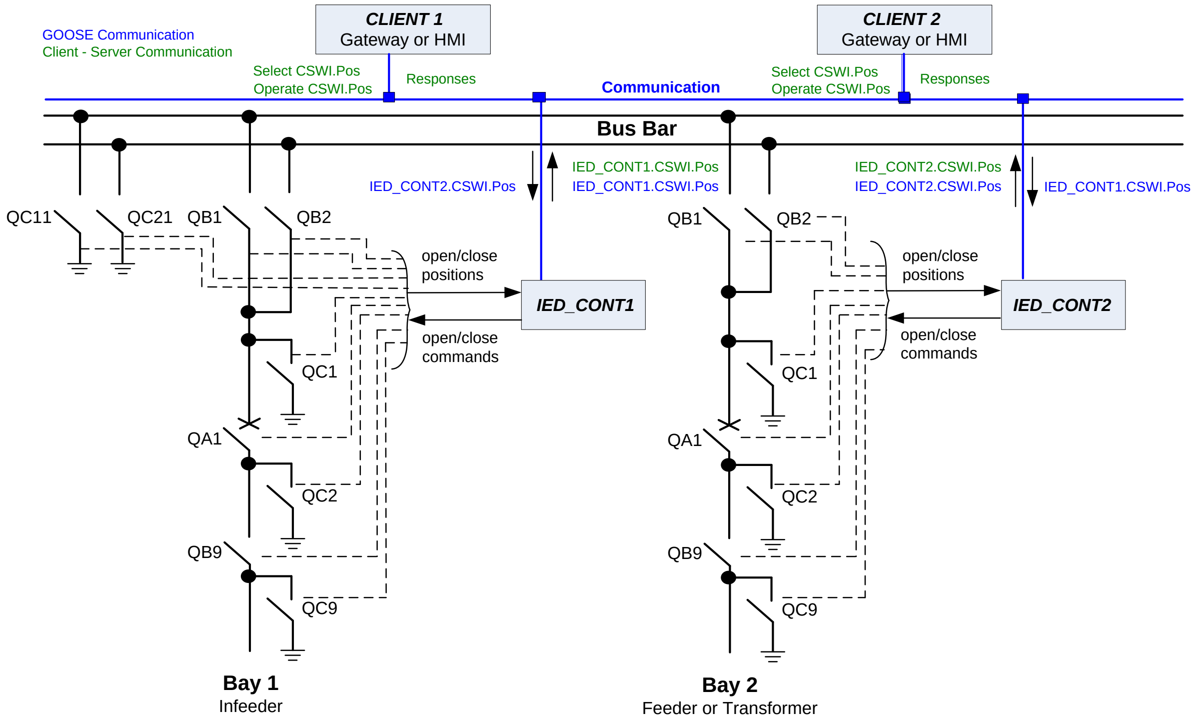


Figure 4-2 Switching by SBO with interlocking – System Overview

4.1.2 Implementation concept

There are two kinds of distributions for the interlocking equation management, centralized in a substation unit or decentralized in each bay unit. This is to define the decentralized concept.
Basically, the concept is called "Distributed interlocking in bay units" because each bay which manages switching devices holds its switching devices interlocking equations.
With this concept, the bay-spanning interlocking logic is distributed among all participating bay units. Moreover, each bay unit provides the status information required by other bay units for calculating the corresponding bay-spanning interlocking conditions.
If one bay unit fails, the bay-spanning interlocking function usually remains functional with limitations. Advantage of this implementation is that there is no need of redundancy to ensure the interlocking functionality compared to centralized approach.
The following figure shows how the different equipments hold the interlocking logics and how the different statuses are exchanged to keep the equations updated.

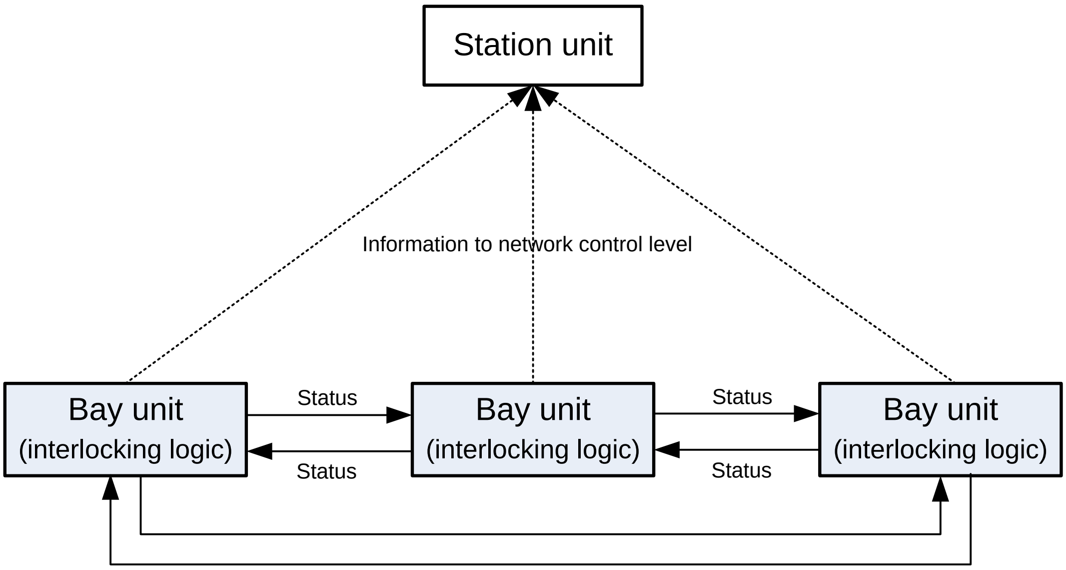


Figure 4-3 Switching by SBO with interlocking – Inter bay units exchange diagram

The XSWI.Pos is exchanged between the Bay Units by GOOSE.

4.2 Configuration

Definition of the interlocking equations for each control of a switching device. The “Close/On” equation and the “Open/Off” equation can be different.

4.3 Use Cases

4.3.1 Decentralized interlocking equation management [UC SI1]

Use case name:	Switching by SBO with interlocking equation enabling switch
Use case id:	[UC SI1]
Version:	1.00
Goal:	Successful operation of a switching device
Summary:	Successful operation of a switching device with interlocking equation depending on bay unit local elements.
Actors:	User, IED1 (Switching device owner), Client

Preconditions:	**Pr1**	IED1 is in remote control mode. No other control is selected in this bay.
	Pr2	Switching device has open status
	Pr3	IED is in normal operation mode, no output operation (protection function or switching operation) is running.
Triggers:	**T1**	Switching device closing request by user
Course of events:	**C1**	USER requests IED1 selection of closing bay switching device.
	C2	IED1 confirms user request.
	C3	IED1 checks for interlocking result
	C4	IED1 interlocking equation enables the control.
	C5	USER requests IED1 to close bay switching device.
	C6	IED1 confirms user request.
	C7	IED1 checks for interlocking result.
	C8	IED1 interlocking equation enables the control.
	C9	IED1 closes switching device.
	C10	IED1 reports USER successful switching operation.
Postconditions:	**Po1**	Bay switching device has closed status.
	Po2	IED is in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

4.3.2 Failure of switching device during selection phase [UC SI2]

Use case name:	Switching by SBO with interlocking equation disabling switch
Use case id:	[UC SI2]
Version:	1.00
Goal:	Failed operation of switching device
Summary:	Failed operation of a switching device with interlocking equation depending on all topological elements during the selection phase of the control sequence.
Actors:	User, IED1 (Switching device owner), IEDx (for all positions involved in the interlocking equation), Client

Preconditions:	**Pr1**	IED1 is in remote control mode. No other control is selected in this bay. Interlocking is enabled.
	Pr2	Switching device QB1 has open status. Switching device E1Q1.QC11 has closed status.
	Pr3	IED is in normal operation mode, no output operation (protection function or switching operation) is running.
Triggers:	**T1**	Switching device QB1 closing request by user
Course of events:	**C1**	USER requests IED1 selection of closing bay switching device.
	C2	IED1 confirms user request.
	C3	IED1 checks for interlocking result.
	C4	Result of the interlocking equation blocks the control. QB1 must not be closed while E1Q1.QC11 is not in open position.
	C5	IED1 does not select close bay switching device.
	C6	IED1 reports USER unsuccessful switching operation.
Postconditions:	**Po1**	Bay switching device QB1 has open status.
	Po2	IED is in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

4.3.3 Failure of switching device during execution phase [UC SI3]

Use case name:		Switching by SBO with interlocking equation disabling switch
Use case id:		[UC SI3]
Version:		1.00
Goal:		Failed operation of switching device
Summary:		Failed operation of a switching device with interlocking equation depending on all topological elements during the execution phase of the control sequence.
Actors:		User, IED1 (Switching device owner), IEDx (for all positions involved in the interlocking equation), Client
Preconditions:	**Pr1**	IED is in remote control mode. No other control is selected in this bay. Interlocking in enabled.
	Pr2	Switching device has open status.
	Pr3	IED is in normal operation mode, no output operation (protection function or switching operation) is running.
Triggers:	**T1**	Switching device closing request by user
Course of events:	**C1**	USER requests IED1 selection of closing bay switching device.
	C2	IED1 confirms user request.
	C3	IED1 checks for interlocking result.
	C4	IED1 interlocking equation enables the control.
	C5	Switching device E1Q1.QC11 is closed.
	C6	USER requests IED1 to close bay switching device.
	C7	IED1 confirms user request.
	C8	IED1 checks for interlocking result.
	C9	Result of the interlocking equation blocks the control. QB1 must not be closed while E1Q1.QC11 is not in open position.
	C10	IED1 does not select close bay switching device.
	C11	IED1 reports USER unsuccessful switching operation
Postconditions:	**Po1**	Bay switching device QB1 has open status.
	Po2	IED is in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

4.4 Requirements

4.4.1 Interfaces

The following tables define type and quantity of interfaces per IED. This definition is the base for system design and system engineering – defining type and quantity of interaction between process and system components in principle.
Table 4-1 defines the interface between process and IEDs.
Table 4-2 defines IEC 61850 based client server communication between IEDs.
Table 4-3 defines IEC 61850 based GOOSE communication between IEDs.

Table 4-1 Switching by SBO with interlocking – Process interface

Data	IED_CONT1	IED_CONT2
Position of busbar earthing switch E1Q1.QC11	BI	
Position of circuit breaker QA1		BI
Position of disconnector switch QB1		BI
Control output to disconnector switch QB1		BO

Table 4-2 Switching by SBO with interlocking – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 data				IED_CONT1	IED_CONT2	IED_Station
	IED_LD	LN	Data	CDC			
IED_CONT1 Pos CSWI	<IED_CONT1><LD>	CSWI	Pos	DPC	Server reporting		Client
IED_CONT2 Pos CSWI	<IED_CONT2><LD>	CSWI	Pos	DPC		Server reporting	Client
IED_CONT2 CILO	<IED_CONT2><LD>	CILO	EnaCls	SPS		Server reporting	Client

Table 4-3 Switching by SBO with interlocking – Communication interface IEC 61850 GOOSE

Use case Data	IEC 61850 data					IED_CONT1	IED_CONT2
	IED_LD	LN	Data	Attribut	CDC/Type		
IED_CONT1 Pos XSWI	<IED_CONT1><LD>	XSWI	Pos	stVal	DPS/ DBPOS	GOOSE publisher	GOOSE subscriber
				q	DPS/ Quality		

4.4.2 Performance

The time performance depends on the control/protection performance class defined either by the bay type or by the customer's requirement.
At least performance class 1 should be provided, i.e. according to IEC61850-5 a transfer time for the interlocking result of not more than 10ms.

5 Test Case – Reverse blocking

5.1 Description

In radial networks with single infeed, the reverse blocking approach can be used to set up a basic busbar protection. Figure 5-1 shows the system view of the reverse blocking approach. The system consists of one incoming feeder (Bay 1) with protection device IED_IN and 1 to n outgoing feeder (Bay2, Bay 3) with the protection devices IED_OUT1 to IED_OUTn (IED_OUT1 and IED_OUT2).

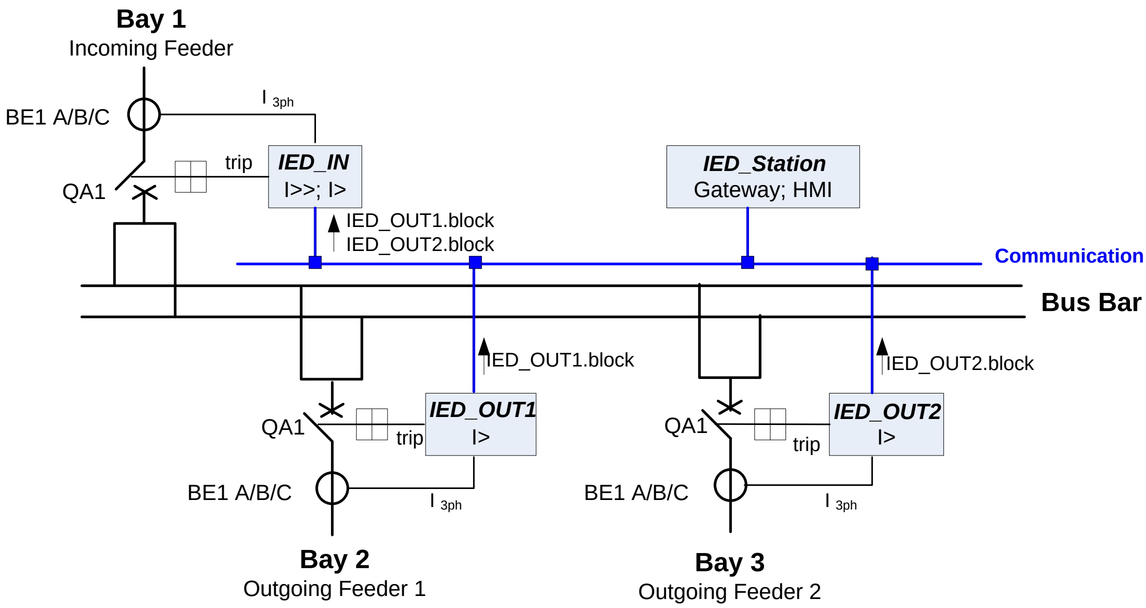


Figure 5-1 Reverse blocking – System overview

A fault in an outgoing feeder causes high fault currents both in the incoming feeder and the concerned outgoing feeder. A fault on a bus bar causes high fault currents in the incoming feeder only. There is no high current in outgoing feeders in case of bus bar fault. Based on this criterion the reverse blocking supports basic bus bar protection.

Every IED measures the current I_{3ph} per bay from CT BE1. If a current is measured by an outgoing feeder IED IED_OUTx and it is in overcurrent stage I> (fault in outgoing feeder), the overcurrent protection of incoming feeder IED_IN stage I>> will be blocked by the signal IED_OUTx.block immediately. The fault will be cleared by the IED of outgoing feeder IED_OUTx in a selective way. The bus bar remains energized.

If the current measured by the outgoing feeder device IED_OUTx is not in overcurrent stage I> (fault on bus bar), the overcurrent protection of the incoming feeder will not be blocked by the signal IED_OUTx.block. The fault will be cleared by IED_IN of the incoming feeder.

Figure 5-2 shows the application of IED_OUTx in an outgoing feeder. IED_OUTx supports time delayed overcurrent protection PTOC with stage I>. The time delayed output of the device trips the circuit breaker QA1 of the bay. The undelayed start of overcurrent protection PTOC is used as blocking signal for IED_IN in the incoming feeder.

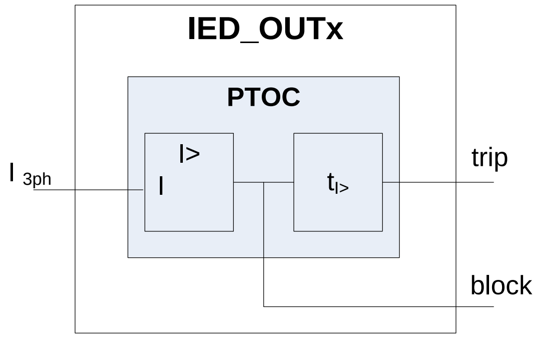


Figure 5-2 Reverse blocking – IED application outgoing feeder

Figure 5-3 shows the application of IED_IN in the incoming feeder. IED_IN supports time delayed overcurrent protection PTOC1 with stage I>> and time delayed overcurrent protection PTOC2 with stage I>. The time delayed output of both protection functions trips the circuit breaker QA1 of the bay. PTOC1 is blocked by blocking signals of IED_OUT1 to IED_OUTn.

Blocking for IED_IN per IED_OUTx is active, if

- blocking by IED_OUTx is active and
- blocking signal is valid and
- communication status is valid (GOOSE is valid).

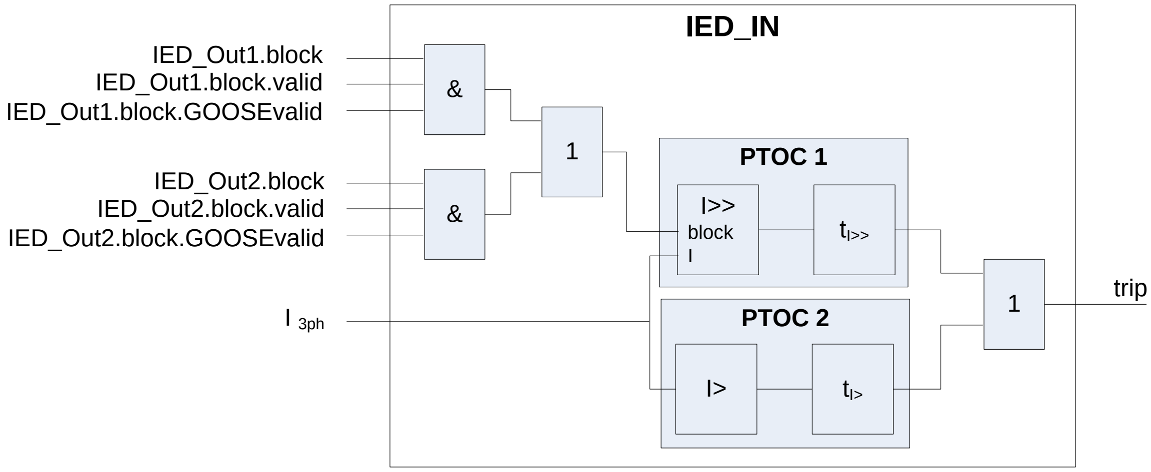


Figure 5-3 Reverse blocking – IED application incoming feeder

Blocking signals from all IED_OUT1 … IED_OUTn of outgoing feeders to IED_IN of the incoming feeder will be transmitted via serial communication based on IEC 61850 / Ethernet (see communication in Figure 5-1). The information is transmitted in one direction only, i.e. to the incoming feeder protection. GOOSE is used for blocking signals.
All status changes of IEDs are reported via serial communication based on IEC 61850 / Ethernet to client on station level IED_Station (see communication in Figure 5-1).
The status to be reported is the following:

- Start of protection functions IED_IN, IED_OUTx
- Trip of protection functions IED_IN, IED_OUTx
- Status of protection functions IED_IN, IED_OUTx

Client server communication / reporting is used for reporting of status changes to the client IED_Station.

The following important condition has to be fulfilled by the system solution:
Total time delay of

- indication of fault current stage PTOC I> in outgoing feeder as blocking output of IED_OUTx (see t_{d1} in Figure 5-5)
  plus
- transfer time for blocking signal from IED_OUTx to IED_IN (see t_{d2} in Figure 5-5)
  plus
- blocking of protection function PTOC1 I>> of IED_IN in incoming feeder (see t_{d3} in Figure 5-5)

has to be shorter than time delay $t_{I>>}$ of stage I>> of IED_IN.

5.2 Configuration

Table 5-1 shows the needed configuration of IEDs for reverse blocking.

Table 5-1 Reverse blocking – Configuration

Parameter	IED_IN	IED_OUT1	IED_OUT2
PTOC: I>		X	X
PTOC: $t_{I>}$		X	X
PTOC1: I>>	X		
PTOC1: $t_{I>>}$	X		
PTOC2: I>	X		
PTOC2: $t_{I>>}$	X		

5.3 Use Cases

5.3.1 Scope of use cases

The objective of use case definitions is the verification of IEC 61850 based system applications focussed on interoperability and performance. There is no intention to cover all possible applications by these defined use cases. Therefore the defined test cases support investigation of functions in principle and handling of disturbed communication.

5.3.2 Fault clearance – fault on bus bar [UC RB01]

Use case name:	Selective fault clearance in case of bus bar fault
Use case id:	[UC RB01]
Version:	1.00
Goal:	Selective fault clearance in case of bus bar fault
Summary:	Selective fault clearance with minimum tripping time in case of fault on a busbar. E.g. circuit breaker QA1 of the incoming feeder in Bay 1 is tripped by IED_IN.
Actors:	IED_IN, IED_Station
Sequence chart:	Figure 5-4

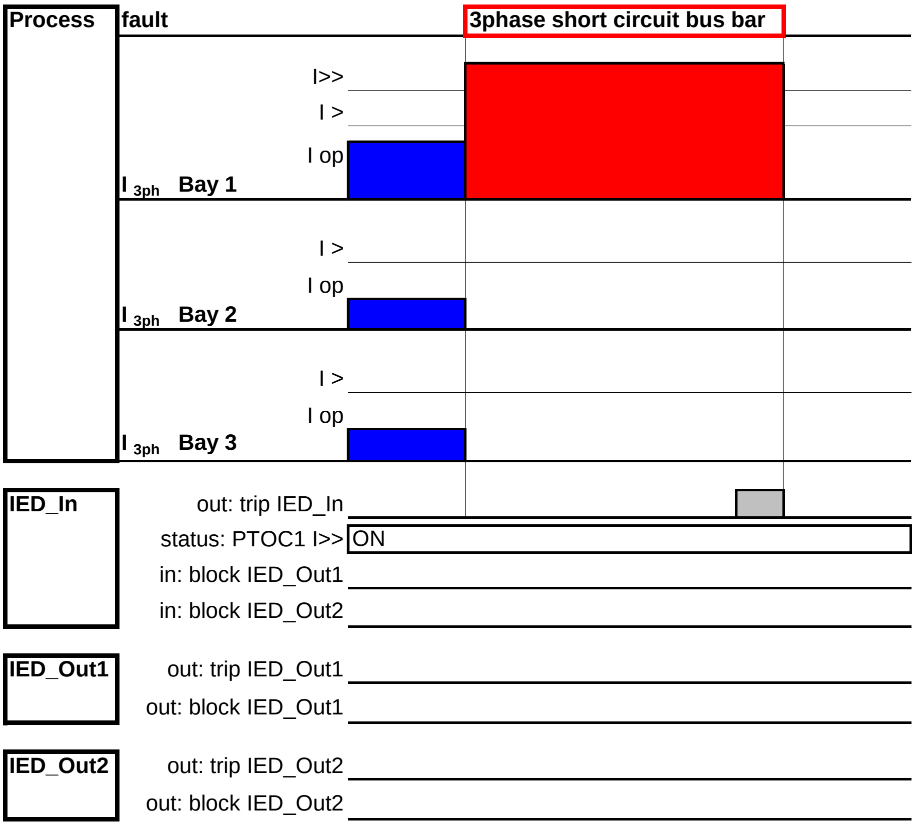


Figure 5-4 Reverse blocking – Sequence chart use case [UC RB01] fault on bus bar

Preconditions:	**Pr1**	The test system is installed and in operation according to the description in paragraph 5.1
	Pr2	The process is simulated as follows:
	Pr2-1	Busbar is energized; e.g. all circuit breakers are closed: Bay 1 QA1, Bay 2 QA1, Bay 3 QA1
	Pr2-2	Measured currents of Bay 1, Bay 2 and Bay 3 are in stage Iop
	Pr3	The IEDs have the following status:
	Pr3-1	Protection of IED_IN, IED_OUT1 and IED_OUT2 is in status 'ON'.
	Pr3-2	Protection of IED_IN, IED_OUT1 and IED_OUT2 is not activated.
	Pr4	The communication has the following status:
	Pr4-1	All communication connections are established and have status 'OK'.
Triggers:	**T1**	A 3 phase short circuit occurs on the bus bar.
Course of events:		See sequence chart Figure 5-4
	C1	Measured currents of Bay 1, Bay 2 and Bay 3 change to fault values:
	C1-1	Measured current of Bay 1 increases to stage I>>.
	C1-2	Measured current of Bay 2 and Bay 3 is zero.
	C2	Start of PTOC I>> of IED_IN is activated. Activation of start is reported to IED_Station.
	C3	When time delay $t_{I>>}$ of IED_IN is lapsed, QA1 of Bay 1 is tripped by IED_IN. Tripping is reported to IED_Station.
	C4	Measured current value changes as follows:
	C4-1	Measured current of Bay 1 is zero.
	C5	Start and trip of PTOC I>> of IED_IN are deactivated. Deactivation of start and trip is reported to IED_Station.
Postconditions:	**Po1**	The process is simulated as follows:
	Po1-1	Busbar is deenergized; e.g. the circuit breaker QA1 in Bay 1 is open, the circuit breakers QA1 in Bay 2 and Bay 3 are closed.
	Po1-2	Measured currents of Bay 1, Bay 2 and Bay 3 are zero.
	Po2	The IEDs have the following status:
	Po2-1	Protection of IED_IN, IED_OUT1 and IED_OUT2 is in status 'ON'.
	Po2-2	Protection of IED_IN, IED_OUT1 and IED_OUT2 is not activated.
Notes:		none

5.3.3 Fault clearance – fault on outgoing feeder [UC RB02]

Use case name:	Selective fault clearance in case of fault on an outgoing feeder
Use case id:	[UC RB02]
Version:	1.00
Goal:	Selective fault clearance in case of fault on an outgoing feeder
Summary:	Selective fault clearance in case of fault on an outgoing feeder. E.g. circuit breaker QA1 of outgoing feeder in Bay 2 is tripped by IED_OUT1.
Actors:	IED_IN, IED_OUT1, IED_Station
Sequence chart:	Figure 5-5

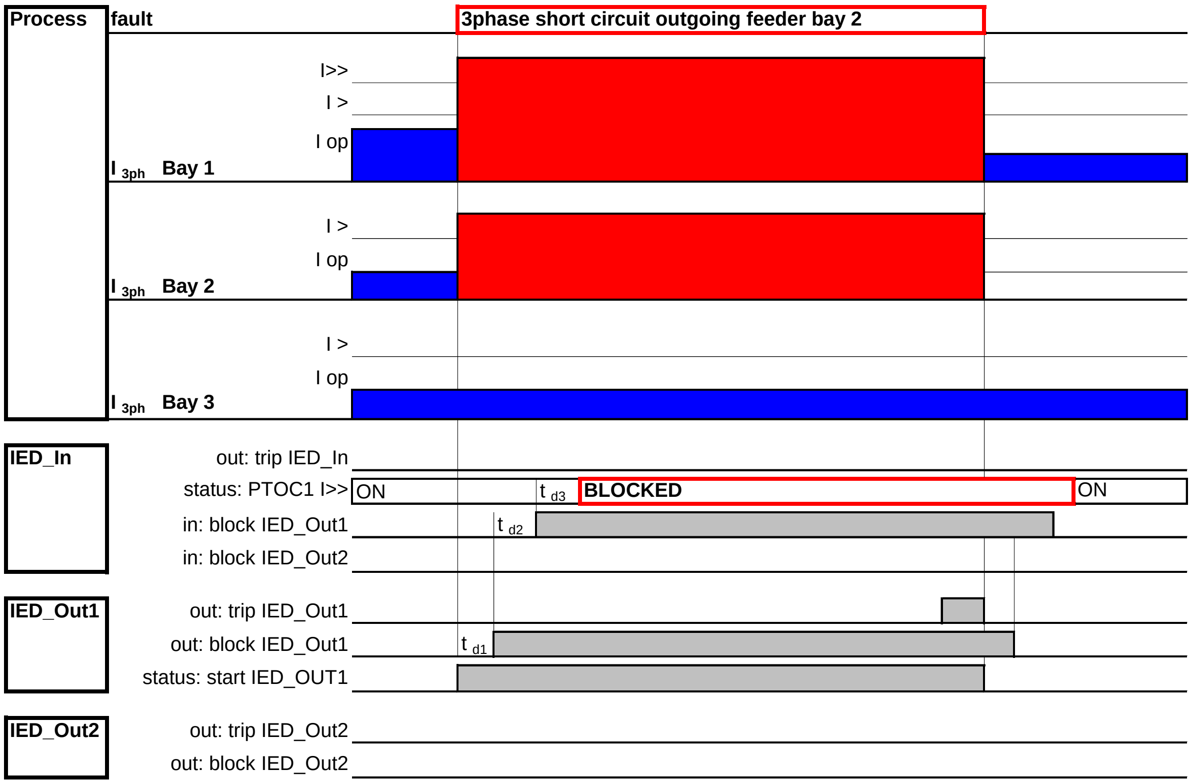


Figure 5-5 Reverse blocking – Sequence chart use case [UC RB02] fault on outgoing feeder

Preconditions:	**Pr1**	The test system is installed and in operation according to the description in paragraph 5.1
	Pr2	The process is simulated as follows:
	Pr2-1	Busbar is energized; e.g. all circuit breakers are closed: Bay 1 QA1, Bay 2 QA1 and Bay 3 QA1
	Pr2-2	Measured currents of Bay 1, Bay 2 and Bay 3 are in stage Iop
	Pr3	The IEDs have the following status:
	Pr3-1	Protection of IED_IN, IED_OUT1 and IED_OUT2 is in status 'ON'.
	Pr3-2	Protection of IED_IN, IED_OUT1 and IED_OUT2 is not activated.
	Pr4	The communication has the following status:
	Pr4-1	All communication connections are established and have status OK.
Triggers:	**T1**	A 3 phase short circuit occurs in outgoing feeder Bay 2.

Course of events: See sequence chart Figure 5-5

C1 Measured currents of Bay 1, Bay 2 and Bay 3 change to fault values as follows

C1-1 Measured current of Bay 1 increases to stage I>>.

C1-2 Measured current of Bay 2 increases to stage I>.

C2 Start of PTOC I>> of IED_IN and PTOC I> of IED_OUT1 is activated. Activation of start is reported to IED_Station.

C3 Blocking signal of IED_OUT1 is activated.

C4 Activated blocking signal of IED_OUT1 is transmitted to IED_IN.

C5 Activated blocking signal of IED_OUT1 is received by IED_IN and blocks PTOC1 I>> of IED_IN.

C6 Protection PTOC1 I>> of IED_IN changes to status 'BLOCKED'. Change of status is reported to IED_Station.

C7 When time delay $t_{I>}$ of IED_OUT1 is lapsed, QA1 of Bay 2 is tripped by IED_OUT1. Tripping is reported to IED_Station.

C8 Measured currents change to the following values:

C8-1 Measured current of Bay 2 is zero.

C8-2 Measured current of Bay 1 decreases to Iop.

C9 Start of PTOC I>> of IED_IN are deactivated. Deactivation of start is reported to IED_Station.

C10 Start and trip of PTOC1 I> of IED_OUT1 are deactivated. Deactivation of start and trip is reported to IED_Station.

C11 Blocking signal of IED_OUT1 is deactivated.

C12 Deactivated blocking signal of IED_OUT1 is transmitted to IED_IN.

C13 Deactivated blocking signal of IED_OUT1 is received by IED_IN and releases PTOC1 I>> of IED_IN.

C14 Protection PTOC1 I>> of IED_IN changes to status 'ON'. Change of status is reported to IED_Station.

Postconditions:

Po1 The process is simulated as follows:

Po1-1 Busbar is energized; e.g. circuit breaker QA1 in Bay 1 and QA1 in Bay 3 are closed, circuit breaker QA1 in Bay 2 is open.

Po1-2 Measured currents of Bay 1 and Bay 3 are in stage Iop.

Po1-3 Measured current of Bay 2 is zero.

Po2 The IEDs have the following status:

Po2-1 Protection of IED_IN, IED_OUT1 and IED_OUT2 is in status 'ON'.

Po2-2 Protection of IED_IN, IED_OUT1 and IED_OUT2 is not activated.

Notes: none

5.3.4 Disturbed communication – communication of outgoing feeder is interrupted [UC RB03]

Use case name: Fault clearance in case of a fault on an outgoing feeder and communication of outgoing feeder is interrupted

Use case id: [UC RB03]

Version: 1.00

Goal: Safe fault clearance in case of a fault on the outgoing feeder and disturbed communication

Summary: Fault clearance in case of a fault on the outgoing feeder and interrupted communication of outgoing feeder. E.g. circuit breaker QA1 of outgoing feeder in Bay 2 is tripped by IED_OUT1 and circuit breaker QA1 of incoming feeder in Bay 1 is tripped by IED_IN.

Actors: IED_IN, IED_OUT1, IED_Station

Sequence chart: Figure 5-6

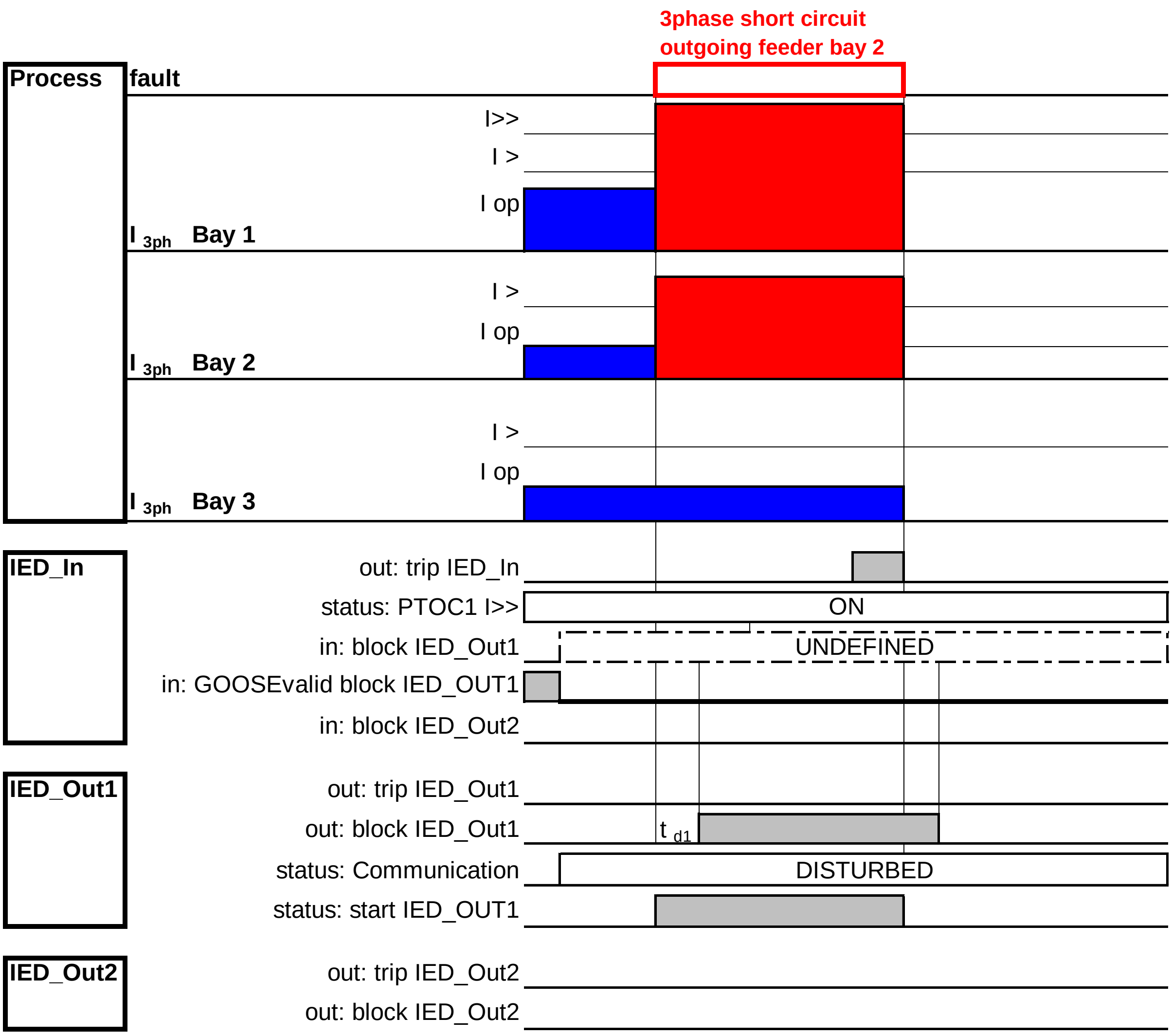


Figure 5-6 Reverse blocking – Sequence chart use case [UC RB03] disturbed communication

Preconditions: **Pr1** The test system is installed and in operation according to the description in paragraph 5.1

Pr2 The process is simulated as follows:

Pr2-1 Busbar is energized; e.g. all circuit breaker are closed: Bay 1 QA1, Bay 2 QA1 and Bay 3 QA1

Pr2-2 Measured currents of Bay 1, Bay 2 and Bay 3 are in stage Iop

Pr3 IED have following status:

Pr3-1 Protection of IED_IN, IED_OUT1 and IED_OUT2 is in status 'ON'.

Pr3-2 Protection of IED_IN, IED_OUT1 and IED_OUT2 is not activated.

Pr4 The communication has the following status:

Pr4-1 All communication connections to the network are established and have status 'OK' except for the communication connection IED_OUT1.

Pr4-2 Communication connection IED_OUT1 to network is interrupted. IED_OUT1.block.GOOSEvalid is FALSE.

Triggers:

T1 A 3 phase short circuit occurs in the outgoing feeder in Bay 2.

Course of events:

See sequence chart Figure 5-5

C1 Measured currents of Bay 1, Bay 2 and Bay 3 change to fault values:

C1-1 Measured current of Bay 1 increases to stage I>>.

C1-2 Measured current of Bay 2 increases to stage I>.

C2 Start of PTOC I>> of IED_IN and PTOC I> of IED_OUT1 is activated. Activation of start is reported to IED_Station.

C3 Blocking signal of IED_OUT1 is activated.

C4 Activated blocking signal of IED_OUT1 is **not** transmitted to IED_IN.

C5 When time delay $t_{I>>}$ of IED_IN has lapsed, QA1 of Bay 1 is tripped by IED_IN. Tripping is reported to IED_Station.

C6 Measured current values change:

C6-1 Measured current of Bay 1 is zero.

C6-2 Measured currents of Bay 2 and Bay 3 are zero.

C7 Start and trip of PTOC I>> of IED_IN are deactivated. Deactivation of start and trip is reported to IED_Station

C8 Start of PTOC I> of IED_OUT1 is deactivated. Deactivation of start is reported to IED_Station.

C9 Blocking signal of IED_OUT1 is deactivated.

C10 Deactivated blocking signal of IED_OUT1 is **not** transmitted to IED_IN.

Postconditions:

Po1 The process is simulated as follows:

Po1-1 Busbar is not energized; e.g. circuit breaker QA1 in Bay 1 is open. QA1 in Bay 2 and QA1 in Bay 3 are closed.

Po1-2 Measured currents of Bay 2 and Bay 3 are zero.

Po1-3 Measured current of Bay 1 is zero.

Po2 The IEDs have the following status:

Po2-1 Protection of IED_IN, IED_OUT1 and IED_OUT2 is in status 'ON'.

Po2-2 Protection of IED_IN, IED_OUT1 and IED_OUT2 is not activated.

Notes:

none

5.4 Requirements

5.4.1 Interfaces

The following tables define type and quantity of interfaces per IED. This definition is the base for system design and system engineering – defining type and quantity of interaction between process and system components in principle.
Table 5-2 defines the interface between process and IEDs.
Table 5-3 defines IEC 61850 based client server communication between IEDs.
Table 5-4 defines IEC 61850 based GOOSE communication between IEDs.

Table 5-2 Reverse blocking – Process interface

Data	IED_IN	IED_OUT1	IED_OUT2
Current input 3phase Bay 1 BE1	AI		
Current input 3phase Bay 2 BE1		AI	
Current input 3phase Bay 3 BE1			AI
Trip Bay 1 QA1	BO		
Trip Bay 2 QA1		BO	
Trip Bay 3 QA1			BO

Table 5-3 Reverse blocking – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 data				IED_IN	IED_OUTx	IED_Station
	IED_LD	LN	Data	CDC			
IED_IN Start PTOC1 I>>	<IED_IN><LD>	PTOC1	Str	ACD	Server reporting		Client
IED_IN Trip PTOC1 I>>	<IED_IN><LD>	PTOC1	Op	ACT	Server reporting		Client
IED_IN Status PTOC1	<IED_IN><LD>	PTOC1	Beh	INS	Server reporting		Client
IED_IN Start PTOC2 I>	<IED_IN><LD>	PTOC2	Str	ACD	Server reporting		Client
IED_IN Trip PTOC2 I>	<IED_IN><LD>	PTOC2	Op	ACT	Server reporting		Client
IED_IN Status PTOC2	<IED_IN><LD>	PTOC2	Beh	INS	Server reporting		Client
IED_IN Pos XCBR	<IED_IN><LD>	XCBR	Pos	DPC	Server reporting		Client
IED_OUTx Start PTOC I>	<IED_OUTx><LD>	PTOC	Str	ACD		Server reporting	Client
IED_OUTx Trip PTOC I>	<IED_OUTx><LD>	PTOC	Op	ACT		Server reporting	Client
IED_OUTx Status PTOC	<IED_OUTx><LD>	PTOC	Beh	INS		Server reporting	Client

Use case Data	IEC 61850 data				IED_IN	IED_OUTx	IED_Station
	IED_LD	LN	Data	CDC			
IED_OUTx Pos XCBR	<IED_OUTx><LD>	XCBR	Pos	DPC		Server reporting	Client

IED_OUTx: IED_OUT1, IED_OUT2

Table 5-4 Reverse blocking – Communication interface IEC 61850 GOOSE

Use case Data	IEC 61850 data					IED_IN	IED_OUTx
	IED_LD	LN	Data	Attribut	CDC/Type		
IED_OUTx block	<IED_OUTx><LD>	PTOC	Str	general	ACD/ BOOLEAN	GOOSE subscriber	GOOSE publisher
				q	ACD/ Quality		

IED_OUTx: IED_OUT1, IED_OUT2

5.4.2 Performance

The definite time delay PTOC1 I>> $t_{I>>}$ of IED_IN shall be set to 100ms.
The overall delay time of transmission IED_OUTx.block from IED_OUTx to IED_IN and blocking of PTOC1 I>> of IED_IN has to be half of definite time delay PTOC1 I>> $t_{I>>}$ maximum, e. g. 50ms.

6 Test Case – Autoreclosure coordination

6.1 Description

Analysis of faults on overhead line network operating has shown that the majority of faults are transient in nature. A transient fault, such as an insulator flash-over, is one which is cleared by the immediate tripping of one or more circuit breakers to isolate the fault, and which does not recur when the line is re-energized.
This means that in the majority of fault incidents, if the faulty line is immediately tripped out, and time is allowed for the fault arc to de-ionize, reclosure of the circuit breakers will result in the line being successfully re-energized.
Auto-reclose schemes are employed to carry out this duty automatically; they have been the cause of a substantial improvement in continuity of supply. A further benefit is the maintenance of system stability and synchronism.
A big variety of different control schemes for auto-reclosing exists. It is not in the focus of this function specification to select the right scheme depending on an intended application in grid operation. Instead, this function specification and the investigations afterwards focus on decentralized system solutions for auto-reclosure based on IEC 61850 communication.
Auto-reclosure consists of at least two main components: fault detecting component which detects failure and trips the circuit breaker and the auto-reclosing component which recloses the circuit breaker after dead time.
In a centralized solution both fault detecting component and auto-reclosing component are in one device. Therefore, specific measures for connecting both components outside of device are not needed.
In a decentralized solution, fault detecting component and auto-reclosing component are in separated devices. This implies that both functions have to be connected externally via communication / wiring to get the complete auto-reclosure functionality.
Figure 6-1 shows the system view of a decentralized solution for autoreclosure (AR). The system consists of 1 to n protection device IED_PROT, which detects fault incidients, and one control device IED_CONT, which auto-recloses the circuit breaker after tripping out by protection device. The auto-reclosing component of IED_CONT will be started by logic for start of AR as part of device IED_CONT based on signal IED_PROT.start from IED_PROT.
Objective of specified solution for autoreclosure coordination is usage of such IEC 61850 data attributes for communication between protection and control device which are defined and foreseen by standard for intended application. Target is to support maximum of interoperability by defined system solution. The Solution should be applicable independent off specific device types and vendors.

Figure 6-1 shows a solution with only one protection device. In case of usage of several main protection devices, the autoreclosing component of control device IED_CONT can be started by the main protection devices concurrently.

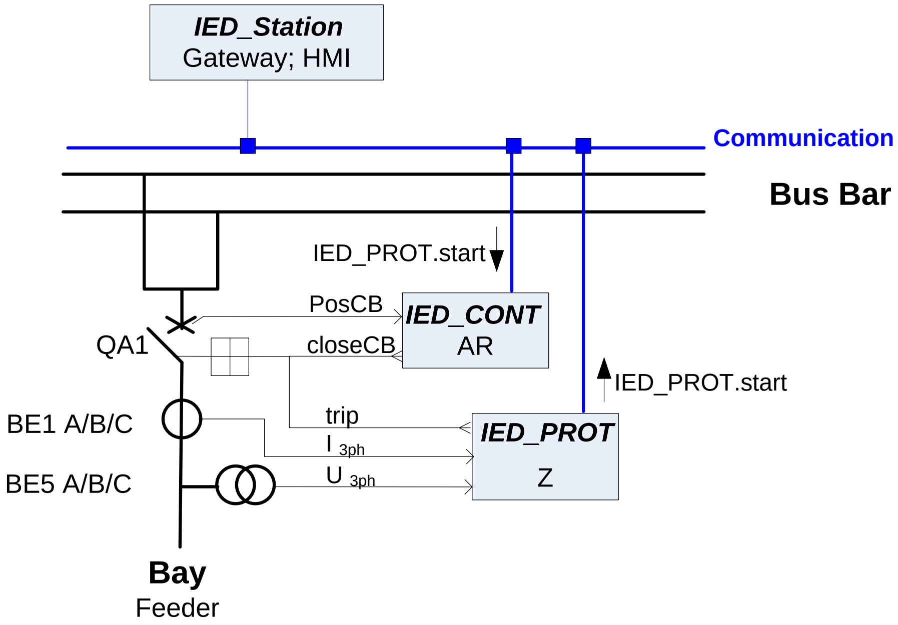


Figure 6-1 AR Coordination – System overview

Figure 6-2 shows the application of IED_PROT. Protection device IED_PROT supports time delayed impedance protection PDIS with stage Z_AR. Stage Z_AR is the zone which causes operation of autoreclosure. The time delayed output of the device trips the circuit breaker QA1 of bay "Feeder". The protection device IED_PROT starts logic for starting of autoreclosure in device IED_CONT via protection start information with signal IED_PROT.start.

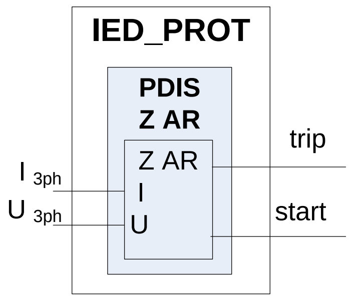
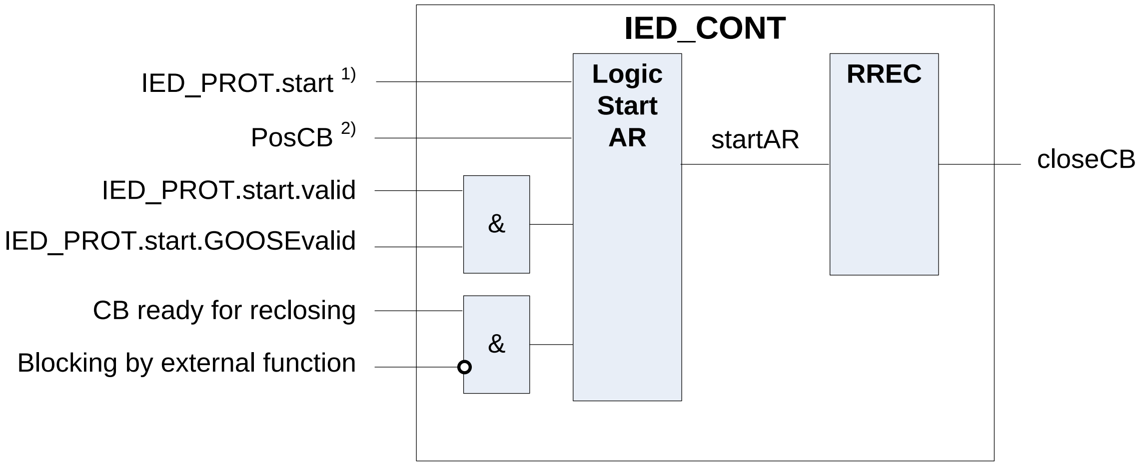


Figure 6-2 AR Coordination – IED application protection device

Figure 6-3 shows the application of IED_CONT. IED_CONT supports time delayed autoreclosure RREC. The output of auto-reclosing function recloses the circuit breaker QA1 of bay after a defined dead time $t_{1\ 1ph}$ for the first shot in case of 1phase fault. Autoreclosure RREC is ready for next autoreclosure after elapsing of reclaim time $t_{reclaim}$.



1) includes directional start information generally and per phase

2) includes circuit breaker position of all 3 phases

Figure 6-3 AR Coordination – IED application control device

Start of autoreclosure of IED_CONT depends on

- start of protection for zone with AR by IED_PROT (criteria 1)
- direction of fault in zone with AR (criteria 2)
- fault type: 3phase , 2phase , 1phase (criteria 3)
- elapsed time between start of protection and opening of circuit breaker (criteria 4)
- start signal IED_PROT.start is valid
- communication status is valid (GOOSE is valid).
- General preconditions for start of autoreclosure are following (see Figure 6-3)
- Circuit breaker is ready for reclosing
- No other functions block or inhibit autoreclosure

Criteria 1, 2 and 3 can be checked by control device IED_CONT based on start information IED_PROT.start from protection device IED_PROT. For that the complete DO str of LN PDIS will be transferred from protection device to control device except time stamp t. Complete provision of DO str supports maximum of flexibility for implementing customized approaches for autoreclosure start logic.
Criteria 4 (elapsed time between start of protection and opening of circuit breaker) is measured and processed for starting logic by control device itself. If elapsed time between start of protection and opening of circuit breaker is less than parameter start time of autoreclosure $t_{\text{start AR}}$, than criteria 4 is fulfilled.
If trip signal of protection were used instead of start signal the configuration of $t_{\text{start AR}}$ would have to be done in a proper way. For interoperability test the start signal of protection is defined for starting of autoreclosure.
Function block 'Logic start AR' Figure 6-3 represents implementation for combination of Criteria 1 … 4 with valid status from IED_PROT and GOOSE communication in a general way. 'Logic start AR' generates the start of autoreclosure startAR by control device. This functionality is not specified in more details as written above in order to confine specification on needed issues for communication aspects. All implementations fulfilling specification above and the test cases described in chapter 6.3 Use Cases are applicable for tests.

Starting signals from all IED_PROT1 … IED_PROTn of Bay Feeder to IED_CONT will be transmitted via serial communication based on IEC 61850 / Ethernet (see communication in Figure 6-1). The information is transmitted in one direction only, i.e. from IED_PROT to IED_CONT. GOOSE is used for starting signals.
All status changes of IEDs are reported via serial communication based on IEC 61850 / Ethernet to client on station level IED_Station (see communication in Figure 6-1). Client server communication (reporting) is used for status information. The status to be reported is as follows:

- Start of protection function IED_PROT
- Trip of protection function IED_PROT
- Status of protection function IED_PROT
- Operation of auto-reclosing function IED_CONT
- Status of auto-reclosing function IED_CONT
- Position of circuit breaker QA1

6.2 Configuration

Table 6-1 shows the needed configuration of IEDs for autoreclosure coordination.

Table 6-1 AR Coordination – Configuration

Parameter		IED_PROT	IED_CONT
PDIS:	Z_AR	X	
PDIS:	$t_{Z\ AR}$	X	
Start logic AR:	$t_{startAR}$		X
RREC:	$t_{1\ 1ph}$		X
RREC:	$t_{reclaim}$		X

6.3 Use Cases

6.3.1 Scope of use cases

The objective of use case definitions is the verification of IEC 61850 based system applications focussed on interoperability and performance. There is no intention to cover all possible applications by these defined use cases. Therefore the defined test cases support investigation of functions in principle and handling of disturbed communication.

6.3.2 3 phase fault without AR [UC AC01]

Use case name:	3 phase fault without AR
Use case id:	[UC AC01]
Version:	1.00
Goal:	Fault clearance in case of 3 phase fault without AR; Autoreclosure is not started by control
Summary:	3 phase fault is cleared without starting of autoreclosure. E.g. circuit breaker QA1 of Bay feeder is tripped by IED_PROT.
Actors:	IED_PROT, IED_CONT, IED_Station
Sequence chart:	Figure 6-4

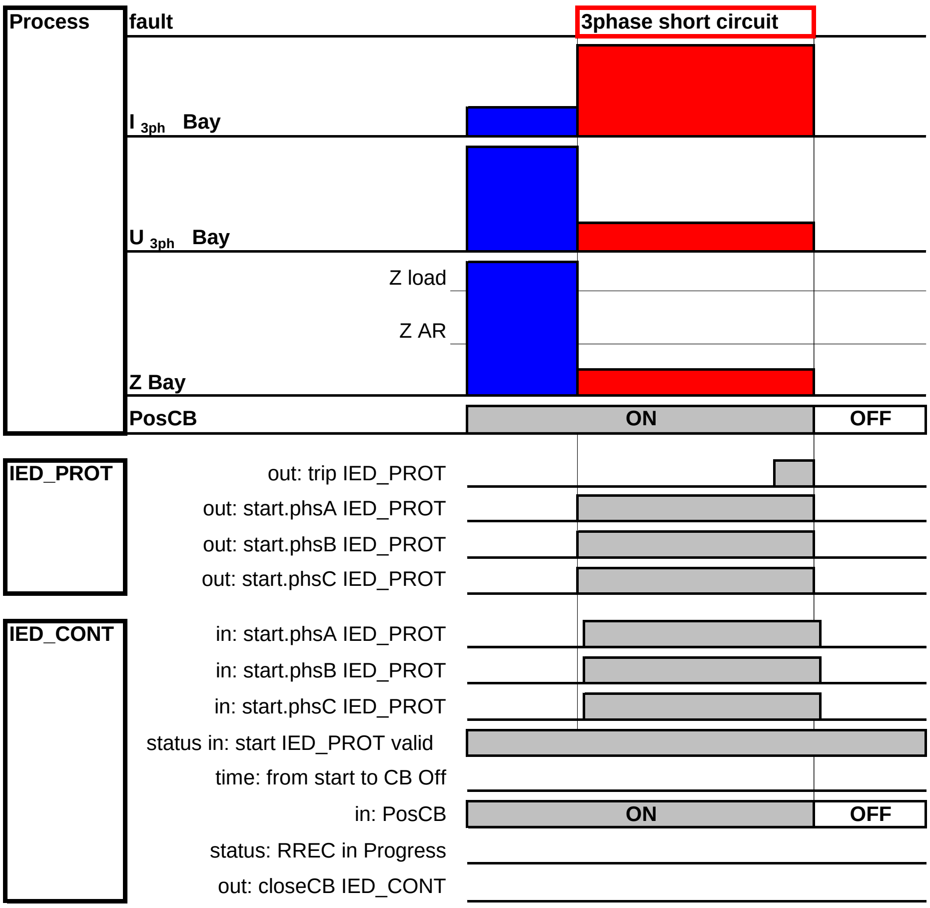


Figure 6-4 AR Coordination – Sequence chart [UC AC01] 3 phase fault without AR

Preconditions:	**Pr1**	Test system is installed and in operation according description in paragraph 6.1
	Pr2	The process is simulated as follows:
	Pr2-1	Busbar and feeder are energized; circuit breaker Bay QA1 is closed
	Pr2-2	Measured impedance of Bay is in stage Z load
	Pr3	The IEDs have the following status:
	Pr3-1	Protection of IED_PROT is in status 'ON'
	Pr3-2	Protection related function RREC of IED_CONT is in status 'ON'
	Pr3-3	Protection of IED_PROT is not activated.
Triggers:	**T1**	3 phase short circuit occurs on feeder.
Course of events:		See sequence chart Figure 6-4
	C1	Measured currents and voltages of Bay change to fault values:
	C1-1	Measured impedance of Bay decreases to stage Z_AR
	C2	Start of PDIS Z_AR of IED_PROT is activated. Activation of start is reported to IED_Station.
	C3	Start of PDIS Z_AR is transferred to IED_CONT. Since IED_CONT detects 3 phase short circuit, starting of autoreclosure RREC is blocked.
	C4	When time delay t_{Z_AR} of IED_PROT is lapsed, QA1 of Bay is tripped by IED_PROT. Tripping is reported to IED_Station.
	C5	Measured current and voltage values change as follows
	C5-1	Measured current of bay is zero.
	C5-2	Measured voltage of bay is zero.
	C6	Start and trip of PDIS Z_AR of IED_PROT are deactivated. Deactivation of start and trip is reported to IED_Station.
Postconditions:	**Po1**	The process is simulated as follows:
	Po1-1	busbar is energized
	Po1-2	feeder is deenergized; circuit breaker QA1 is open
	Po1-3	Measured currents and voltages of bay are zero
	Po2	The IEDs have the following status:
	Po2-1	Protection of IED_PROT is in status 'ON'
	Po2-2	Protection related function RREC of IED_CONT is in status 'ON'
	Po2-3	Protection of IED_PROT is not activated.
	Po4	The communication has the following status:
	Po4-1	All communication connections are established and have status OK.
Notes:		none

6.3.3 Transient 1phase fault with AR [UC AC02]

Use case name: Transient 1phase fault with AR 1shot

Use case id: [UC AC02]

Version: 1.00

Goal: Fault clearance in case of transient 1phase fault with successful AR 1shot

Summary: Transient 1phase fault is cleared with execution of autoreclosure. Breaker QA1 is tripped by IED_PROT and reclosed by IED_CONT.

Actors: IED_PROT, IED_CONT, IED_Station

Sequence chart: Figure 6-5

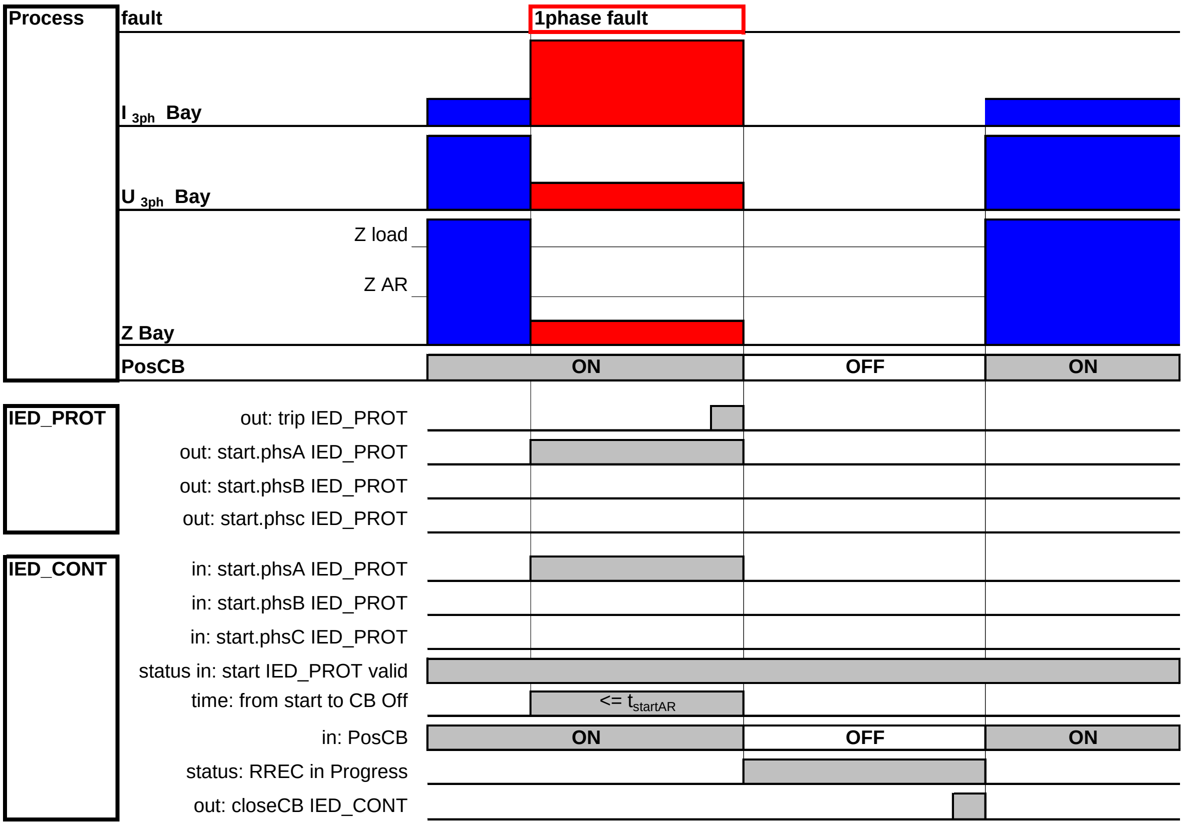


Figure 6-5 AR Coordination – Sequence chart [UC AC02] Transient 1phase fault with AR

Preconditions:

Pr1 Test system is installed and in operation according description in paragraph 6.1

Pr2 <u>The process is simulated as follows:</u>

Pr2-1 Busbar and feeder are energized; circuit breaker QA1 is closed

Pr2-2 Measured impedance is in stage Z load

Pr3 <u>The IEDs have the following status:</u>

Pr3-1 Protection of IED_PROT is in status 'ON'

Pr3-2 Protection related function RREC of IED_CONT is in status 'ON'

Pr3-3 Protection of IED_PROT is not activated.

Pr4 <u>The communication has the following status:</u>

Pr4-1 All communication connections are established and have status OK.

Triggers:	**T1**	Transient 1 phase fault occurs in feeder Bay.
Course of events:		See sequence chart Figure 6-5
	C1	<u>Measured currents and voltages of Bay change to fault values:</u>
	C1-1	Measured impedance decreases to stage Z_AR.
	C2	Start of PDIS Z_AR of IED_PROT is activated. Activation of start is reported to IED_Station.
	C3	Start of PDIS Z_AR is transferred to IED_CONT.
	C4	Since IED_CONT detects 1 phase fault in forward direction, start logic AR measures elapsing time from start of protection IED_PROT to expected opening of circuit breaker.
	C5	When time delay t_{Z_AR} of IED_PROT is lapsed, QA1 of Bay is tripped by IED_PROT. Tripping is reported to IED_Station.
	C6	Circuit Breaker position changes to 'OFF'.
	C7	<u>Measured currents and voltage values change as follows:</u>
	C7-1	Measured current of Bay is zero.
	C7-2	Measured voltage of bay is zero.
	C8	Elapsed time from start of protection IED_PROT to opening of circuit breaker is processed by start logic AR of IED_CONT. Since elapsed time is less than parameter t_{Start_AR}, autoreclosure is started.
	C9	Protection releated function RREC of IED_CONT changes to status 'in Progess'. Status change to 'in Progess' is reported to IED_Station.
	C10	Start and trip of PDIS Z_AR of IED_PROT are deactivated. Deactivation of start and trip is reported to IED_Station.
	C11	When time delay $t_{1\ 1ph}$ of IED_CONT is lapsed, QA1 is reclosed by IED_CONT. Reclosure is reported to IED_Station.
	C12	Circuit Breaker position changes to 'ON'.
	C13	<u>Measured current and voltage values change as follows:</u>
	C13-1	Measured impedance is in stage Z load
	C14	Protection releated function RREC of IED_CONT changes to status 'not in Progess'. Deactivation of reclosure is reported to IED_Station.
Postconditions:	**Po1**	<u>The process is simulated as follows:</u>
	Po1-1	Busbar and feeder are energized; circuit breaker QA1 is closed
	Po1-2	Measured impedance is in stage Z load
	Po2	<u>The IEDs have the following status:</u>
	Po2-1	Protection of IED_PROT is in status 'ON'
	Po2-2	Protection related function RREC of IED_CONT is in status 'ON'
	Po2-3	Protection of IED_PROT is not activated.
Notes:		none

6.3.4 Permanent 1phase fault with AR [UC AC03]

Use case name:	Permanent 1phase fault with AR 1shot
Use case id:	[UC AC03]
Version:	1.00
Goal:	Fault clearance in case of transient 1phase fault with unsuccessful AR 1shot
Summary:	Permanet 1phase fault is clearified with execution of autoreclosure. Breaker QA1 is tripped by IED_PROT, reclosed by IED_CONT and retripped by IED_PROT.
Actors:	IED_PROT, IED_CONT, IED_Station
Sequence chart:	Figure 6-6

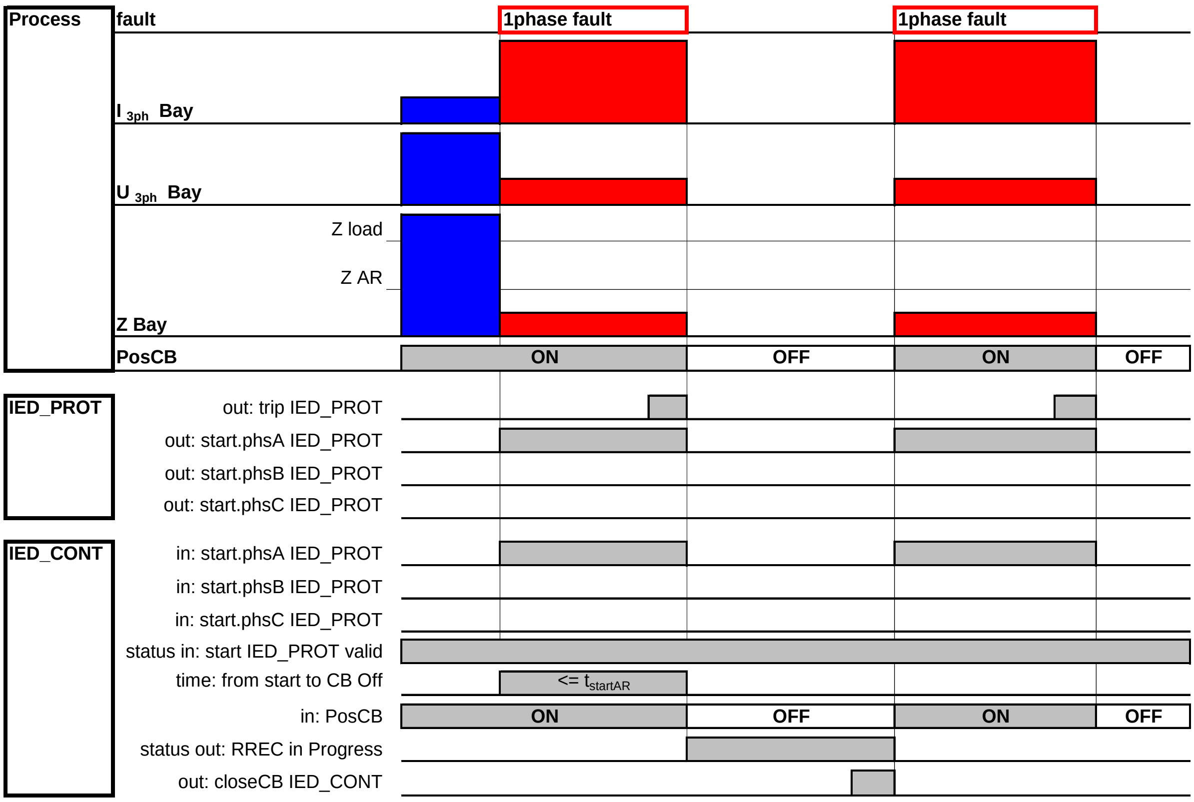


Figure 6-6 AR Coordination – Sequence chart [UC AC03] Permanent 1phase fault with AR

Preconditions:	**Pr1**	Test system is installed and in operation according description in paragraph 6.1
	Pr2	The process is simulated as follows:
	Pr2-1	Busbar and feeder are energized; circuit breaker QA1 is closed
	Pr2-2	Measured impedance is in stage Z load
	Pr3	The IEDs have the following status:
	Pr3-1	Protection of IED_PROT is in status 'ON'
	Pr3-2	Protection related function of IED_CONT is in status 'ON'
	Pr3-3	Protection of IED_PROT is not activated.
	Pr4	The communication has the following status:
	Pr4-1	All communication connections are established and have status OK.

Triggers:	**T1**	Permanent 1 phase fault occurs in feeder Bay.
Course of events:		See sequence chart Figure 6-6
	C1	Measured currents and voltages of Bay change to fault values
	C1-1	Measured impedance of Bay decreases to stage Z_AR.
	C2	Start of PDIS Z_AR of IED_PROT is activated. Activation of start is reported to IED_Station.
	C3	Start of PDIS Z_AR is transferred to IED_CONT.
	C4	Since IED_CONT detects 1 phase fault in forward direction, start logic AR measures elapsing time from start of protection IED_PROT to expected opening of circuit breaker.
	C5	When time delay t_{Z_AR} of IED_PROT is lapsed, QA1 is tripped by IED_PROT. Tripping is reported to IED_Station.
	C6	Circuit Breaker position changes to 'OFF'.
	C7	Measured currents and Voltages change to following values:
	C7-1	Measured current of Bay is zero.
	C7-2	Measured voltage of Bay is zero.
	C8	Elapsed time from start of protection IED_PROT to opening of circuit breaker is processed by start logic AR of IED_CONT. Since elapsed time is less than parameter t_{Start_AR}, autoreclosure is started.
	C9	Protection releated function RREC of IED_CONT changes to status 'in Progess'. Status change to 'in Progess' is reported to IED_Station.
	C10	Start and trip of PDIS Z_AR of IED_PROT are deactivated. Deactivation of start and trip is reported to IED_Station.
	C11	When time delay $t_{1\ 1ph}$ of IED_CONT is lapsed, QA1 of Bay is reclosed by IED_CONT. Reclosure is reported to IED_Station.
	C12	Circuit Breaker position changes to 'ON'.
	C13	Measured currents and voltages of Bay change to fault values:
	C13-1	Measured impedance of Bay decreases to stage Z_AR.
	C14	Start of PDIS Z_AR of IED_PROT is activated. Activation of start is reported to IED_Station.
	C15	Start of PDIS Z_AR is transferred to IED_CONT. Since autoreclosure is configured for only one shot the restart of logic start AR is blocked by reclaim time $t_{reclaim}$.
	C16	When time delay t_{Z_AR} of IED_PROT is lapsed, QA1 of Bay is tripped by IED_PROT. Tripping is reported to IED_Station. Protection releated function RREC of IED_CONT does not change to status 'in Progress', since start of autoreclosure is blocked by reclaim time $t_{reclaim}$.
	C17	Measured currents and voltages change to following values:
	C17-1	Measured current of Bay is zero.
	C17-2	Measured voltage of Bay is zero.
	C18	Start and trip of PDIS Z_AR of IED_PROT are deactivated. Deactivation of start and trip is reported to IED_Station.
	C19	When reclaiming time of Protection releated function RREC is lapsed, RREC is ready for next autoreclosure.
Postconditions:	**Po1**	The process is simulated as follows:

Po1-1	busbar is energized
Po1-2	feeder is deenergized; circuit breaker Bay 1 QA1 is open
Po1-3	Measured currents and voltages of Bay are zero
Po2	<u>The IEDs have the following status:</u>
Po2-1	Protection of IED_PROT is in status ‘ON’
Po2-2	Protection related function of IED_CONT is in status ‘ON’
Po2-3	Protection of IED_PROT is not activated

Notes: none

6.3.5 Transient 1phase fault – communication disturbed [UC AC04]

Use case name: Transient 1phase fault – communication of protection device is disturbed

Use case id: [UC AC04]

Version: 1.00

Goal: Fault clearance in case of transient 1phase fault without AR caused by disturbed communication

Summary: Transient 1phase fault is cleared without execution of autoreclosure. Breaker Bay QA1 is tripped by IED_PROT and not reclosed by IED_CONT.

Actors: IED_PROT, IED_CONT, IED_Station

Sequence chart: Figure 6-7

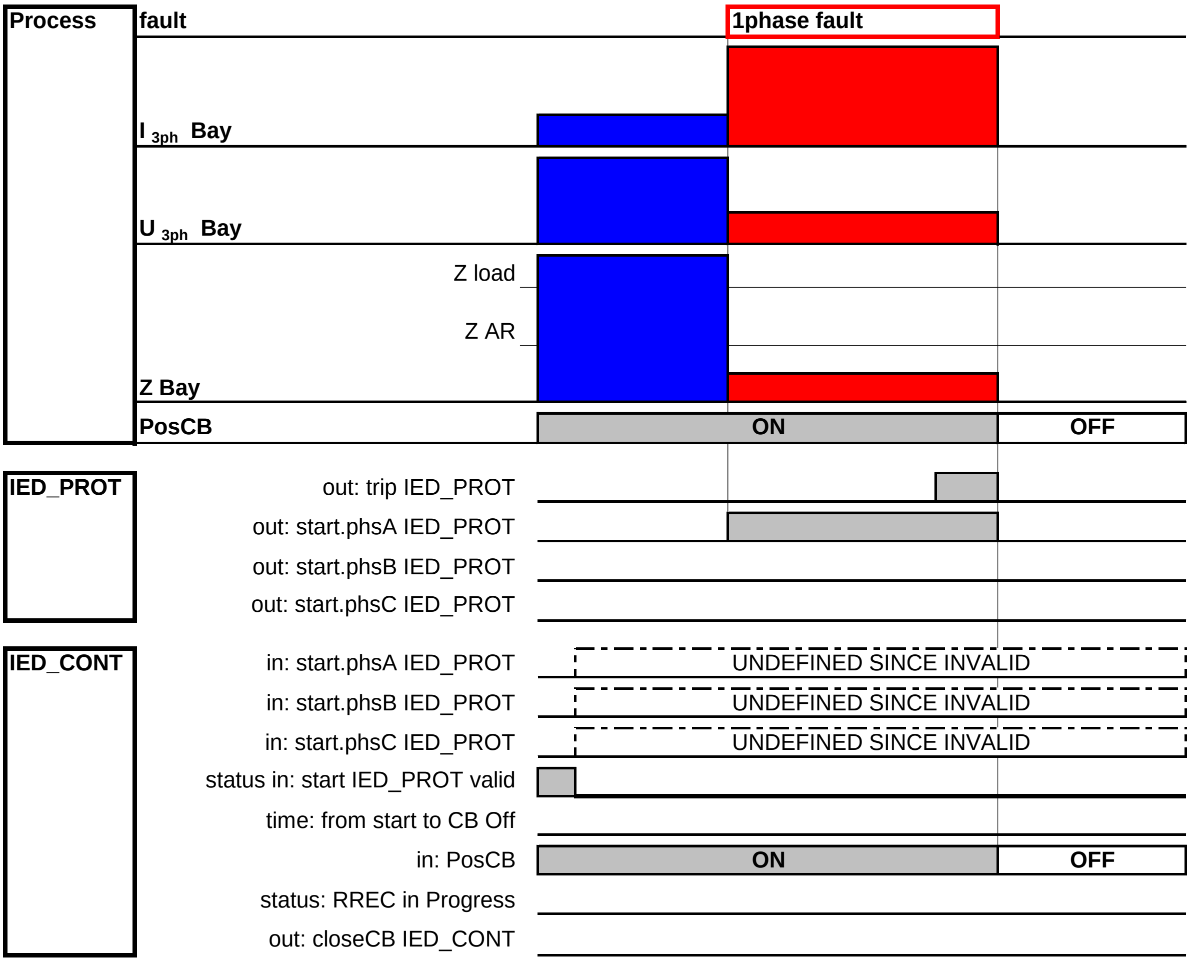


Figure 6-7 AR Coordination – Sequence chart [UC AC04] Transient 1phase fault –communication disturbed

Preconditions:

Pr1 Test system is installed and in operation according description in paragraph 6.1

Pr2 <u>The process is simulated as follows:</u>

Pr2-1 Busbar and feeder are energized; circuit breaker Bay QA1 is closed

Pr2-2 Measured impedance of Bay is in stage Z load

Pr3 <u>The IEDs have the following status:</u>

Pr3-1 Protection of IED_PROT is in status 'ON'

Pr3-2 Protection related function RREC of IED_CONT is in status 'ON'

	Pr3-3	Protection of IED_PROT is not activated.
	Pr4	The communication has the following status:
	Pr4-1	All communication connections to network are established and have status OK except communication connection IED_PROT.
	Pr4-2	Communication connection IED_PROT to network is interrupted. IED_PROT.startAR.GOOSEvalid is FALSE
Triggers:	**T1**	Transient 1 phase fault occurs in feeder Bay.
Course of events:		See sequence chart Figure 6-7
	C1	Measured currents and voltages of Bay change to fault values:
	C1-1	Measured impedance of Bay decreases to stage Z_AR.
	C2	Start of PDIS Z_AR of IED_PROT is activated. Activation of start is reported to IED_Station.
	C3	Start of PDIS Z_AR is **NOT** transferred to IED_CONT because of disturbed communication.
	C4	Start logic AR of IED_CONT is blocked because of invalid communication.
	C5	When time delay t_{Z_AR} of IED_PROT is lapsed, QA1 of Bay is tripped by IED_PROT. Tripping is reported to IED_Station.
	C6	Circuit Breaker position changes to 'OFF'.
	C7	Measured currents and voltages change to the following values:
	C7-1	Measured current of Bay is zero.
	C7-2	Measured voltage of bay is zero.
	C8	Start and trip of PDIS Z_AR of IED_PROT are deactivated. Deactivation of start and trip is reported to IED_Station.
Postconditions:	**Po1**	The process is simulated as follows:
	Po1-1	Busbar is energized.
	Po1-2	Feeder is not energized; circuit breaker Bay QA1 is open.
	Po2	The IEDs have the following status:
	Po2-1	Protection of IED_PROT is in status 'ON'
	Po2-2	Protection related function RREC of IED_CONT is in status 'ON'
	Po2-3	Protection of IED_PROT is not activated.
Notes:		none

6.4 Requirements

6.4.1 Interfaces

The following tables define type and quantity of interfaces per IED. This definition is the base for system design and system engineering – defining type and quantity of interaction between process and system components in principle.

Table 6-2 defines the interface between process and IEDs.
Table 6-3 defines IEC 61850 based client server communication between IEDs.
Table 6-4 defines IEC 61850 based GOOSE communication between IEDs.

Table 6-2 AR Coordination – Process interface

Data	**IED_PROT**	**IED_CONT**
Current input 3phase Bay BE1	AI	
Voltage input 3phase Bay BE5	AI	
Trip Bay QA1	BO	
Reclose Bay QA1		BO
Position Circuit Breaker Bay QA1		BI

Table 6-3 AR Coordination – Communication interface IEC 61850 Client / Server

Use case Data	**IEC 61850 data**				**IED_PROT**	**IED_CONT**	**IED_Station**
	IED_LD	**LN**	**Data**	**CDC**			
IED_PROT Start PDIS Z_AR	<IED_PROT><LD>	PDIS	Str	ACD	Server reporting		Client
IED_PROT Trip PDIS Z_AR	<IED_PROT><LD>	PDIS	Op	ACT	Server reporting		Client
IED_PROT Status PDIS Z_AR	<IED_PROT><LD>	PDIS	Beh	INS	Server reporting		Client
IED_CONT Operate RREC	<IED_CONT><LD>	RREC	Op	ACT		Server reporting	Client
IED_CONT AR status RREC	<IED_CONT><LD>	RREC	AutoRecSt	INS		Server reporting	Client
IED_CONT Status RREC	<IED_CONT><LD>	RREC	Beh	INS		Server reporting	Client
IED_CONT Pos XCBR	<IED_CONT><LD>	XCBR	Pos	DPC		Server reporting	Client

Table 6-4 AR Coordination – Communication interface IEC 61850 GOOSE

Use case Data	IEC 61850 data					IED_PROT	IED_CONT
	IED_LD	**LN**	**Data**	**Attribute**	**CDC/ Type**		
IED_PROT. start	<IED_PROT><LD>	PDIS	Str	general	ACD/ BOOLEAN	GOOSE publisher	GOOSE subscriber
				dirGeneral	ACD/ ENUMERATED		
				phsA	ACD/ BOOLEAN		
				dirPhsA	ACD/ ENUMERATED		
				phsB	ACD/ BOOLEAN		
				dirPhsB	ACD/ ENUMERATED		
				phsC	ACD/ BOOLEAN		
				dirPhsC	ACD/ ENUMERATED		
				neut	ACD/ BOOLEAN		
				DirNeut	ACD/ ENUMERATED		
				q	ACD/ Quality		

6.4.2 Performance

The overall delay time of transfer time for starting signal IED_PROT.start from IED_PROT to IED_CONT and activation of starting logic AR of IED_CONT has to be 50ms maximum.

7 Test Case - Busbar Voltage Replica

7.1 Description

The busbar voltage is required as process information for the substation and bay control level. Furthermore, it is used as reference value for the synchrocheck function.
The function "busbar voltage replica" (BVR) is required in substations where the busbars do not have their own voltage transformers.
The function simulates virtual busbar voltages from the feeder voltages physically measured in the bays. To this end, a logic integrated in the substation automation system selects a reference bay for each busbar or busbar section. This reference bay is topologically connected to the busbar or busbar section. This feeder voltage is logically used as the corresponding busbar voltage.
The BVR in combination with the "distributed synchrocheck" function selects the reference bay whose voltage transformer circuits are connected galvanically to a reference voltage bus of the busbar section.
The following information is required for the BVR sequence:

- Status information of switchgear positions
- Measured voltage values

The logic for the busbar voltage replica function is usually integrated in the substation unit or in the dedicated bay unit. The bay units of the outgoing feeder bays provide position indications of the switchgear and measured voltage values for the substation unit.

Figure 7-1 shows the configuration of the busbar voltage replica function. The logic for the busbar voltage replica function is integrated in the substation unit, represented by the CLIENT device. The CLIENT features two internal virtual busbar voltage measurements U_{3ph}(BB1) and U_{3ph}(BB2). Each IED has binary inputs acquiring positions of disconnectors and circuit breakers for the determination whether the bay is topologically connected to a busbar. Further each IED has analogue inputs for acquisition of line voltages U_{3ph}. IED_NC represents an IED of a bay, which is topologically not connected to a busbar, hence it is not suited for providing a valid virtual busbar voltage. IED_REF represents the IED which is selected to deliver the reference voltage, and IED_NS represents an IED which could provide the reference voltage, but is not selected to deliver it.

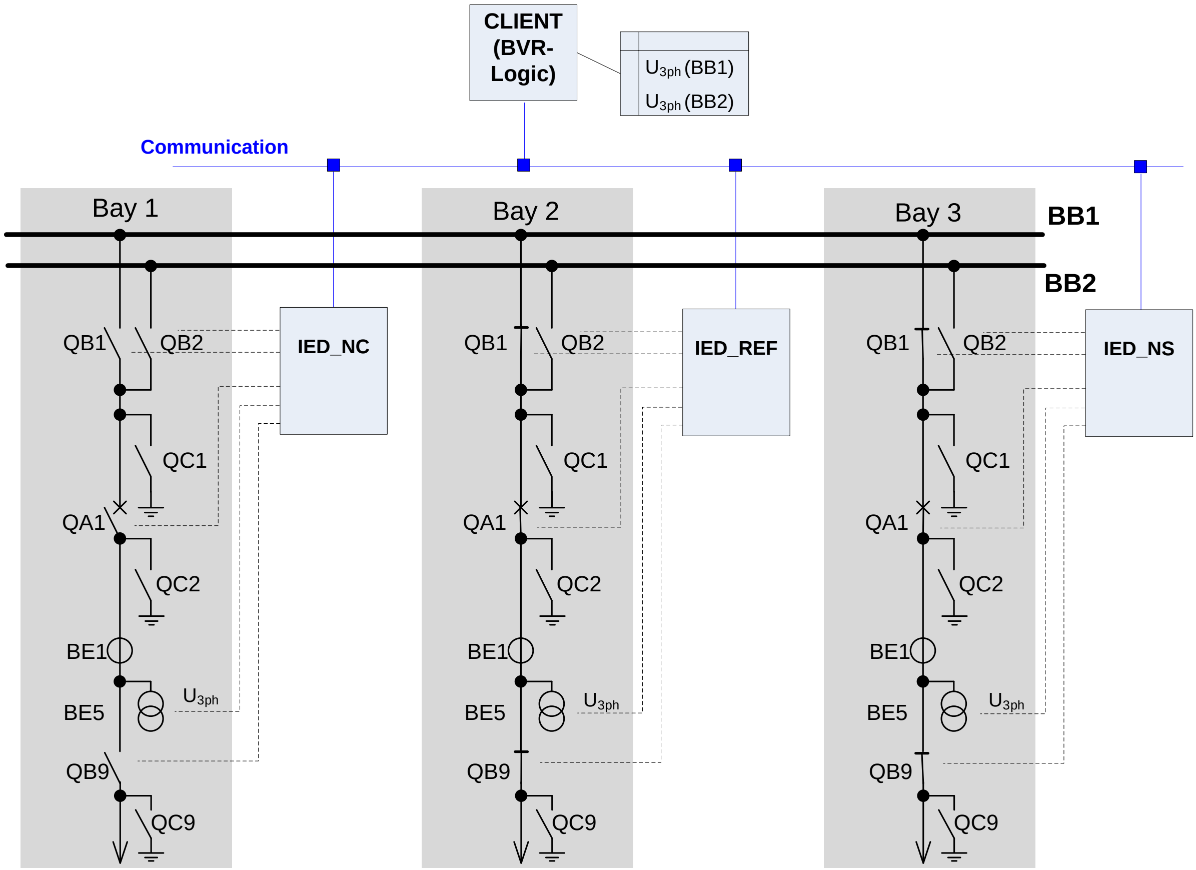


Figure 7-1 Busbar Voltage Replica – system overview

7.2 Configuration

Not applicable.

7.3 Use Cases

7.3.1 Busbar Voltage Replica – Energized Busbar [UC BVR1]

Use case name: Selection of bay voltage as virtual busbar voltage

Use case id: [UC BVR1]

Version: 1.00

Goal: Selection and use of bay voltage measurements of IED_REF to represent virtual busbar voltage

Summary: The CLIENT identifies Bay 2 as the first feeder bay which is topologically connected to the busbar section and assigns its voltage measurements aquired by IED_REF to the virtual busbar voltage measurements of the CLIENT.

Actors: USER, IED_NC, IED_REF, IED_NC, CLIENT

Preconditions:

Pr1 Test system is installed and in operation according to paragraph 7.1.

Pr2 The system is in normal operation mode.

Pr3 All IEDs are in remote control mode

Pr4 The process is simulated as follows:

Pr4-1 All switchgears of Bay 1 are open

Pr4-2 Switchgears QB1, QB9 of Bay 2 are closed, QA1 is open

Pr4-3 Busbar BB1 is energized, switchgears QB1, QA1, QB9 of Bay 3 are closed

Pr4-4 Line voltages U_{3ph} of Bay 1 are 0 V

Pr4-5 Line voltages U_{3ph} of Bay 2 and Bay 3 have nominal value

Triggers:

T1 Circuit breaker QA1 of Bay 2 is closed by remote USER request

Course of events:

C1 See flowchart in Figure 7-2
Circuit breaker QA1 of Bay 2 is closed by remote USER request

C2 CLIENT starts calculation of virtual busbar voltage U_{3ph}(BB1) according to flowchart:

C2-1 CLIENT identifies Bay 2 as topologically connected to busbar BB1

C2-2 CLIENT assigns bay voltage of IED_REF to virtual busbar voltage U_{3ph}(BB1)

C5 CLIENT stops calculation

Postconditions:

Po1 Circuit breaker QA1 of Bay 2 is closed

Po2 All IEDs are in normal operation mode, no output operation (protection function or switching operation) is running

Notes: As an automatic function the BVR should run permanently in the background of the substation automation system without being activated by the operating staff. The calculation of the BVR logic should be triggered either cyclically or when one of the input information changes

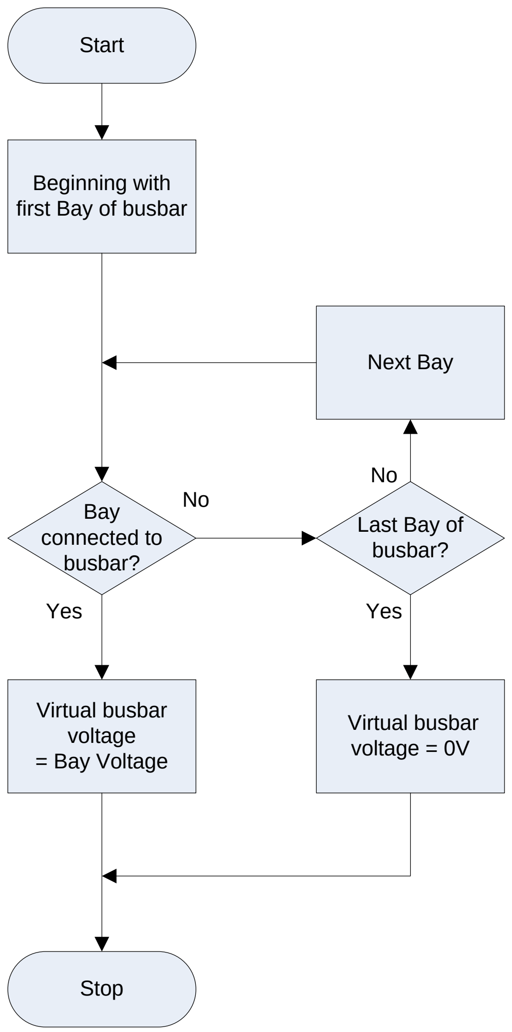


Figure 7-2 Busbar Voltage Replica – flowchart

Note: "first", "next", "last" bay - according bay numbering

7.3.2 Busbar Voltage Replica – Dead Busbar [UC BVR2]

Use case name:	Assignment of virtual busbar voltage in case of dead busbar
Use case id:	[UC BVR2]
Version:	1.00
Goal:	Identification of a dead busbar and assignment of value 0 V as virtual busbar voltage measurement
Summary:	The CLIENT identifies that no bay is topologically connected to the busbar. Hence the CLIENT assigns the value 0 V as virtual busbar voltage.
Actors:	USER, IED_NC, IED_REF, IED_NC, CLIENT

Preconditions:	**Pr1**	Test system is installed and in operation according paragraph 7.1.
	Pr2	The system is in normal operation mode.
	Pr3	All IEDs are in remote control mode
	Pr4	The process is simulated as follows:
	Pr4-1	All switchgears of Bay 1, 2 are open
	Pr4-2	Busbar BB1 is energized, switchgears QB1, QA1, QB9 of Bay 3 are closed

	Pr4-3	Line voltages U_{3ph} of Bays 1, 2 are 0 V
	Pr4-4	Line voltages U_{3ph} of Bay 3 have nominal value
Triggers:	**T1**	Circuit breaker QA1 of Bay 3 is opened by remote USER request
Course of events:	**C1**	Circuit breaker QA1 of Bay 3 is opened by remote USER request
	C2	CLIENT starts calculation of virtual busbar voltage U_{3ph}(BB1) according to flowchart:
	C2-1	CLIENT identifies determined that no bay is topologically connected to busbar BB1
	C2-2	CLIENT assigns value of 0 V to virtual busbar voltage U_{3ph}(BB1)
	C3	CLIENT stops calculation
Postconditions:	**Po1**	Circuit breaker of Bay 3 is open
	Po2	All IEDs are in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

7.4 Requirements

7.4.1 Interfaces

Table 7-1 Busbar Voltage Replica – Process interface

Data	IED_NC	IED_REF	IED_NS
Voltage input 3phase (U3ph) Bay 1	AI		
Voltage input 3phase (U3ph) Bay 2		AI	
Voltage input 3phase (U3ph) Bay 3			AI
Binary Input Bay 1: QB1, QB2, QA1, QB9	BI		
Binary Input Bay 2: QB1, QB2, QA1, QB9		BI	
Binary Input Bay 3: QB1, QB2, QA1, QB9			BI
Command Output Bay 1 QA1	BO		
Command Output Bay 2 QA1		BO	
Command Output Bay 3 QA1			BO

Table 7-2 Busbar Voltage Replica – Communication interface IEC 61850 Client/Server–Status Information

Use case Data	IEC 61850 Data				IED_x	CLIENT
	IED_LD	**LN**	**Data**	**CDC**		
IED_x Position of QA1	<IED_x><LD>	XCBR1	Pos	DPC	Server reporting	Client
IED_x Position of QB1	<IED_x><LD>	XSWI1	Pos	DPC	Server reporting	Client
IED_x Position of QB2	<IED_x><LD>	XSWI2	Pos	DPC	Server reporting	Client
IED_x Position of QB9	<IED_x><LD>	XSWI3	Pos	DPC	Server reporting	Client
IED_x Voltage measurements	<IED_x><LD>	MMXU1	PPV	DEL	Server reporting	Client
IED_x Voltage measurements	<IED_x><LD>	MMXU1	PhV	WYE	Server reporting	Client
IED_x Request for closing/opening QA1	<IED_x><LD>	CSWI1	Pos	DPC	Control object CB	SBO Ctrl. with enhanced security

IEDx: IED_NC, IED_REF, IED_NS

Note: XSWI is used instead of CSWI in order to detect intermediate status of switchgear for representing potential unavailability of BVR function.

7.4.2 Performance Requirements

The time requirements are uncritical. Response times below 1 second are sufficient.

8 Test Case - Switching with synchrocheck function

8.1 Description

The synchrocheck function is used when connecting two network sections or when energizing during normal operation. It ensures that the connection is only performed if both network sections are synchronous to each other or the deviation lies within defined limits. The connection is performed if the following conditions are met at the moment of establishing the galvanic connection:

- Voltage magnitudes Umin < | U |< Umax
- Difference of the voltage magnitudes | ΔU | < ΔUmax
- Frequencies fmin ≤ f ≤ fmax
- Difference of frequencies Δf < Δfmax
- Difference of voltage phase angles Δα < Δαmax

A check of the synchronism conditions can be performed by the comparison of bay and a reference voltage, typically the voltage of the busbar, to which the bay should be connected. The reference voltage is either fixed connected to the IED (e.g. fed by a busbar VT), or is connected via relay during the runtime of the synchrocheck function.
The synchrocheck with reference voltage connection during runtime is necessary e.g. for multiple busbars or in case of a failure of the coupling circuit breaker (backup circuit). The busbar voltage replica function (BVR) is usually used to provide the reference voltage. The synchrocheck with reference voltage connection during runtime comprises the following partial functions:

- Connection of the reference voltage
- Synchronous switching / parallel switching
- Reference voltage de-selection

The synchrocheck with connection during runtime is carried out by the IED of the bay to be connected.

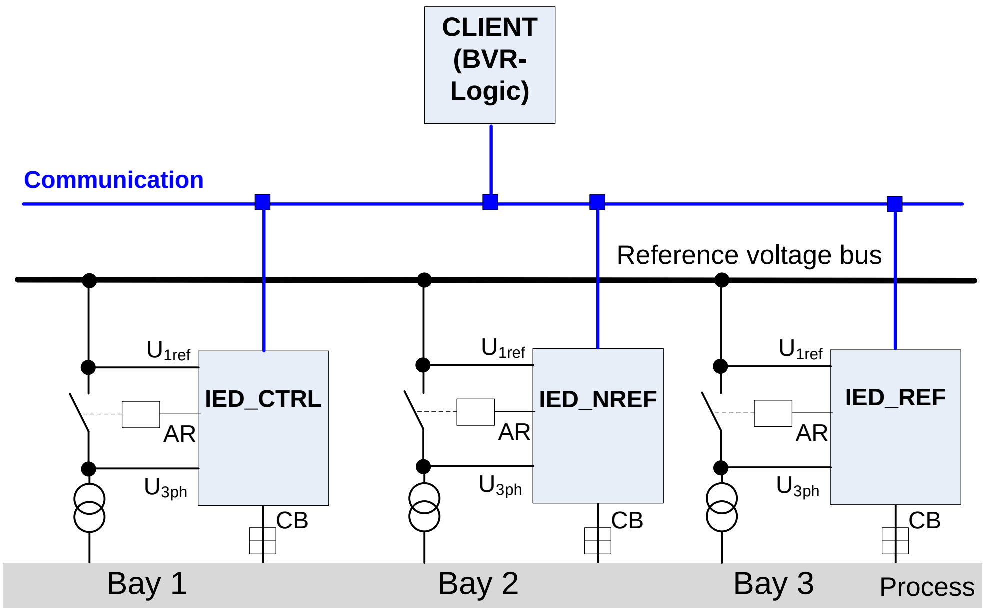


Figure 8-1 Distributed synchrocheck function – system overview

Figure 8-1 shows the configuration of the distributed synchrocheck function using a reference voltage bus. Each IED has analogue inputs for line voltages U_{3ph} and a reference voltage U_{1ref}. Furthermore, each IED has a binary output for the control of the auxiliary relay AR, and a command output CB for circuit breaker control. IED_CTRL represents the IED which is intended to perform the synchronous switching of its circuit breaker, IED_REF represents the IED which is selected to deliver the reference voltage, and IED_NREF represents an IED which is not selected to deliver the reference voltage.

8.2 Configuration

Table 8-1 shows the required configuration for the distributed synchrocheck function.

Table 8-1 Switching with synchrocheck function – Configuration

Parameter	IED_CTRL	IED_NREF	IED_REF
Umin, Umax, ΔUmax, fmin, fmax, Δfmax, Δαmax	x		

8.3 Use Cases

8.3.1 Successful Switching with Synchrocheck [UC SC1]

Use case name: Successful Synchrocheck switching with reference voltage connection during runtime

Use case id: [UC SC1]

Version: 1.00

Goal: Successful closing of bay circuit breaker

Summary: Successful closing of bay circuit breaker by IED_CTRL after successful checking of synchronism conditions by use of reference voltage connection during runtime.

Actors: USER, IED_CTRL, IED_REF, CLIENT (SCADA)

Preconditions:

Pr1 Test system is installed and in operation according paragraph 8.1.

Pr2 The system is in normal operation mode

Pr3 IED_CTRL is in remote control mode

Pr4 The process is simulated as follows:

Pr4-1 Busbar is energized, circuit breaker of Bay 3 is closed

Pr4-2 Circuit breakers of Bay 1 and Bay 2 are open

Pr4-3 Line voltages U_{3ph} of Bays 1, 2, 3 have nominal value

Pr4-4 Auxiliary relays AR of all IEDs are open

Triggers:

T1 Remote circuit breaker closing request by user

Course of events:

C1 USER requests CLIENT to close circuit breaker of Bay 1 with synchrocheck function

C1-1 Client requests IED_CTRL to close bay circuit with synchrocheck function by remote control of IED_CTRL

C1-2 IED_CTRL confirms CLIENT request

C2 IED_CTRL activates reference voltage connection

	C2-1	IED_CTRL requests CLIENT for reference voltage connection
	C2-2	CLIENT requests IED_REF to connect voltage of phase AB to reference bus by closing the auxiliary relay AR.
	C2-3	IED_REF closes auxiliary relay AR
	C2-4	IED_REF confirms CLIENT that auxiliary relay AR is closed
	C2-5	CLIENT confirms IED_CTRL that reference voltage is connected to reference bus
	C3	IED_CTRL checks synchronism conditions
	C4	IED_CTRL closes bay circuit breaker after successful check of synchronism
	C5	IED_CTRL reports CLIENT end of checking synchronism
	C5-1	CLIENT requests IED_REF to disconnect voltage of phase AB to reference bus by opening the auxiliary relay AR.
	C5-2	IED_REF opens auxiliary relay AR
	C5-3	IED_REF confirms CLIENT that auxiliary relay AR is open
	C6	CLIENT reports USER successful switching operation
Postconditions:	**Po1**	Circuit breaker of Bay 1 is closed
	Po2	All IEDs are in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

8.3.2 Unsuccessful Switching with Synchrocheck – Check of Synchronism Conditions fails [UC SC2]

Use case name:	Unsuccessful Synchrocheck switching because of failed check of synchronism conditions
Use case id:	[UC SC2]
Version:	1.00
Goal:	Abortion of synchrocheck procedure
Summary:	The synchrocheck procedure is aborted due to the fact that the check of the synchronism conditions failed
Actors:	USER, IED_CTRL, IED_REF, CLIENT

Preconditions:	**Pr1**	Test system is installed and in operation according paragraph 8.1.
	Pr2	The system is in normal operation mode.
	Pr3	IED_CTRL is in remote control mode
	Pr4	The process is simulated as follows:
	Pr4-1	Busbar is energized, circuit breaker of Bay 3 is closed
	Pr4-2	Circuit breakers of Bay 1 and Bay 2 are open
	Pr4-3	Line voltages U_{3ph} of Bays 1, 2 have nominal value
	Pr4-4	Line voltages U_{3ph} of Bay 3 have values beyond Umin
	Pr4-5	Parameter Umin of IED_CTRL is set to a value beyond nominal value
	Pr4-6	Auxiliary relays AR of all IEDs are open

Triggers:	**T1**	Remote circuit breaker closing request by user
Course of events:	**C1**	USER requests CLIENT to close circuit breaker of Bay 1 with synchrocheck function
	C1-1	Client requests IED_CTRL to close bay circuit with synchrocheck function by remote control of IED_CTRL
	C1-2	IED_CTRL confirms CLIENT request
	C2	IED_CTRL activates reference voltage connection
	C2-1	IED_CTRL requests CLIENT for reference voltage connection
	C2-2	CLIENT requests IED3 to connect voltage of phase AB to reference bus by closing the auxiliary relay AR.
	C2-3	CLIENT confirms IED_CTRL that reference voltage is connected to reference bus
	C3	IED_CTRL checks synchronism conditions
	C3-1	IED_CTRL reports CLIENT that synchrocheck is running
	C3-2	Voltage magnitude of reference voltage U_{1ref} is below minimum value Umin for meeting of synchronism condition
	C3-3	IED_CTRL reports CLIENT violation of voltage difference
	C4	IED_CTRL does not close bay circuit breaker
	C4-1	IED_CTRL reports CLIENT that close command is not released
	C5	IED_CTRL reports CLIENT end of checking synchronism
	C5-1	IED_CTRL reports CLIENT that synchrocheck is faulted
	C5-2	CLIENT requests IED_REF to disconnect voltage of phase AB to reference bus by opening the auxiliary relay AR.
	C5-3	IED_REF opens auxiliary relay AR
	C5-4	IED_REF confirms CLIENT that auxiliary relay AR is open
	C6	CLIENT reports USER unsuccessful switching operation
Postconditions:	**Po1**	Circuit breaker of Bay 1 is open
	Po2	All IEDs are in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

8.3.3 Unsuccessful Switching with Synchrocheck – Missing Reference Voltage [UC SC3]

Use case name: Unsuccessful synchrocheck switching because of missing reference voltage

Use case id: [UC SC3]

Version: 1.00

Goal: Abortion of synchrocheck procedure

Summary: The synchrocheck procedure is aborted due to the fact that there is no reference voltage available

Actors: User, IED_CTRL (CB Operation Bay), IED2, IED3 (Reference Bay), Client

Preconditions:	**Pr1**	Test system is installed and in operation according paragraph 8.1.
	Pr2	The system is in normal operation mode.
	Pr3	IED_CTRL is in remote control mode
	Pr4	<u>The process is simulated as follows:</u>
	Pr4-1	Busbar is not energized, circuit breakers of Bays 1, 2, 3 are open
	Pr4-2	Line voltages U_{3ph} of Bays 1, 2, 3 have nominal value
	Pr4-3	Auxiliary relays AR of all IEDs are open
Triggers:	**T1**	Remote circuit breaker closing request by user
Course of events:	**C1**	<u>USER requests CLIENT to close circuit breaker of Bay 1 with synchrocheck function</u>
	C1-1	Client requests IED_CTRL to close bay circuit with synchrocheck function by remote control IED_CTRL
	C1-2	IED_CTRL confirms CLIENT request
	C2	<u>IED_CTRL activates reference voltage connection</u>
	C2-1	IED_CTRL requests CLIENT for reference voltage connection
	C2-2	CLIENT identifies that no reference voltage is available
	C2-3	CLIENT informs IED_CTRL that no reference voltage is available
	C3	IED_CTRL does not close bay circuit breaker
	C4	IED_CTRL reports CLIENT end of checking synchronism
	C5	CLIENT reports USER unsuccessful switching operation
Postconditions:	**Po1**	Circuit breaker of Bay 1 is open
	Po2	All IEDs are in normal operation mode, no output operation (protection function or switching operation) is running
Notes:		none

8.4 Requirements

8.4.1 Interfaces

Table 8-2 Switching with synchrocheck function – Process interface

Data	IED_CTRL	IED_NREF	IED_REF
Voltage input 3phase (U3ph) Bay 1	AI		
Voltage input 3phase (U3ph) Bay 2		AI	
Voltage input 3phase (U3ph) Bay 3			AI
Voltage input 1phase (U1ref) Bay 1	AI		
Voltage input 1phase (U1ref) Bay 2		AI	
Voltage input 1phase (U1ref) Bay 3			AI
Binary Output (AR) Bay 1 QA1	BO		
Binary Output (AR) Bay 2 QA1		BO	
Binary Output (AR) Bay 3 QA1			BO
Command Output (CB) Bay 1 QA1	BO		
Command Output (CB) Bay 2 QA1		BO	
Command Output (CB) Bay 3 QA1			BO

Table 8-3 Switching with synchrocheck function – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 Data				IED_CTRL	IED_REF	CLIENT
	IED_LD	LN	Data	CDC			
IED_CTRL Request for closing QA1	<IED_CTRL><LD>	CSWI1	Pos	DPC	Control object CB		SBO Ctrl. with enh. security
IED_CTRL Request for Ref. Volt. connection	<IED_CTRL><LD>	GGIO1	SPCSO1	SPC	Server reporting		Client
IED_CTRL confirmation of ref. voltage connection	<IED_CTRL><LD>	GGIO1	SPCSO2	SPC	Control object		SBO Ctrl. with enh. security
IED_REF Req. for closing aux. relay AR	<IED_REF><LD>	GGIO2	SPCSO1	SPC		Control object AR	SBO Ctrl. with enh. security
IED_REF Status of aux. relay AR	<IED_REF><LD>	GGIO2	SPCSO1	SPC		Server reporting	Client
IED_CTRL Synchrocheck running	<IED_CTRL><LD>	RSYN1	SynPrg	SPS	Server reporting		Client

Use case Data	IEC 61850 Data				IED_CTRL	IED_REF	CLIENT
	IED_LD	LN	Data	CDC			
IED_CTRL Synchronization faulted	<IED_CTRL><LD>	RSYN1	Health	INS	Server reporting		Client
IED_CTRL Release close command	<IED_CTRL><LD>	RSYN1	Rel	SPS	Server reporting		Client
IED_CTRL Violation of voltage difference	<IED_CTRL><LD>	RSYN1	VInd	SPS	Server reporting		Client
IED_CTRL Violation of angle difference	<IED_CTRL><LD>	RSYN1	AngInd	SPS	Server reporting		Client
IED_CTRL Violation of frequency difference	<IED_CTRL><LD>	RSYN1	HzInd	SPS	Server reporting		Client
IED_CTRL Voltage difference	<IED_CTRL><LD>	RSYN1	DifVClc	MV	Server reporting		Client
IED_CTRL Angle difference	<IED_CTRL><LD>	RSYN1	DifAngClc	MV	Server reporting		Client
IED_CTRL Frequency difference	<IED_CTRL><LD>	RSYN1	DifHzClc	MV	Server reporting		Client

Note: GGIO has to be used because for BVR no semantic correct LN is defined in IEC 61850.

8.4.2 Performance Requirements

The time requirements are uncritical. Response times below 1 second are sufficient if the switching operation is triggered by a user.

9 Test Case - Substation Supervision

9.1 Description

Substation supervision is used to report the current status of the primary and secondary equipment to local SCADA systems and control centers. In case of changes of any important status this is spontaneously reported to SCADA and control centers. The following information is typically acquired and reported.

- Status information of switchgear positions
- Indications of warnings and alarms
- Measurement values (voltages, currents, power, frequency)

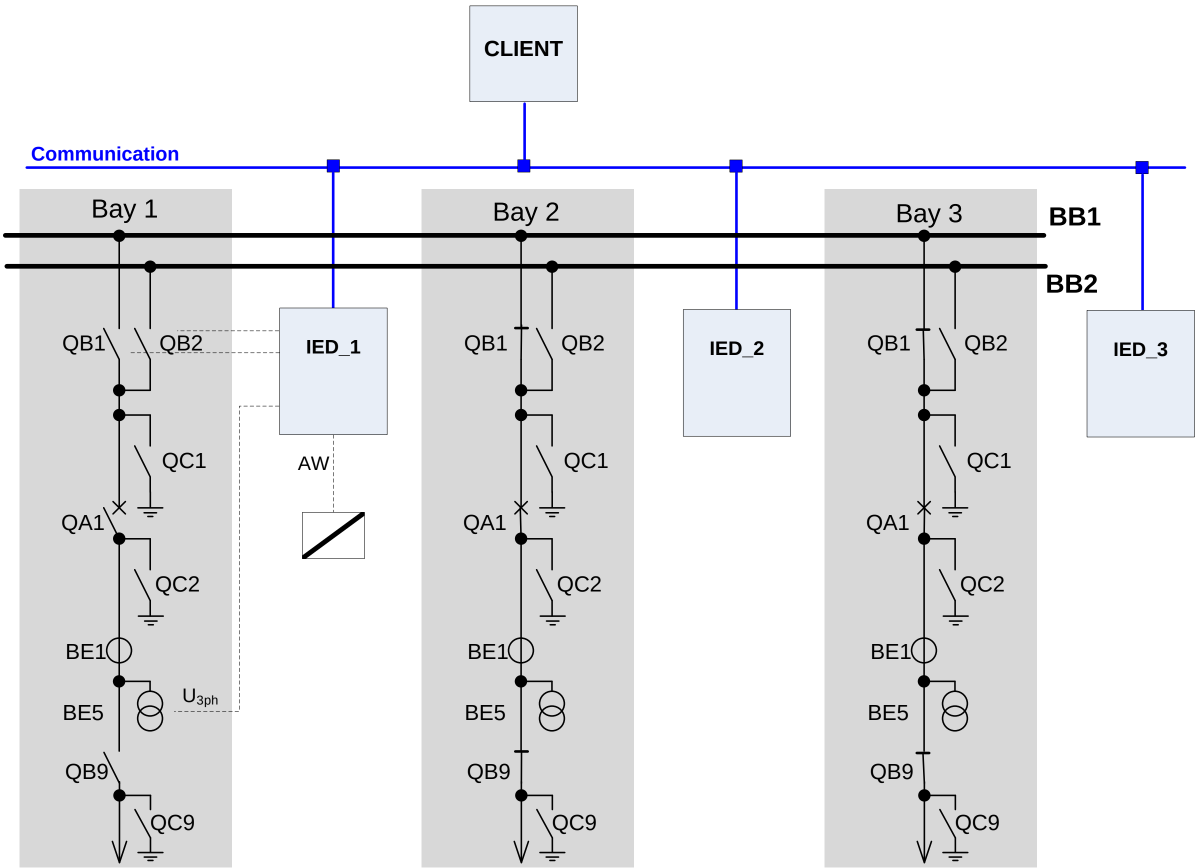


Figure 9-1 Substation Supervision – System overview

Figure 9-1 shows the configuration of a substation automation system featuring supervision function. IED_1 acquires the positions of busbar disconnectors QB1 and QB2, the line voltages U_{3ph} and the indication of an external alarm sensor AW (Alarm/Warning Indication). The information acquired is reported to the CLIENT. This scheme also applies to IED_2 and IED_3.

9.2 Configuration

Not applicable.

9.3 Use Cases

9.3.1 Supervision of status information using buffered reporting [UC SV1]

Use case name: Supervision of status information using buffered reporting

Use case id: [UC SV1]

Version: 1.00

Goal: IED reports status information to CLIENT using buffered reporting

Summary: IED reports spontaneously status to CLIENT using buffered reporting after a status has changed

Actors: IED_1, CLIENT

Preconditions:	**Pr1**	Test system is installed and in operation according paragraph 9.1.
	Pr2	The system is in normal operation mode.
	Pr3	IED_1 is in remote control mode
	Pr4	The process is simulated as follows:
	Pr4-1	Busbar is energized, QB1 and QB2 of Bay 1 are open
	Pr4-2	QB9 of Bay 1 is closed
	Pr4-3	Line voltages U_{3ph} of Bays 1, 2, 3 have nominal value
	Pr4-4	Status of alarm indicator AW is false
Triggers:	**T1**	Status of alarm indicator AW is true
Course of events:	**C1**	Status of alarm indicator changes from false to true status
	C2	IED_1 reports status information of Alarm Indicator to CLIENT using buffered reporting
Postconditions:	**Po1**	Status of alarm indicator AW is true
Notes:		none

9.3.2 Supervision of status information using unbuffered reporting [UC SV2]

Use case name:	Supervision of status information using unbuffered reporting	
Use case id:	[UC SV2]	
Version:	1.00	
Goal:	IED reports status information to CLIENT using unbuffered reporting	
Summary:	IED reports spontaneously status to CLIENT using unbuffered reporting after a status has changed	
Actors:	IED_1, CLIENT	
Preconditions:	**Pr1**	Test system is installed and in operation according paragraph 9.1.
	Pr2	The system is in normal operation mode.
	Pr3	IED_1 is in remote control mode
	Pr4	The process is simulated as follows:
	Pr4-1	Busbar is energized, QB1 of and QB2 of Bay 1 are open
	Pr4-2	QB9 of Bay 1 is closed
	Pr4-3	Line voltages U_{3ph} of Bays 1, 2, 3 have nominal value
	Pr4-4	Status of alarm indicator AW is false
Triggers:	**T1**	Position of disconnector QB1 changes from open to closed
Course of events:	**C1**	Position of disconnector QB1 changes from open to closed by USER request
	C2	IED_1 reports status information of disconnector QB1 to CLIENT using unbuffered reporting
Postconditions:	**Po1**	Position of disconnector QB1 is closed.
Notes:		none

9.3.3 Supervision of measurement information using periodic reporting [UC SV3]]

Use case name:	Supervision of measurement information using periodic reporting
Use case id:	[UC SV3]
Version:	1.00
Goal:	IED reports measurement information to CLIENT using periodic reporting
Summary:	IED reports periodically voltage measurments to CLIENT using periodic reporting
Actors:	IED_1, CLIENT

Preconditions:	**Pr1**	Test system is installed and in operation according paragraph 9.1.
	Pr2	The system is in normal operation mode.
	Pr3	IED_1 is in remote control mode
	Pr4	The process is simulated as follows:
	Pr4-1	Busbar is energized, QB1 of and QB2 of Bay 1 are open
	Pr4-2	QB9 of Bay 1 is closed
	Pr4-3	Line voltages U_{3ph} of Bays 1, 2, 3 have nominal value
	Pr4-4	Status of alarm indicator AW is false
Triggers:	**T1**	runs permanently
Course of events:	**C1**	IED_1 reports voltage measurements to CLIENT using periodic reporting
Postconditions:	**Po1**	equivalent to preconditions
Notes:		none

9.3.4 General interrogation after communication re-establishment [UC SV4]

Use case name:	General interrogation after communication re-establishment
Use case id:	[UC SV4]
Version:	1.00
Goal:	IED reports status and measurement information to CLIENT after communication re-establishment
Summary:	On general interrogation request of CLIENT, IED status and measurement information to CLIENT
Actors:	IED_1, CLIENT

Preconditions:	**Pr1**	Test system is installed and in operation according paragraph 9.1.
	Pr2	The system is in normal operation mode.
	Pr3	IED_1 is in remote control mode
	Pr4	<u>The process is simulated as follows:</u>
	Pr4-1	Busbar is energized, QB1 of and QB2 of Bay 1 are open
	Pr4-2	QB9 of Bay 1 is closed
	Pr4-3	Line voltages U_{3ph} of Bays 1, 2, 3 have nominal value
	Pr4-4	Status of alarm indicator AW is false
	Pr5	Reports are configured for general interrogation
	Pr6	Communication link between IED_1 and CLIENT is broken
Triggers:	**T1**	Communication link between IED_1 and CLIENT is re-established
Course of events:	**C1**	CLIENT requests IED_1 for general interrogation
	C2	<u>IED_1 reports information to CLIENT as follows:</u>
	C2-1	IED_1 reports positions of disconnectors QB1 and QB2 to CLIENT using unbuffered reporting
	C2-2	IED_1 reports status information of Alarm Indicator to CLIENT using buffered reporting
	C2-3	IED_1 reports voltage measurements to CLIENT using periodic reporting
Postconditions:	**Po1**	Communication link between IED_1 and CLIENT is established
Notes:		none

9.4 Requirements

9.4.1 Interfaces

Table 9-1 Substation Supervision – Process interface

Data	IED_1	IED_2	IED_3
Voltage input 3phase (U3ph) Bay 1	AI		
Voltage input 3phase (U3ph) Bay 2		AI	
Voltage input 3phase (U3ph) Bay 3			AI
Binary Input Bay 1: QB1, QB2, AW	BI		
Binary Input Bay 2: QB1, QB2, AW		BI	
Binary Input Bay 3: QB1, QB2, AW			BI

Table 9-2 Substation Supervision – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 Data				IED_1	CLIENT
	IED_LD	LN	Data	CDC		
IED_x Position of QB1	<IED_x><LD>	CSWI1	Pos	DPC	Server reporting	Client
IED_x Position of QB2	<IED_x><LD>	CSWI2	Pos	DPC	Server reporting	Client
IED_x Voltage measurements	<IED_x><LD>	MMXU1	PPV	DEL	Server reporting	Client
IED_x Voltage measurements	<IED_x><LD>	MMXU1	PhV	WYE	Server reporting	Client
IED_x Alarm indication	<IED_x><LD>	CALH	GrAlm	SPS	Server reporting	Client

IEDx: IED_1, IED_2, IED_3

9.4.2 Performance Requirements

The time requirements are uncritical. Response times below 1 second are sufficient.

10 Test Case - Earthfault detection

10.1 Description

In many countries of the EC the "resonant grounding" is one of the most important options in electrical network design to obtain the optimal power supply quality. The main advantage of the treatment of the neutral point is the possibility of continuing the network operation during a sustained earth fault. As a consequence this reduces the number of interruptions of the power supply for the customer.

Up to now, the advantage of transient relays lies in the fact that they are working almost perfect for very low ohmic earth faults with a fault-resistance less than a few ohms, either in isolated or resonant grounded networks.

Combining the transient detection method with stationary methods like directional wattmetric or directional harmonic method gives additional possibilities to locate the earthfault without interrupting the power supply.

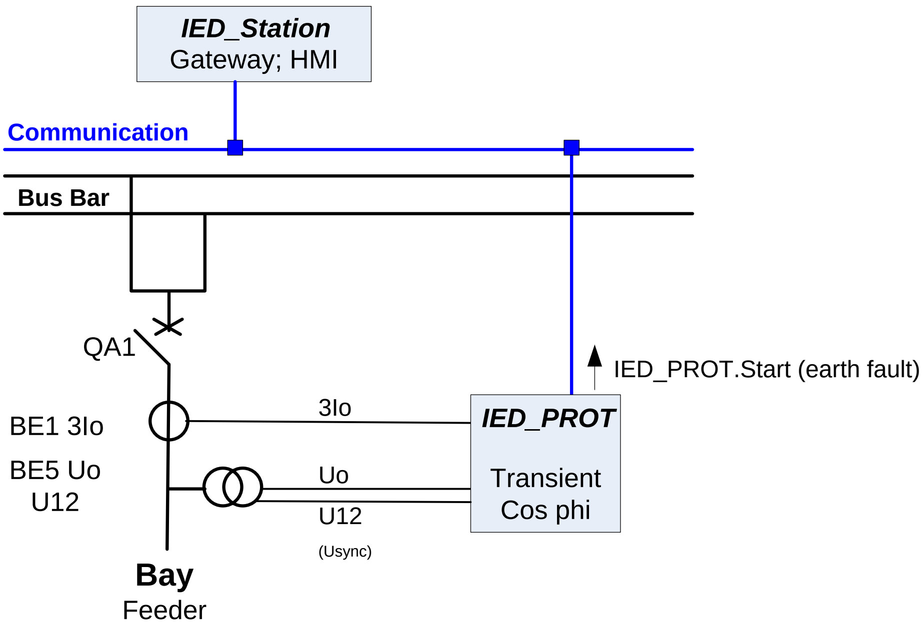


Figure 10-1 Earthfault detection – System overview

10.2 Configuration

Figure 10-1 illustrates the schema of the IED and the earthfault detection relay function and the needed necessary connection to the process.

The device parameterisation is set via tools prepared from the manufacturer.

10.3 Use Cases

10.3.1 Transient Earthfault Detection PTEF Forward [UC EF1]

Use case name:	Transient Earthfault Detection Forward
Use case id:	[UC EF1]
Version:	1.00
Goal:	Successful detection and signalisation of the direction of the transient earth fault on the particular feeder
Summary:	Correct signalisation of the earthfault-direction on the faulty feeder as a result of the evaluation of the zero-sequence transients. There is only a signalisation of the starting event. Signalisation will be reset automatically after a defined time.
Actors:	Network, IED_PROT, IED_Station, USER

Preconditions:	**Pr1**	Bay circuit breaker has closed status
	Pr2	IED_PROT is in normal operation mode, protection function is running
Triggers:		Single Line Earthfault occurs in the network, in direction of the feeder
Course of events:	**C1**	Measured zero-sequence current and voltage change to fault values
	C2	IED_PROT reports IED_Station the direction of the earthfault
	C3	IED_PROT signals on-site the fault direction
	C4	The signalisation of on-site signalisation stops after a defined time delay
	C5	The USER switches off the faulty feeder
Postconditions:	**Po1**	The earth fault has been switched off and the network is in a healthy state
	Po2	IED_PROT is in normal operation mode, protection function is running
Notes:		none

10.3.2 Transient Earthfault Detection PTEF Backward [UC EF2]

Use case name:	Transient Earthfault Detection Backward
Use case id:	[UC EF2]
Version:	1.00
Goal:	Successful detection and signalisation of the direction of the earthfault transient **not** on the feeder
Summary:	Correct signalisation of the earthfault-direction on the healthy feeder as a result of the evaluation of the zero-sequence transients. There is only a signalisation of the starting event. Signalisation will be reset automatically after a defined time.
Actors:	Network, IED_PROT, IED_Station, USER

Preconditions:	**Pr1**	Bay circuit breaker has closed status
	Pr2	IED_PROT is in normal operation mode, protection function is running
Triggers:	**T1**	Single Line Earthfault occurs in the network, not on the supervised feeder
Course of events:	**C1**	IED_PROT reports IED_Station the direction of the earth fault
	C2	IED_PROT signals on-site the fault direction
	C3	The signalisation of on-site signalisation stops after a defined time delay
	C4	The USER switches off the faulty feeder
Postconditions:	**Po1**	The earth fault has been switched off. So the network is in a healthy state
	Po2	IED_PROT is in normal operation mode, protection function is running
Notes:		none

10.3.3 Wattmetric Earthfault Detection PSDE Forward [UC EF3]

Use case name:	Wattmetric Earthfault Detection Forward
Use case id:	[UC EF3]
Version:	1.00
Goal:	Successful detection and signalisation of the direction of the stationary earthfault on the feeder
Summary:	Correct signalisation of the earthfault-direction on the faulty feeder as a result of the evaluation of the zero-sequence components
Actors:	Network, IED_PROT, IED_Station, USER

Preconditions:	**Pr1**	The earth fault has been switched off. So the network is in a healthy state
	Pr2	IED_PROT is in normal operation mode, protection function is running
Triggers:	**T1**	Single Line Earthfault occurs in the network, in direction of the feeder
Course of events:	**C1**	Measured zero-sequence current and voltage change to fault values
	C2	IED_PROT reports IED_Station the direction of the earthfault
	C3	IED_PROT signals on-site the fault direction
	C4	The signalisation of on-site signalisation stops after a defined time delay
	C5	The USER switches off the faulty feeder
Postconditions:	**Po1**	The earth fault has been switched off and the network is in a healthy state
	Po2	IED_PROT is in normal operation mode, protection function is running
Notes:		none

10.3.4 Wattmetric Earthfault Detection PSDE Backward [UC EF4]

Use case name:	Wattmetric Earthfault Detection Backward
Use case id:	[UC EF4]
Version:	1.00
Goal:	Successful detection and signalisation of the direction of the stationary earthfault **not** on the feeder
Summary:	Correct signalisation of the earthfault-direction on the healthy feeder as a result of the evaluation of the zero-sequence components
Actors:	Network, IED_PROT, IED_Station, USER

Preconditions:	**Pr1**	Bay circuit breaker has closed status
	Pr2	IED is in normal operation mode, protection function is running
Triggers:	**T1**	Single Line Earthfault occurs in the network, not on the supervised feeder
Course of events:	**C1**	Measured zero-sequence current and voltage change to fault values
	C2	IED_PROT reports IED_Station the direction of the earthfault
	C3	IED_PROT signals on-site the fault direction
	C4	The signalisation of on-site signalisation stops after a defined time delay
	C5	The USER switches off the faulty feeder
Postconditions:	**Po1**	The earth fault on another feeder has been switched off. So the network is in a healthy state
	Po2	IED_PROT is in normal operation mode, protection function is running
Notes:		none

10.4 Requirements

10.4.1 Required Information

Process Interface Zero-Sequence Voltage

Zero-Sequence Current

Reference Voltage U_{12}

Communication interface IEC61850
The following information is usually valid for all modes of the earthfault-detection functions:

Information in reporting direction:

Transient earth fault forward

Transient earth fault backward

Wattmetric earth fault detection forward

Wattmetric earth fault detection backward

The status information of the earth fault detection function is shown in the table below.

Table 10-1 Earthfault detection – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 data				IED_PROT	IED_Station
	IED_LD	**LN**	**Data**	**CDC**		
IED_PROT Start PTEF	<IED_PROT><LD>	PTEF	Str	ACD	Server reporting	Client
IED_PROT Start PSDE	<IED_PROT><LD>	PSDE	Str	ACD	Server reporting	Client

10.4.2 Performance Requirements

The time requirements are uncritical in isolated and compensated networks. Response times below 2 seconds are sufficient. The final decision of switching of the feeder is decided by the user.

11 Test Case - Frequency Relay Function

11.1 Description

The low frequency alert is used when the network frequency decreases below or increases above a defined threshold.

The warning is performed if one of the following conditions is met:

f_{10ms} < f_min_warning

f_{10ms} > f_max_warning

An alert is performed if one of the following conditions is met:

f_{10ms} < f_min_alert

f_{10ms} > f_max_alert

To reduce the number of signals only the alarm message will be used for this project.

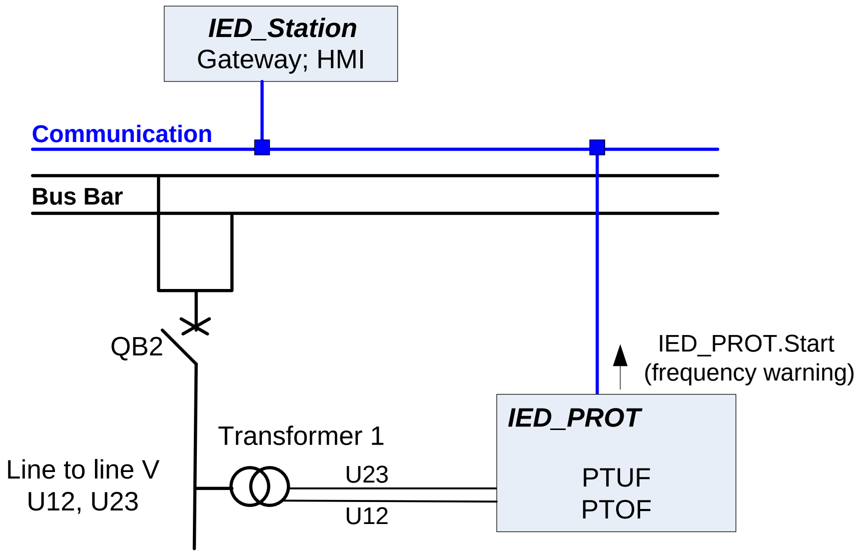


Figure 11-1 Frequency Relay Function – System overview

11.2 Configuration

Figure 11-1 illustrates the schema of the IEDs and the frequency relay function and the needed necessary connection to the process.

The device parameterisation is set via tools prepared from the manufacturer.

11.3 Use Cases

11.3.1 Message if frequency changes below defined alarming threshold [UC UF1]

Use case name: Under Frequency Function

Use case id: [UC UF1]
Version: 1.00
Goal: Message “alarm” frequency below defined threshold
Summary: Successful if the message under frequency alert is sent
Actors: IED_Station, IED_PROT, Network

Preconditions:
Pr1 IED_PROT is in normal operation mode, no further outputoperation is running
Pr2 Voltages are at nominal values
Pr3 Frequency of input signal is within the range:
f_min_warning < f10ms < f_max_warning

Triggers:
T1 Frequency drops below the defined alert stage f_min_warning

Course of events:
C1 IED_PROT detects violation of alert threshold: under frequency
C2 IED_PROT sends message alert “under frequency”

Post conditions:
Po1 Input of a signal at changed frequency value but rated voltage
Po2 IED_PROT is in normal operation mode, no output operation is running
Po3 IED_Station indicates “under frequency”

Notes: none

11.3.2 Message if frequency changes above defined alarming threshold [UC OF1]

Use case name: Over Frequency Function
Use case id: [UC OF1]
Version: 1.00
Goal: Message “alarm” frequency below defined threshold
Summary: Successful if the message under frequency alert is sent
Actors: IED_Station, IED_PROT, Network

Preconditions:
Pr1 IED_PROT is in local mode
IED_PROT is in normal operation mode, no further output operation is running
Pr2 Frequency of input signal is within the range
f_min_warning < f10ms < f_max_warning

Triggers:
T1 Frequency rises above the defined alarming stage f_max_warning

Course of events:
C1 IED_PROT detects violation of alert threshold: over frequency
C2 IED_PROT sends message alert “over frequency”

Post conditions:

Po1 IED_PROT detects violation of alert threshold: over frequency

Po2 IED_PROT is in normal operation mode, no output operation is running

Po3 IED_Station indicates "over frequency"

Notes: none

11.4 Requirements

11.4.1 Required Information

Process Interface

Two consecutive line to line voltages – such as U_{12} and U_{23}

Communication interface IEC61850

The following information is usually valid for the first simulation of the collapse prediction functions in this project:

Information in reporting direction

Voltage magnitudes f_{10ms} < f_min_warning

Voltage magnitudes f_{10ms} > f_max_warning

Voltage magnitudes f_{10ms} < f_min_alert

Voltage magnitudes f_{10ms} > f_max_alert

Table 11-1 Frequency Relay Function – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 data				IED_PROT	IED_CONT	IED_Station
	IED_LD	LN	Data	CDC			
IED_PROT UC_UF1	<IED_PROT><LD>	PTUF	Str	ACD	Server reporting		Client
IED_PROT UC_OF2	<IED_PROT><LD>	PTOF	Str	ACD	Server reporting		Client

11.4.2 Performance Requirements

The time requirements can be critical. Response times within a second are sufficient if the frequency drop/rise operation is triggered by a user.

12 Test Case - Automatic Neutral Current Regulator (Petersen- Coil Regulator)

12.1 Description

An automatic Petersen coil regulator is used for automatic tuning of the Petersen coil to corresponding network capacitance plus the desired detuning in % or A.
It is designed for continuous movable Petersen coils.
The controller gives the up or down command to the motor drive at the coil. The motor drive receives the corresponding control signals from the automatic Petersen coil regulator. With these signals, the coil is moved as long as the particular signal (either up or down) is applied.

Two modes for running the motor drive unit are:

Automatic mode Changed network conditions (switching operation) that lead to higher or lower values for the network capacitance are detected by the Petersen coil controller. Trigger is the measured zero sequence voltage. If the trigger level is reached the controller starts a search (for the resonant point of in the network) to tune the coil to the present network capacitance and the adjusted value for the detuning.

Manual mode No automatic tuning is carried out by the controller. The coil can be moved by up and down commands given by the user.

To allow individual adaption of the control system to the various field service conditions encountered, influencing variables such as:

- time delay / search delay
- rate of detuning
- zero sequence voltage dependent limits

can be adjusted.

As a special feature, the Petersen coil controller is also capable of controlling parallel Petersen coils in the same or even in separate substations respectively. But this is not in the scope of this document.

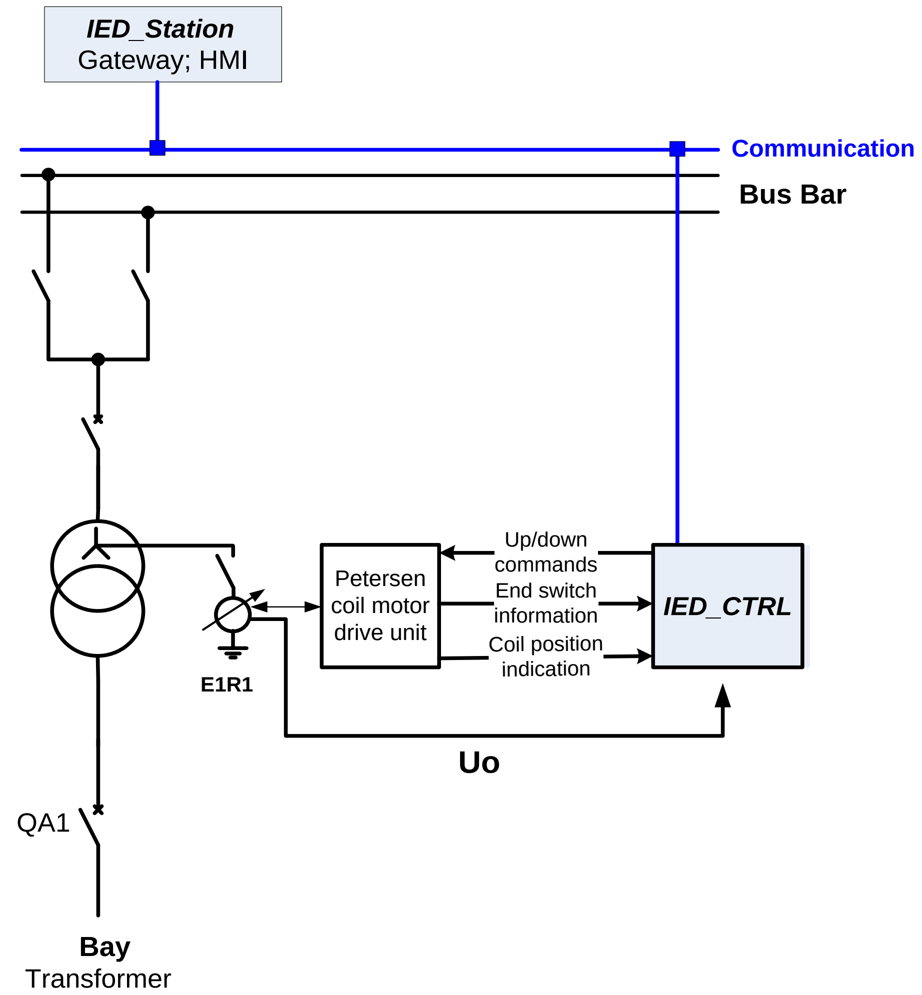


Figure 12-1 Automatic Neutral Current Regulator – System overview

12.2 Configuration

12.2.1 Device parameter configuration

Figure 12-1 illustrates the schema of the IEDs and the automatic neutral current regulator function and the needed necessary connection to the process.

The device parameterisation is set via tools and / or parameter files prepared from vendor.

12.2.2 Definition of general precondition

In order to start each use case in a defined condition, the following settings have to be initiated:

- IED_CTRL in manual regulation mode
- Signalised Coil position is valid and within the range of (simulated) Petersen Coil
- Simulation equipment is prepared, adapted and working properly
- Communication between corresponding client is working properly
- No error is reported by the device itself

12.3 Use Cases

12.3.1 Scope of use cases

Following listed use cases are to be validated by the test personal.

12.3.2 ANCR in automatic mode [UC NCR1]

Use case name:	automatic tuning of Petersen coil
Use case id:	[UC NCR1]
Version:	1.00
Goal:	search operation initiated by IED_CTRL itself
Summary:	The variation of the zero sequence voltage forces the start of the search for the new resonant point of the network.
Actors:	IED_CTRL, IED_Station, network

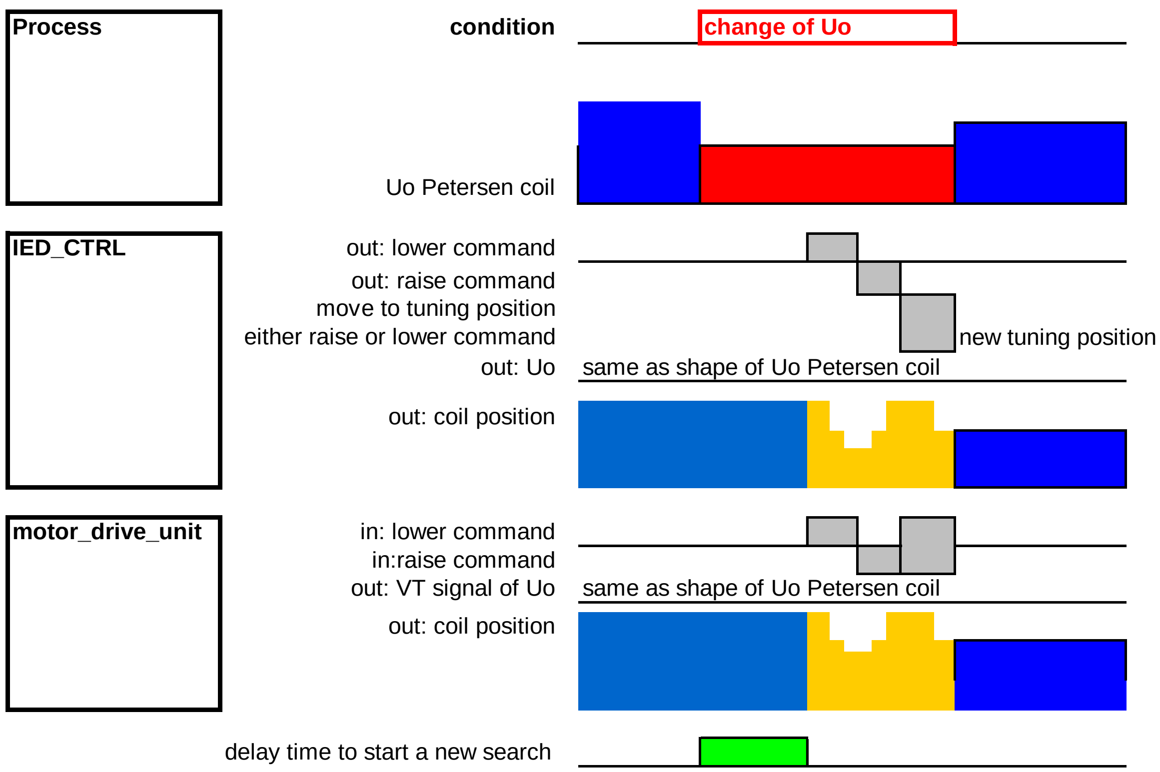


Figure 12-2 Automatic Neutral Current Regulator– Sequence Chart [UC NCR1]

Preconditions:	**Pr1**	<u>The process is simulated as follows:</u>
	Pr1-1	Test system is installed and in operation according description in paragraph 12.2.2
	Pr1-2	Regulator IED_CTRL is in automatic mode (First successfully tuning operation is assumed => The network is tuned)
Triggers:	**T1**	The zero sequence voltage level leaves the selected bandwidth

Course of events:

Course of events:	**C1**	After the parameterised time delay the IED_CTRL issues commands to the motor drive unit to move either up or down to determine the new resonance curve of the network
	C2	IED_CTRL reports value for zero sequence voltage permanently
	C3	IED_CTRL reports coil position permanently in Ampere
	C4	IED_CTRL reports successful tuning
Post conditions:	**Po1**	The process is simulated as follows:
	Po1-1	After successful tuning, the Petersen coil controller IED_CTRL is still in the Auto mode and the coil movements are stopped
	Po2	The IED_CTRL has the following status:
	Po2-1	IED_CTRL reports Petersen coil is “tuned”
	Po2-2	IED_CTRL reports the Petersen coil position
	Po2-3	IED_CTRL reports the zero-sequence voltage
	Po3	The communication has the following status:
	Po3-1	All communication connections are established and have status OK.
Notes:		none

12.3.3 ANCR in manual mode [UC NCR2]

Use case name:	manual tuning / moving of the Petersen coil by the user
Use case id:	[UC NCR2]
Version:	1.00
Goal:	changing the Petersen coil position is indicated by the client
Summary:	The IED_CTRL (ANCR) gets the command to raise or lower the position of the Petersen coil from the IED_Station
Actors:	IED_CTRL, IED_Station

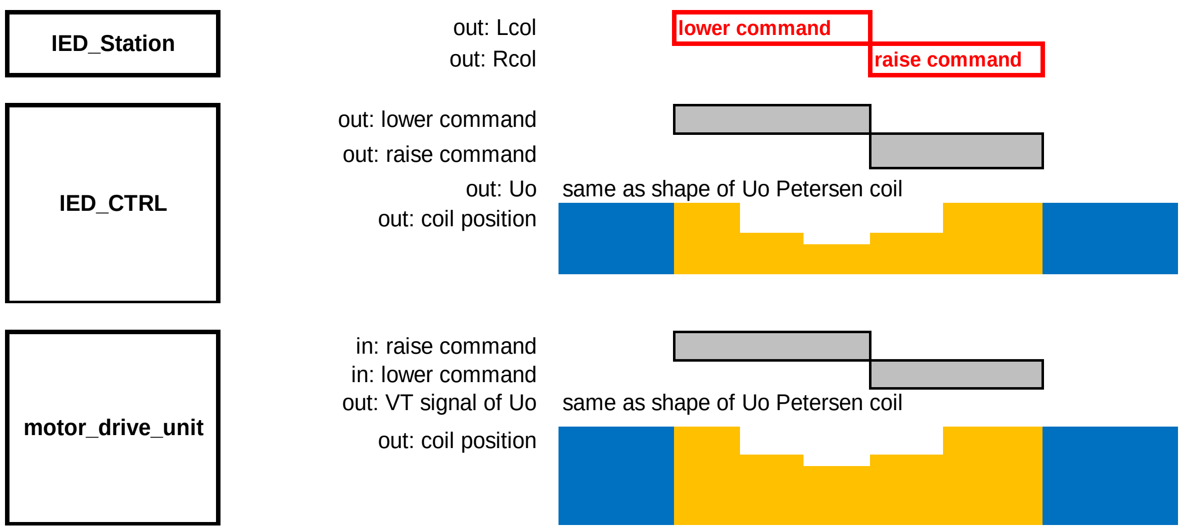


Figure 12-3 Automatic Neutral Current Regulator– Sequence Chart [UC NCR2]

Preconditions:	**Pr1**	The process is simulated as follows:

	Pr1-1	Test system is installed and in operation according description in paragraph 12.2.2
	Pr1-2	The IED_CTRL is in manual mode
Course of events:	**C1**	IED_Station sends a position raise or lower command
	C2	IED_CTRL sends a hardwired command to raise or lower
	C3	IED_CTRL reports value for zero sequence voltage permanently
	C4	IED_CTRL reports coil position permanently in Ampere
Post conditions:	**Po1**	The process is simulated as follows:
	Po1-1	New coil position is indicated
	Po2	The IED_CTRL have the following status:
	Po2-1	No error messages are present
	Po3	The communication has the following status:
	Po3-1	All communication connections are established and have status OK.
Notes:		none

12.4 Requirements

12.4.1 Interfaces

Table 12-1 Automatic Neutral Current Regulator – Process interface

Data	IED_CTRL
Zero-Sequence Voltage from the Petersen coil	AI
Petersen coil position indicated by the potentiometer	AI
Raise/lower commands to the Petersen Coil motor drive unit	BO
End switch information of the upper and lower end switch	BI

Communication interface IEC61850

In Edition 1 of the IEC61850 the ANCR model has only reduced functionality, which does not enable a practical use of the ANCR in combination with a Petersen-Coil. In Edition 2 this functionality will be expanded. For the actual test the necessary functions are modelled with GGIO's.

The following information is usually valid for all modes of the Petersen coil control function:

- Information in command direction:
  - Raise and lower commands from the client
  - Manual / Auto command from the client
  - Local / Remote command from the client

- Information in command direction:
  - Information Petersen coil is tuned
  - Coil position information in Ampere
  - Zero sequence voltage (Uo)

- Status information of the controller is given by the GGIO, available in IED_CTRL (ANCR) in Edition 2

Table 12-2 Automatic Neutral Current Regulator – Process interface

Use case Data	IEC 61850 data				IED_CONT	IED_Station	Description in case of GGIO
	IED_LD	**LN**	**Data**	**CDC**			
IED_CTRL Raise ANCR	<IED_CTRL><LD>	ANCR	RCol	SPC	Server reporting	Client control	
IED_CTRL Lower ANCR	<IED_CTRL><LD>	ANCR	LCol	SPC	Server reporting	Client control	
IED_CTRL Auto ANCR	<IED_CTRL><LD>	GGIO	SPCSO01	SPC	Server reporting	Client control	Manual/ automatic operation of ANCR
IED_CTRL Pos ANCR	<IED_CTRL><LD>	GGIO	AnIn01	MV	Server reporting	Client	Petersen Coil position in Ampere
IED_CTRL Uo ANCR	<IED_CTRL><LD>	GGIO	AnIn02	MV	Server reporting	Client	Zero sequence voltage in V
IED_CTRL Status ANCR	<IED_CTRL><LD>	GGIO	IntIn01	INS	Server reporting	Client	Device status of ANCR

12.4.2 Performance

The time requirements are uncritical in case of Petersen coil regulation. Response times below 2 seconds are sufficient.

13 Test Case - Automatic OLTC controller

13.1 Description

An automatic tap change controller is used for automatic control of transformers with motor driven on load tap changers. The motor drive mechanism receives the corresponding control signals from the automatic tap change controller. With these signals, the tap changer unit moves to the next position and the transformer's voltage value is adapted to the preset reference voltage level.

In general there are two different operation modes:

Automatic mode	Switching operations are controlled and initiated via the automatic tap change controller regarding the measured voltage level.
Manual mode	Switching operations are forced by user or others (e.g. SCADA client, hard wired signal, …)

To allow individual adaption of the control system to the various field service conditions encountered, influencing variables such as:

- time delay
- voltage setpoint value
- bandwidth
- line or load-dependent parameters for compensating voltage drops
- different voltage or current-dependent limits

can be programmed.

As a special feature, the voltage controller is also capable of controlling parallel transformer operation. But this is not in scope of this document.

The principal schematic for a generic automatic OLTC is shown in Figure 13-1.

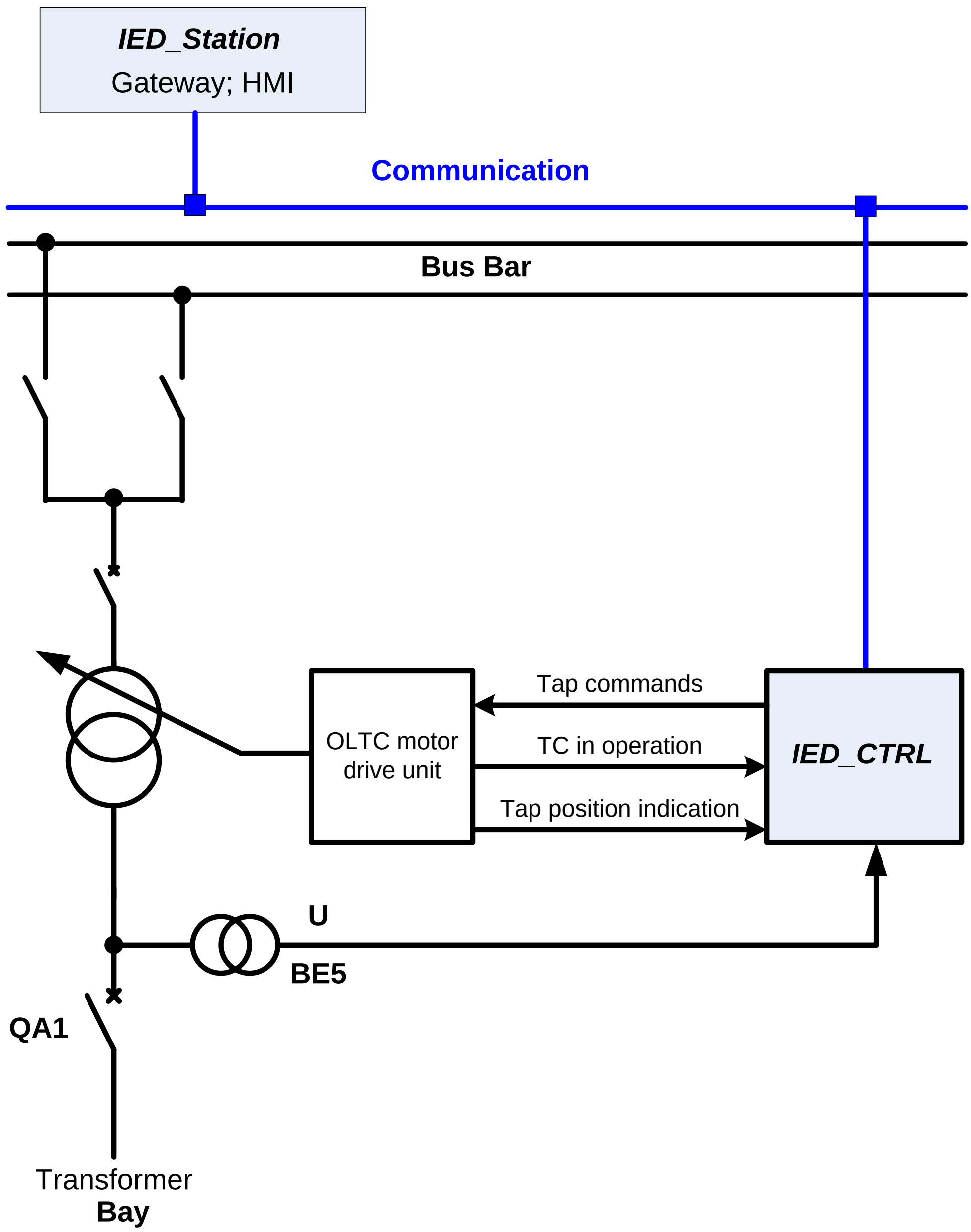


Figure 13-1 Automatic OLTC controller – System overview

13.2 Configuration

13.2.1 Device parameter configuration

Figure 13-1 illustrates the schema of the IED Station and the automatic voltage regulator function (IED_CTRL) and the needed necessary connection to the process.

The device parameterisation is set via tools and / or parameter files prepared from the vendor.

13.2.2 Definition of general precondition

In order to start each use case in a defined condition, the following settings have to be initiated:

- IED_CTRL in manual regulation mode
- IED_CTRL in remote control mode
- Used voltage reference set to nominal voltage (VRef1 = 100V and active)
- VT measured voltage within set bandwidth (bandwidth[2% of nominal voltage level] = 98..102V)
- Signalised tap position is valid and within tap range of (simulated) OLTC
- Communication between corresponding client is working properly
- Simulation equipment is prepared, adapted and working properly
- No error is reported by the device itself

13.3 Use Cases

13.3.1 Scope of use cases

Following listed use cases are to be validated by the test personal.

13.3.2 ATCC in automatic mode [UC TCC1]

Use case name:	automatic regulation of busbar voltage
Use case id:	[UC TCC1]
Version:	1.00
Goal:	Tap change operation initiated by IED_CTRL itself
Summary:	The AVR should force a tap change in order to raise/lower the bus bar voltage back into permissible bandwidth.
Actors:	IED_CTRL, IED_Station
Sequence chart:	Figure 13-2

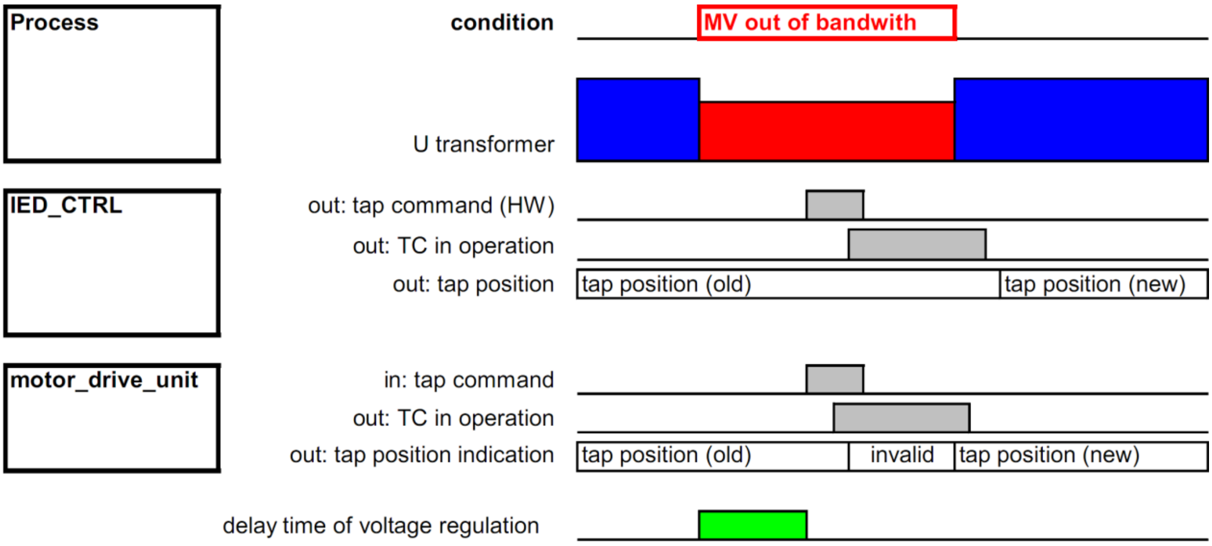


Figure 13-2 Automatic OLTC controller – Sequence chart [UC TCC1]

Preconditions:	**Pr1**	The process is simulated as follows:
	Pr1-1	Test system is installed and in operation according description in paragraph 13.2.2
	Pr1-2	Regulation mode is set from manual to automatic
Triggers:	**T1**	measured voltage level resident out of preset bandwidth
Course of events:	**C1**	Reported measured voltage level is changing accordingly
	C2	After the parameterised time delay the IED_CTRL gives a command for motor drive unit to step the OLTC
	C3	IED_CTRL reports motor drive in progress active
	C4	IED_CTRL reports motor drive in progress inactive
	C5	IED_CTRL reports new valid tap position indication
Post conditions:	**Po1**	The process is simulated as follows:
	Po1-1	New tap position is indicated without any failures
	Po1-2	Controlled voltage level is in-between bandwidth of IED_CTRL
	Po2	The IEDs have the following status:
	Po2-1	New tap position is indicated
	Po2-2	Tap change in progress indication is inactive
	Po3	The communication has the following status:
	Po3-1	All communication connections are established and have status OK.
Notes:		none

13.3.3 ATCC in manual mode [UC TCC2]

Use case name: manual regulation of bus bar voltage

Use case id: [UC TCC2]

Version: 1.00

Goal: Tap change operation initiated by client

Summary: The AVR is forced to change the tap position in order to raise/lower the OLTC tap position.

Actors: IED_CTRL, IED_Station

Sequence chart: Figure 13-3

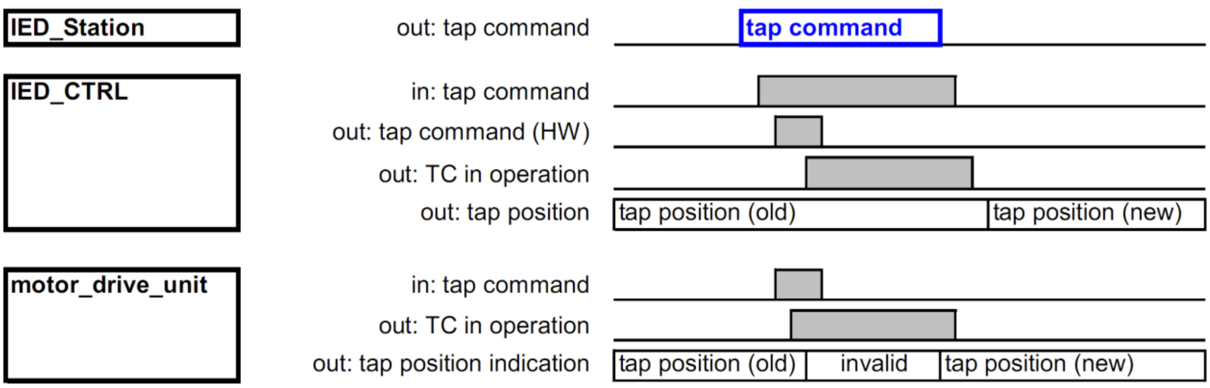


Figure 13-3 Automatic OLTC controller – Sequence Chart [UC TCC2]

Preconditions:

Pr1 The process is simulated as follows:

Pr1-1 Test system is installed and in operation according description in paragraph 13.2.2

Triggers:

T1 measured voltage level resident out of preset bandwidth

Course of events:

C1 IED_Station sends a tap raise or lower command

C2 IED_CTRL sends an hardwired command to raise or lower

C3 IED_CTRL reports motor drive in progress active

C4 IED_CTRL reports motor drive in progress inactive

C5 IED_CTRL reports new valid tap position indication

Post conditions:

Po1 The process is simulated as follows:

Po1-1 New tap position is indicated without any failures

Po2 The IEDs have the following status:

Po2-1 New tap position is indicated

Po2-2 motor drive in progress indication is inactive

Po3 The communication has the following status:

Po3-1 All communication connections are established and have status OK.

Notes: none

13.4 Requirements

13.4.1 Interfaces

Table 13-1 Automatic OLTC controller – Process interface

Data	IED_CTRL
Current input BE1 (one phase current, optional)	AI
Voltage input BE5 (phase to phase or phase to neutral voltage)	AI
Tap commands (HW) to the motor drive unit	BO
TC in operation signal from the motor drive	BI
Tap position indication from the motor drive	BI

Table 13-2 Automatic OLTC controller – Communication interface IEC 61850 Client / Server

Use case Data	IEC 61850 data				IED_CTRL	IED_Station
	IED_LD	LN	Data	CDC		
IED_CTRL U transformer	<IED_CTRL><LD>	ATCC	CtlV	MV	Server reporting	Client
IED_CTRL tap position	<IED_CTRL><LD>	ATCC	TapChg.valWTr.posVal	BSC	Server reporting	Client
IED_CTRL *) TC in operation	<IED_CTRL><LD>	ATCC	TapChg.valWTr.transInd	BSC	Server reporting	Client
	<IED_CTRL><LD>	ATCC	MotDrv.stVal	SPS		
IED_CTRL tap command	<IED_CTRL><LD>	ATCC	TapChg.ctlVal	BSC	Server	Client command

*) The use of transInd attribut of the TapChg data object is optional. At least one of the two status information (TapChg.valWTr.transInd, MotDrv) shall be used.

13.4.2 Performance

The time requirements are uncritical in case of voltage regulation. Response times below 2 seconds are sufficient.