***A**rbeits**K**reis **952.0.1**:*

Applications using the Services of IEC61850

Version 1.0

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1 General

1.1 Substation topology

The applications and services presented in this working paper refer to selected bays of the sample substation created in GAK 15 (Fig. 1, with equipment designations according to IEC61346).

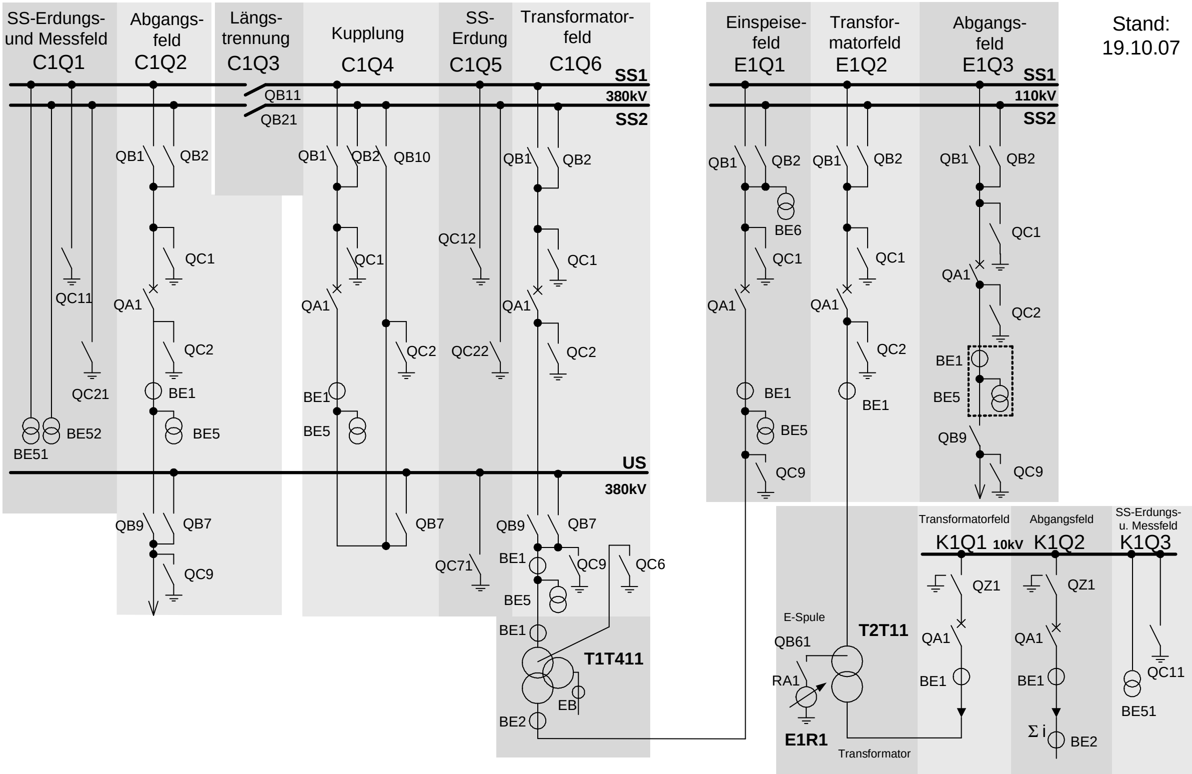


Fig. 1: GAK 15 sample substation

1.2 Designations

The term “bay unit” describes any device on bay control level that is connected to the primary system. A “bay unit” can be any kind of bay devices such as a protection device, control device or combined protection and control devices. It does not have to be assigned to one specific bay; it can also possess bay-spanning functions. Even several such bay devices, e.g. one protection device and one control device can exist in parallel. All functions described in this document are thus intended for each bay unit independently.

Within the context of IEC61850, a bay unit corresponds to an IED (Intelligent Electronic Device).

1.3 Available services according to IEC61850

The following table describes the services available in IEC61850, their advantages and disadvantages or the associated marginal conditions.

Service model	Description	Services	Sequence	Advantage	Disadvantage	Marginal condition
Server	Represents the external behaviour of an IED. All other services are part of the server.	ServerDirectory	Polling per request / response: Client-server communication for selective reading / writing of data on the server	▪ Data volume is limited to the portion required for the client. ▪ Connection monitor included implicitly	Large data volume due to point-to-point communication and thus one message per recipient → therefore limited suitability for time critical applications,	The behaviour for establishing the connection must be defined in the client (e.g. GI).
Application association (application connection)	Procedure how two or more devices can be connected Provides different views on a device: limited access to the information and functions of the server	Associate Abort Release				
Logical device	Represents a group of functions; each function is defined as a logical node.	LogicalDeviceDirectory GetAllDataValues				
Logical node	Represents a certain function of the substation system, e.g. overvoltage protection	LogicalNodeDirectory				
Data object	Provides an opportunity to specify entered information, e.g. position of a switch with quality information and time stamp	GetDataValues SetDataValues GetDataDefinition GetDataDirectory				
Data set	Allows grouping different kinds of data	GetDataSetValue SetDataSetValue CreateDataSet DeleteDataSet GetDataSetDirectory				
Substitution	Allows replacing a process value by a manually entered value	SetDataValues	Client writes the substitute values into the process image.	Connection monitor included implicitly No alternative possible		The behaviour for establishing the connection must be defined in the client. After restarting the server, the substitute value must remain active.
Setting group control (changing setting values)	Defines how to switch over values of setting groups and edit setting groups	SelectActiveSG SelectEditSG SetSGValues ConfirmEditSGValues	Client selectively switches over setting groups	Connection monitor included implicitly No alternative possible		The behaviour for establishing the connection must be defined in the client.

Service model	Description	Services	Sequence	Advantage	Disadvantage	Marginal condition
		GetSGValues GetSGCBValues				After restarting the server, the selected setting group must remain active.
Reporting and logging	Describes the conditions for reporting entries in the event log (history) based on the parameters specified by the client Messages can be triggered by changing process data values or quality information. Event logs can be queried later. Messages can be sent immediately or with delay (buffered).	**Buffered RCB:** Report GetBRCBValues SetBRCBValues	Server has one control block per client and sends reports spontaneously or cyclically If interrupted, the messages are buffered in a limited buffer.	Optimizing the data traffic No loss of status changes while the transmission is interrupted	Limited suitability for time critical applications After the connection has been restored, old/historical data are transmitted which can delay current status messages.	The total reporting time is increased by the number of clients involved.
		Unbuffered RCB: Report GetURCBValues SetURCBValues	Server has one control block per client and sends reports spontaneously or cyclically	Optimizing the data traffic	Limited suitability for time critical applications Status changes are lost in the event of an interruption.	The total reporting time is increased by the number of clients involved.
		Log CB: GetLCBValues SetLCBValues **Log:** QueryLogByTime QueryLogAfter GetLogStatusValues	The archive (log) is generated in the server and sent upon request to the querying client.	Data transfer only as required and does not burden the operational data traffic	Resources (memory) required in the server Not suited for time critical applications	
Generic substation events (GSE) (general event transmission)	Offers quick and reliable system-wide distribution of data, peer-to-peer data exchange of binary status information of the protection devices	**GOOSE CB:** SendGOOSEMessage GetGoReference GetGOOSEElement Number GetGoCBValues SetGoCBValues	Cyclical / spontaneous multicast transmission of datasets without receipt acknowledgement	Fast transmission since directly on link layer Prioritizing via VLAN Configuration via SCL based on datasets	No direct connection monitoring	Evaluation of data backup must be accomplished in the application.
		GSSE CB: SendGSSEMessage GetGsReference GetGSSEElement Number GetGsCBValues SetGsCBValue	Cyclical / spontaneous multicast transmission of binary information as bit pair without receipt acknowledgement	Fast transmission since directly on link layer Prioritizing via user priority acc. to IEEE802.1Q, Configuration via IED name, bit pair number and function assignment	No direct connection monitoring Only binary information can be transmitted. No transmission of a quality byte, validity included in bit pair Only limited suitability for substation interlocking since no two-pole information are transmitted	Simple data backup also by bit pairs
Transmission of sampled values (transformer data transmission)	Quick and cyclical transfer of sampled values e.g. from transformers	**Multicast SVC:** SendMSVMessage GetMSVCBValues SetMSVCBValues Unicast SVC:	Not considered	Not considered	Not considered	Not considered

Service model	Description	Services	Sequence	Advantage	Disadvantage	Marginal condition
		SendUSVMessage GetUSVCBValues SetUSVCBValues				
Control	Describes the services to control e.g. devices or setting groups	Select SelectWithValue Cancel Operate CommandTermination TimeActivatedOperate	Direct control(wES): Operate → (CommandTermination)	Procedure designed specifically for switching auxiliary equipment		
			SBO(wES): Select → Operate → (CommandTermination)	Procedure designed specifically for controlling switching devices, with prior exclusive selection of the equipment		
Time and time synchronisation	Provides the time basis for devices and system	Services in SCSM	Not considered	Not considered	Not considered	
File transfer	Defines the exchange of huge data block like programs	GetFile SetFile DeleteFile GetFileAttributeValues	Standardised transfer of files like fault records	Uniform procedure for transmission and management	Data contents not specified, no security mechanisms for data access	Fault records should be saved consistently in Comtrade format.

1.4 Comparison of the access methods

Method	Time critical information exchange	Loss of message changes (only secured by access)	Multi-client communication	Buffered by
Polling (GetDataValues)	No	Yes	Yes	**-**
Unbuffered Reporting	Yes	Yes	No	**-**
Buffered Reporting	Yes	No	No	Server
Log (for SOE logging)	No	No	Yes	Client
GOOSE	Yes	Yes	Yes	-

1.5 Standardized evaluation table for the applications

The following table is used to evaluate the requirements and the possible services for the corresponding application of the subsequent chapters.

The following criteria are considered in the evaluation:

- Returning a receipt acknowledgement – Each message from a server IED is acknowledged by a response message of the receiving client to notify the server that the information has been transmitted faultlessly.
- Reception by several clients (multicast) – A server IED sends a message to more than one client IED simultaneously to reduce the data traffic.
- Time critical information exchange – Here, the time or response time is considered which the application needs when using the service or which is provided by the corresponding service. Only the transmission time of the service itself is considered; the processing times inside the IEDs for generation and further processing have been excluded deliberately.
- Continuous data traffic – Here, the required data volume is evaluated that results from using this service on the application level of the Ethernet. The following parameters are evaluated here: e.g. multiple sending of the same information, sporadic or permanent cyclical repetitions, sending the data upon request only etc. The evaluation is purely subjective by considering the number of messages during normal operation and is not based on a real measurement of the data traffic that occurs. It is difficult to define a numerical value in kBytes/s since the data block size of the messages can not be definitely determined and the actual system load depends on additional factors such as the number of switches and IEDs in the network.
- System load directly after the event – The same subjective evaluation as in the previous point, but here the higher data traffic is evaluated as often occurs during a status change or when the transmission is triggered (e.g. triggering file transfer or logging).
- Repeating the information after the connection was interrupted – While the communication is interrupted, status changes can occur which are important for certain applications to log or evaluate the history of the status changes. This criterion evaluates whether after the client-server connection was restored a service will repeat the message changes that have occurred at the time the connection was interrupted in addition to the present status in order to reconstruct a continuous flow of information on the client side.

The plain-text entries in the table are defined in the legend below. The properties have been defined for all service together so that the grading of the properties is clear. The corresponding line will be inserted in the table of the particular application if the service is possible for this application. This facilitates the comparison between the requirements of the application and the performance features offered by the services.

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Process step 1 (e.g. activation)						
Requirement for this application	see below	see below	see below	see below	see below	see below
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
SetURCBValues / SetBRCBValues	satisfied	not satisfied	<500ms	low	low	not satisfied
Substitution per Request / Response	satisfied	not satisfied	<=1s	very low	low	not satisfied
Setting Group Control p. Request / Response	satisfied	not satisfied	<=1s	very low	low	not satisfied
Control via request/response	satisfied	not satisfied	< 100ms	very low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low ***)**	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low ***)**	average	satisfied
Logging	not satisfied	not satisfied	> 1s	very low	very high	not satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied
L	not satisfied	satisfied	<20ms	very high	very high	not satisfied
File transfer	not satisfied	not satisfied	> 1s	very low	very high	not satisfied
Process step 2 (e.g. monitoring)						
See above.		***) Depending on the configuration of the measured values also "very low" to "average"**				
Process step n						
See above.						

Scope of possible plain-text entries:

Requirement for this application	required	required	> 1s	very high	very high	required
	not required	not required	<=1s	high	high	not required
			<500ms	average	average	
			< 100ms	low	low	
			<20ms	very low	very low	
Applicability of the possible services	satisfied	satisfied	> 1s	very high	very high	satisfied
	not satisfied	not satisfied	<=1s	high	high	not satisfied
			<500ms	average	average	
			< 100ms	low	low	
			<20ms	very low	very low	

2 Reverse interlocking

2.1 Application

In radial networks with single infeed, the reverse interlocking can be used to set up a simple busbar protection. The second overcurrent stage I>> of the definite time overcurrent device of the busbar’s incoming feeder bay (here transformer bay K1) is set to a short tripping time of e.g. 0.1 seconds. Additionally, blocking of this stage is configured via a binary input. The first overcurrent stage I> of the definite time overcurrent device of the outgoing feeder bays of the busbar (here e.g. outgoing bay K2) are set to a tripping time of e.g. 1 second. The pickup signal of the I> stage or the general pickup signal are configured to a binary output. All binary outputs of the outgoing protection devices are connected as ring circuit to the blocking input of the infeed protection (see Fig. 2).

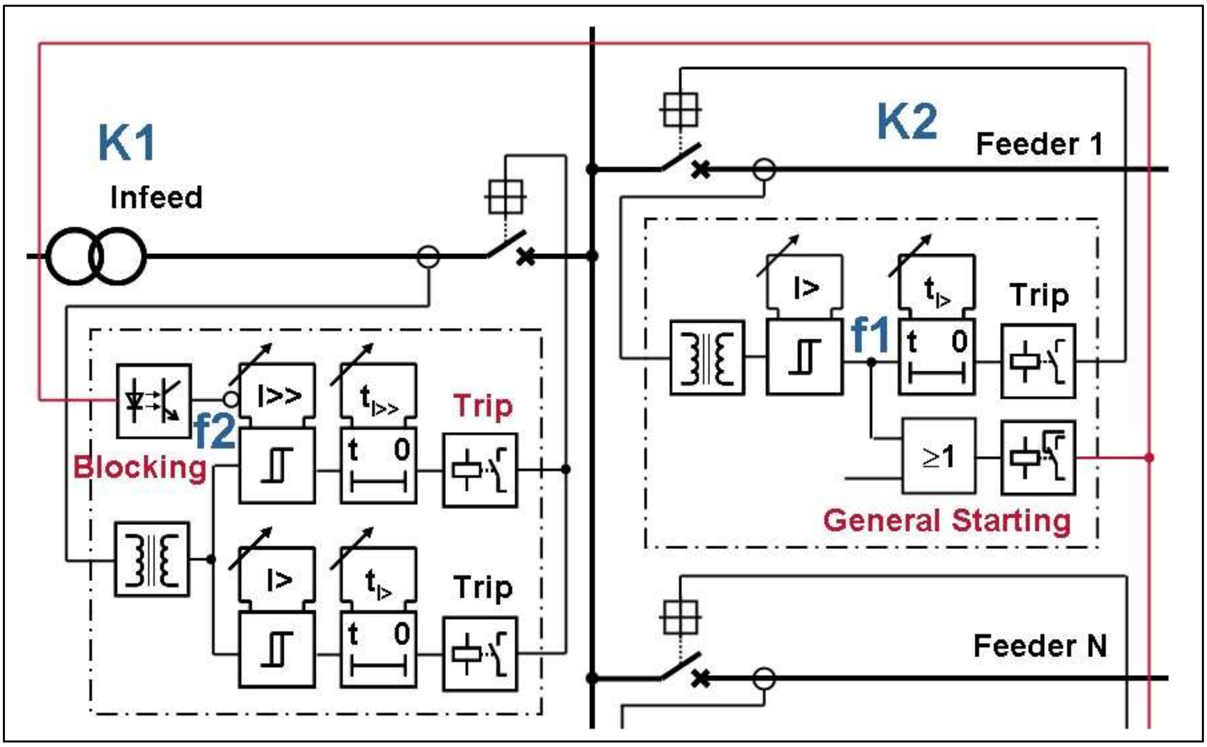


Fig. 2: Signal path of reverse interlocking

Behaviour in the event of faults on the outgoing feeder

When a fault occurs on the outgoing feeder, the pickup of the protection of the affected outgoing feeder will instantaneously generate a blocking signal to the protection device of the incoming feeder via the configured output and its I>> stage will trip instantaneously (condition < e.g. 100ms!). The outgoing feeder protection generates a trip selectively for the faulted outgoing feeder and the busbar can remain operational.

Behaviour in the event of busbar faults

When a fault occurs on the busbar, the I>> stage of the infeed protection will pick up but none of the outgoing feeder protection will generate the blocking signal since the affected protection devices of the outgoing feeders do not pick up. The infeed protection will thus switch off the infeed instantaneously after 0.1 sec.

2.2 Information and communication subscribers

The bays of the 10-kV substation with single busbar were selected.

K1 – Incoming feeder unit of 10-kV medium voltage

K2 – Outgoing feeder unit of 10-kV medium voltage

The implementation acc. to IEC61850 requires all pickup signals of the outgoing feeder protection devices (here K2) to be transmitted to the incoming feeder protection (here K1). The use of Ethernet communication thus replaces the ring circuit and the required binary outputs of the outgoing feeder protection and the binary input at the incoming feeder protection for blocking the trip. The information is transmitted in one direction only, i.e. to the incoming feeder protection.

2.3 Required object information (LN/DO/DA)

The devices transmit the following information from bay K2 to bay K1:

P-K2/PTOC/Str/general (pickup message of I> or general pickup)

Extract from the modelling:

LN	Data	CDC	Attributes	Values and Report Text	Comment
PTOC					Overall commands and messages
	Str	ACD	general	Pickup: general	Pickup
			dirGeneral	Direction information	
			q	Quality	
			t	Time stamp	

In the receiving IED the information is forwarded to the configurable logic or it is ORed by direct function assignment to the Mod/ctlVal of the PTOC to be blocked. When doing so, the quality attribute has to be evaluated to ensure that the transmission has been carried out correctly. The blocking may only be activated for as long as .q is marked as “valid”.

LN	Data	CDC	Attributes	Values and Report Text	Comment
PTOC					
	Mod	INC	CtlVal	on, blocked, test, test/blocked, off	Control of the logical node (used as blocking here)
			stVal	on, blocked, test, test/blocked, off	Status of the logical node
			q		
			t		
			ctlModel	status-only, direct-control-with-normal-security	Control method of the logical node

2.4 Time requirements

The transmission must be completed within less than the set command time tI>> of the incoming feeder protection, which is 100 ms in our example. The time requirement applies here for the transmission path from generation of the pickup **f1** until the actual blocking takes effect **f2** (see picture above) according to IEC61850 part 5, page 45. The transmission must take place without delay, i.e. a spontaneous transmission is an absolute precondition.

Note: For GOOSE inputs/outputs the response time within the device between Ethernet interface and internal function always depends on the manufacturer-specific device functionality or the performance available for this process at the time of transmission. Proving that this time requirement is met reliably when implementing the GOOSE transmission between devices from different manufacturers is presently only possible by conducting measurements under typical operation conditions.

2.5 Evaluation of the possible services

Service used	Returning a reception acknowledgement	Reception of several clients (multicast)	Time critical information exchange	Continuous data traffic	System load directly after event	Sending buffered data after a communication interruption
Transmission of the blocking information						
Requirement for this application	***not required***	***not required***	***<20ms***	***average***	***high***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

The requirement "<20 ms" was chosen because the requirement to the transmission time of the service itself is meant here. Since the total transmission time is max. 100 ms as mentioned in section 2.4, only a service with a much smaller transmission time is possible for this application!

2.6 Selected services

The normal reporting of the protection LN PTOC1 is triggered directly from the internal status change of the pickup message. However, this can exceed the required time depending on the load or buffer status of the normal client-server communication since there is no prioritization. Transmission via GOOSE or GSSE is accomplished directly on Ethernet level and is therefore immediately inserted into the running data traffic. Thus data can be transmitted reliably within a few milliseconds. The reverse interlocking is a part of the protection system and as such as a high security level. This is why GOOSE or GSSE are especially suitable for its transmission.

Each IED with GOOSE function has a permanent dataset with series-connected signal assignment or a configurable dataset that can be assembled using the signals modelled in the IEC data model.

The IED K1 "collects" all GOOSE information and links them in its own programmable logic function to form a common blocking signal. Devices may provide this link already with the common signal assignment logic to the blocking signal.

Switch blocks in the network that provide a prioritization via "VLAN priority" allow optimizing the transmission time on Ethernet side significantly by selective prioritizing in the switches. This requires the corresponding IEDs to feature this function (optional function in IEC61850).

2.7 Procedures

The GOOSE message is sent by K2 without status change in a constant rhythm. K1 receives the cyclical GOOSE message and checks whether the identification part is consistent with its settings. If the received GOOSE message was intended to be further processed in this device, i.e. the identification section is conforming, the internal link will switch from default mode to active mode. This should have the status “not blocked” in the GOOSE message currently received.

If now a pickup occurs on the side of K2 and if the pickup is linked to the GOOSE message, the IED K2 will immediately generate a corresponding GOOSE message with the new status. The IED K1 receives the GOOSE message and thus sets the internal blocking of the I>> stage which is configured to the corresponding data point in the GOOSE dataset.

To prevent that data is lost when the communication is interrupted (e.g. reconfigurations in the network), the GOOSE message will be repeated subsequently in increasing time intervals until its normal slow sending rhythm (without status change) has been restored.

2.8 Marginal conditions

The following criteria have to be observed in order to ensure fault-free operation.

- The number of GOOSE messages or sampled values in the affected network should not become too high (-> e.g. no merging unit on the same bus) to ensure the high demands on the transmission time.

3 Controlling switchgear

3.1 Application

Controlling switchgear in a substation is a safety-relevant function and must be implemented so as to reliably prevent maloperations. Since control with direct command output does not come up to this requirement, the “Select-Before-Operate” sequence (SBO) was defined.

Select-Before-Operate enables the exclusive reservation for controlling a piece of equipment. A second switching command, e.g. sent by another client is rejected for as long as the first switching command has been completed.

This interlocking of the command processing can be extended to a group of equipment, e.g. to the entire equipment of a bay or substation, by using additional mechanism like the 1-out-of-n logic (see also section 4.1 “Double operation block”).

Below this sequence will be described at an example. The operator at the substation HMI of a sample substation has the task to close the disconnector QB1 in the coupler bay C4 of this substation. The disconnector QB1 is connected directly to the bay controller of this bay (FLG_C4). The sequence ideally comprises the following steps:

1. The HMI sends a *SelectRequest* to the FLG_C4 inquiring whether QB1 can be closed.
2. In FLG_C4 the conditions for releasing the switching operation are checked (e.g. comparison of actual switching status with the target status, check of the interlocking conditions, check of the current status of the switching device etc.). If the result is positive, the FLG_C4 will send a positive acknowledgement *SelectResponse+* to the HMI. In addition, a timer is started in the FLG_C4 to monitor the further sequence.
3. After reception of the acknowledgement *SelectResponse+* (and additional checks, operator request etc. if required) the HMI sends an *OperateRequest* (on) to the FLG_C4.
4. In the FLG_C4 the conditions for releasing the switching operation are checked again. If the result is positive, the output for closing disconnector QB1 is activated in the FLG and an acknowledgement *OperateResponse+* is sent to the HMI.
5. If configured, the FLG_C4 reports the intermediate position via *ReportRequest.* The intermediate position is not reported if the intermediate position suppression is activated in the FLG_C4 for a configurable disconnector operating time.
6. After the final position of QB1 (“closed”) has been reached, the output in the FLG_C4 is deactivated and the new switching status signalled to the HMI via *ReportRequest* (on). Finally, *CommandTermination+* indicates that the sequence has been finished successfully.

The sequence described above requires that all test results are positive and the responses occur within the (configurable) monitoring times. If test results turn out negative or the time is exceeded, the sequence is aborted by negative acknowledgements (from the bay controller FLG_C4) or via *CancelRequest* (from the HMI).

In some cases, the sequence of the switching procedure can be influenced by means of additional parameters in the bay unit.

- Pulse command: The command output is activated for a preset time only. The influence on the communication level is in delaying the command termination if the feedback from the switching device arrives before the pulse time has expired and thus the switching operation has not been completed yet.
- Persistent command with termination delay: The command output remains activated for a preset period of time after reaching the new position. The influence on the communication level is in delaying the command termination until the command output is really deactivated and thus the switching command has been completed.

3.2 Information and communication subscribers

The busbar disconnector QB1 in coupler bay C4 was chosen to describe the flow of information. Furthermore, it is assumed that the disconnector QB1 is directly connected to the bay controller of coupler bay FLG_C4. The sample substation is controlled from the substation operator terminal (HMI).

The services *SelectWithValue, Cancel, Operate* and *CommandTermination* are used for the control (s. IEC 61850-7-2, section 17: Control class model).

3.3 Required object information (LN/DO/DA)

LD Control					
LN	Data	CDC	Attributes	Values and Report Text	Comment
XSWI					Overall commands and messages
	Pos	DPC	stVal q t ctlVal ctlModel	0 - Intermediate 1 - off 2- on 3 - bad	Switchgear status

3.4 Time requirements

The time requirements are uncritical. Response times of ≤1 s when the switching operation is triggered by an operator and ≤ 100 ms for automatic functions are sufficient (without disconnector operating time, see also IEC61850-5, Annex G2.2).

3.5 Evaluation of the possible services

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Activation (central)						
Requirement for this application	***required***	***not required***	***<100ms / <=1s***	***very low***	***average***	***not required***
Applicability of the possible services						
Control via request/response	satisfied	not satisfied	< 100ms	very low	low	not satisfied
Supervision of the switching status (central/distributed)						
Requirement for this application	***not required***	***not required***	***<100ms / <=1s***	***low***	***high***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

3.6 Selected services

In the guidelines of GAK15 it was already decided to control equipment only via “select before operate with enhanced security“. Therefore, the alternatives “direct control without security“, “direct control with security“ or “SBO without enhanced security“ are not taken into consideration here.

The following services have to be used for switching with “SBO with enhanced security”:

- *SelectWithValue*
- *Cancel*
- *Operate*
- *CommandTermination*

Unbuffered reports (URCB) / buffered reports (BRCB) or GOOSE / GSSE can be used to continuously report or update status changes of the equipment. Reports are preferred for those applications which are not based on particularly time-critical functions such as the substation control unit or operator PCs. The feedback messages are here required for visualization purposes only to obtain an overview of the substation status. Since this will be the most frequent case, this service is recommended for this application.

There are, however, applications like the substation interlocking (see also section 4) where central devices assume an important role when handling a command release. In order to release commands as soon as possible, GOOSE is preferred here since updating the equipment states is more critical with regard to time.

3.7 Procedures

Below the SBO sequence (SBO control with enhanced security) is demonstrated for several cases:

1. Fault-free sequence (picture 3)
2. Abort of the sequence by negative response to the *Select* command (e.g. if not released by interlocking, picture 4)
3. Abort of the sequence by *Cancel* command (e.g. cancelled by operator, picture 5)
4. Abort of the sequence after timeout in the *Select* phase (*Operate* does not arrive or comes too late, picture 6)
5. Abort of the sequence by negative response to the *Operate* command (e.g. if not released by interlocking, picture 7)
6. Abort of the sequence after timeout in the *Operate* phase (e.g. switching device does not start or does not reach the final position, picture 8)

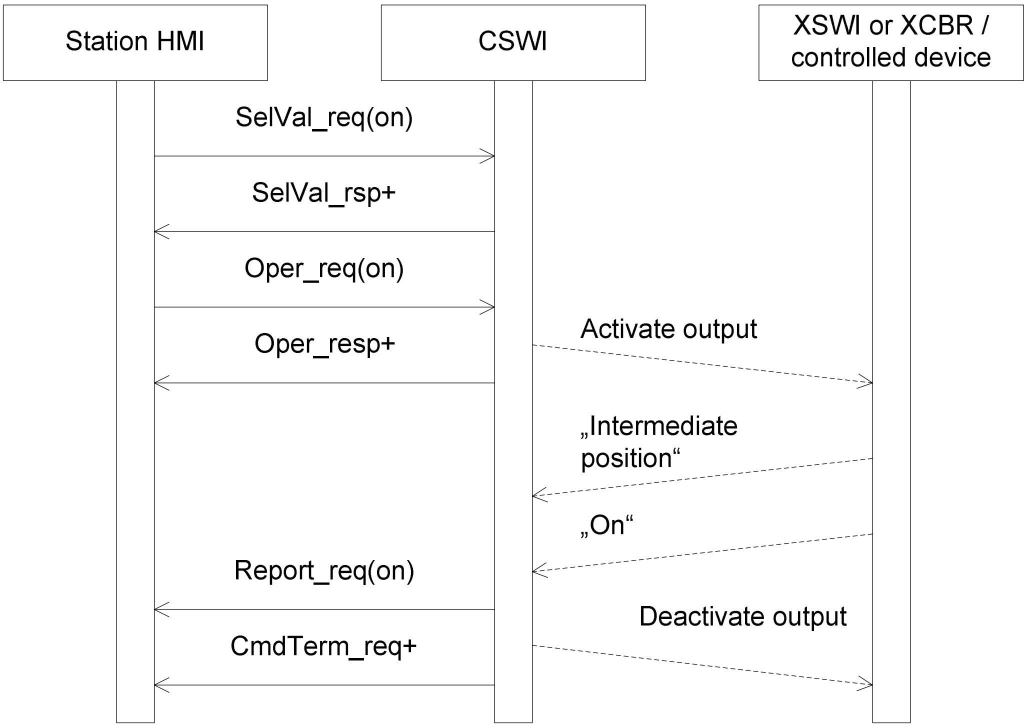


Fig. 3: Fault-free sequence

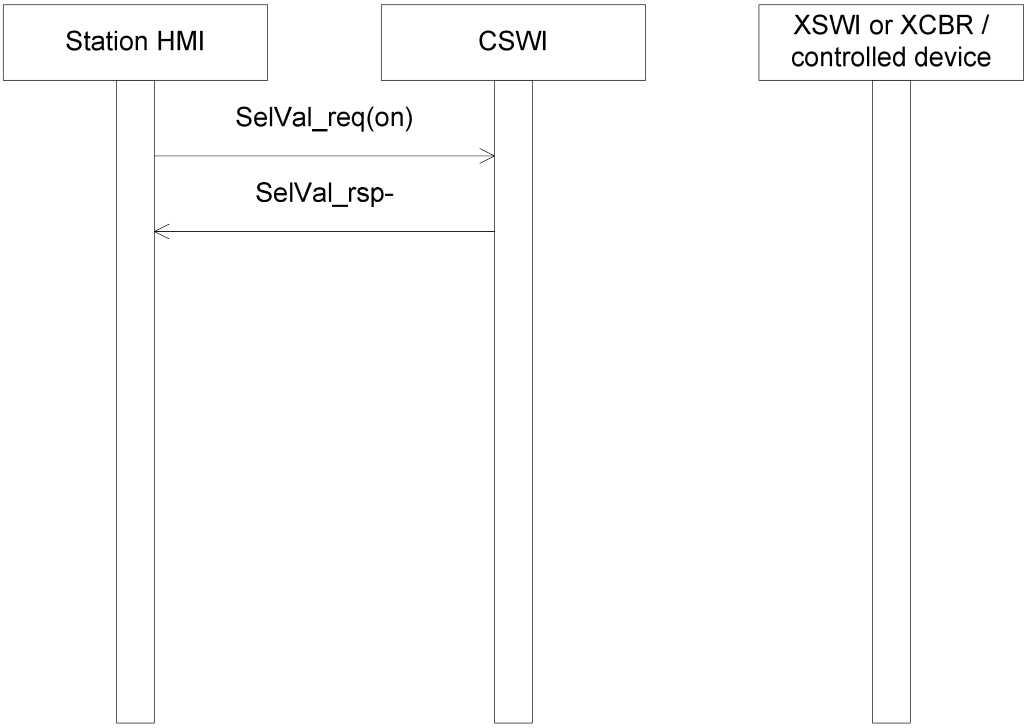


Fig. 4: Abort of the sequence after negative test result ("*Select*" phase)

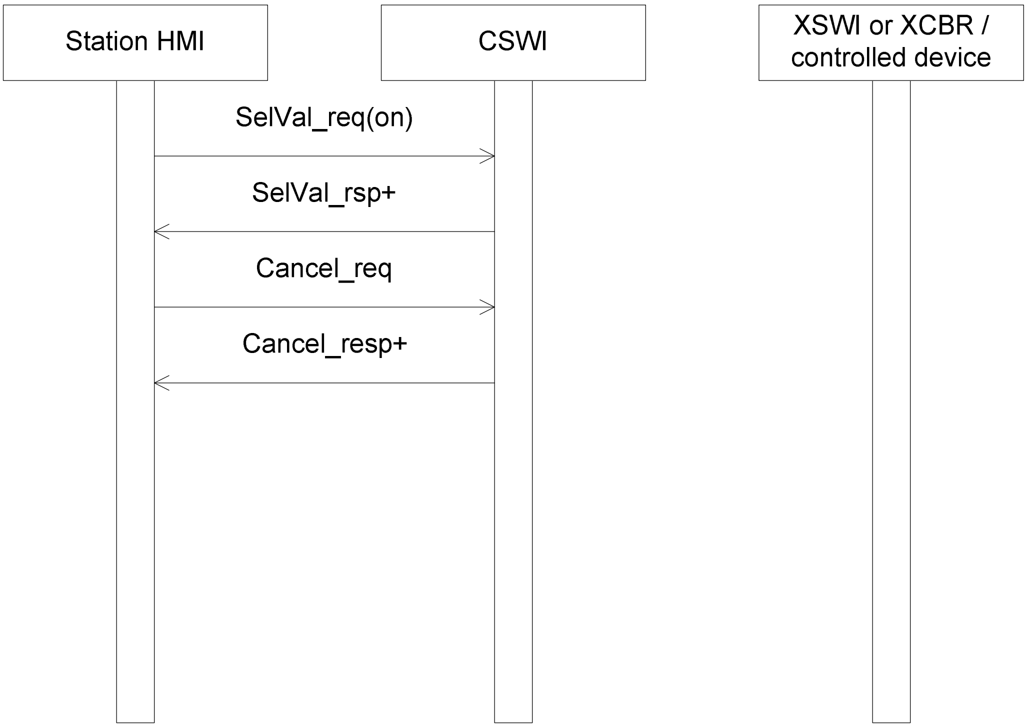


Fig. 5: Abort of the sequence by "*Cancel*"

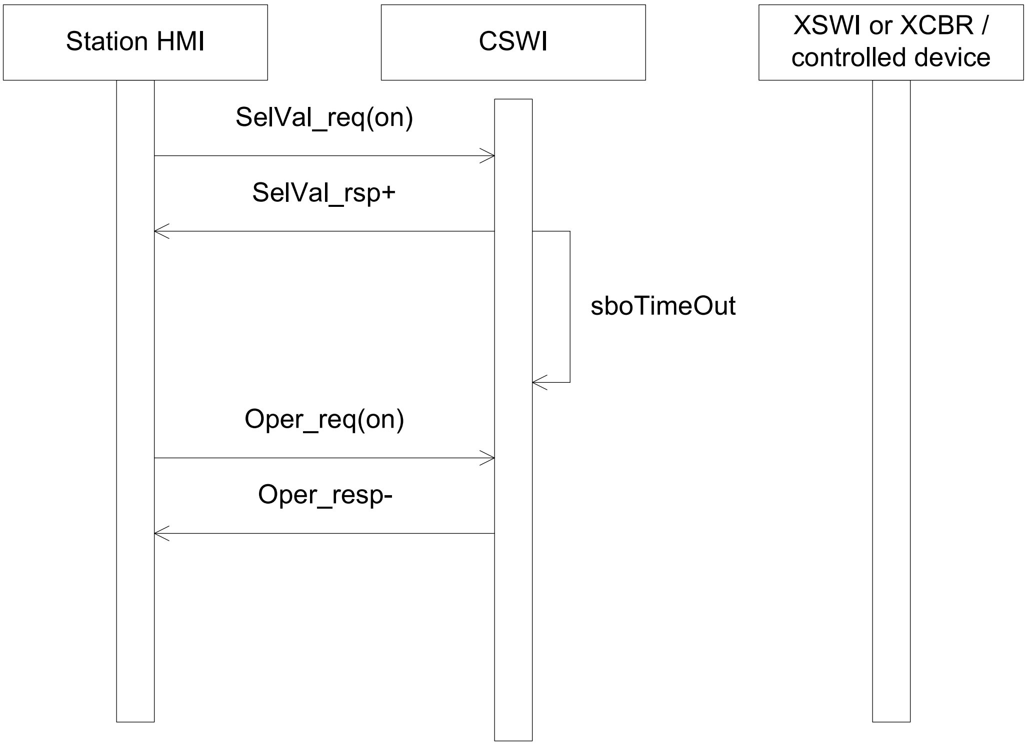


Fig. 6: Abort of the sequence after timeout ("*Select*" phase)

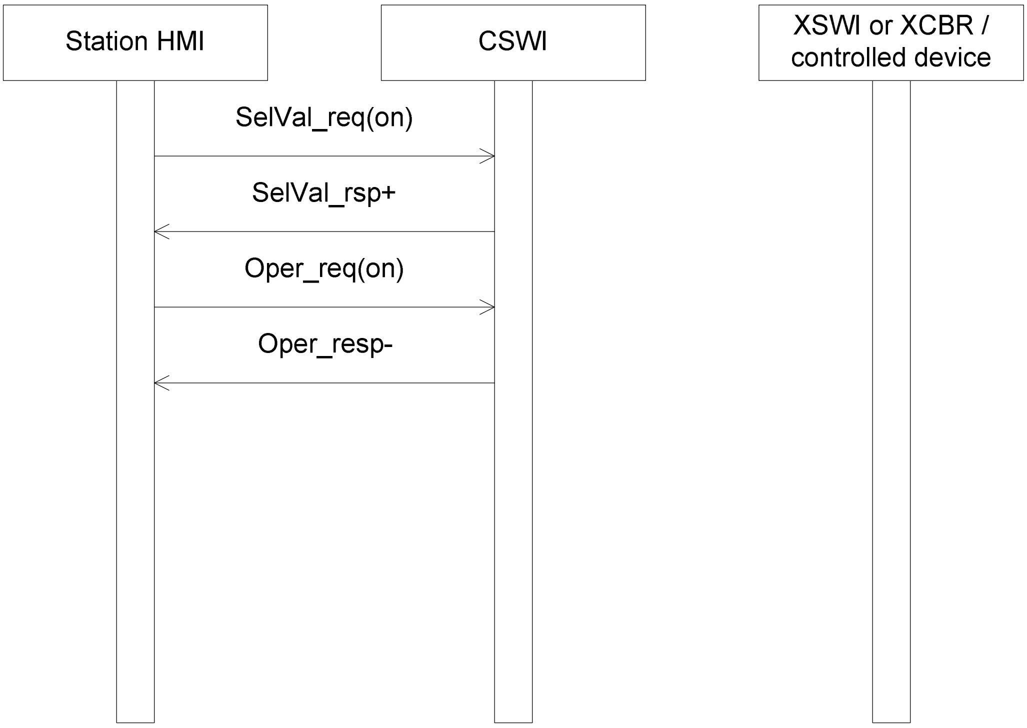


Fig. 7: Abort of the sequence after negative test result ("*Operate*" phase)

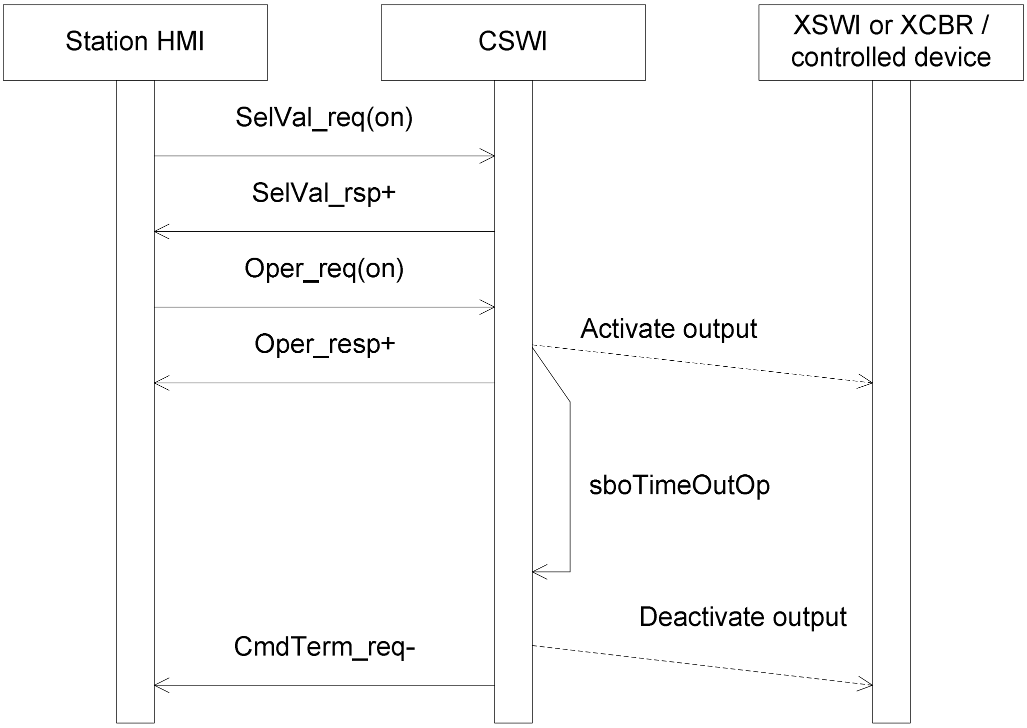


Fig. 8: Abort of the sequence after timeout ("*Operate*" phase)

3.8 Marginal conditions

None!

4 Implementation of substation interlocking

4.1 Application

The interlocking function serves to block the actuation of switching devices if this could impose a danger for humans, devices or the operation. 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. A differentiation is made between bay interlocking and substation interlocking.

Bay interlocking affects only the switchgear of a bay whereas substation interlocking concerns the entire substation or parts thereof. The interlocking conditions of the individual bays are included in these bay-spanning interlocking conditions.

Furthermore, the “double operation block” function is usually counted as a subfunction of substation interlocking.

The double operation block ensures that only one switching device within a bay, substation section or in the entire substation can be operated.

IEC61850 provides a mechanism via the „DPC.stSeld“ to implement the double operation block (see section 4.3.1). This mechanism causes the bay unit to send a message to all subscribers in the same network section before starting a switching operation so that no additional switching operation is started in a predefined substation section (e.g. bay, substation etc.). Only after feedback has been given that the switching operation has been completed, can the next switching command be processed. The switching operation is considered to have been started when the bay unit has received either “Select” (SBO) or “Operate” (Direct Control).

4.2 Information and communication subscribers

4.2.1 Types of information

The following types of information are used to implement the substation interlocking:

- Command outputs that can be initiated via local or remote operation or from the network control center,
- Status information such as
    - position indications from switching devices
    - warning and fault messages from auxiliary equipment
    - measured values
- Release information

Implementing a bay-spanning interlocking function requires these information items to be exchanged between the participating IEDs.

4.2.2 Implementation concepts

Basically, there are three different implementation concepts (Fig. 9, 10, 11). The concepts differ in which IEDs exchange information with each other and in which IEDs the interlocking conditions are checked by the interlocking logic.

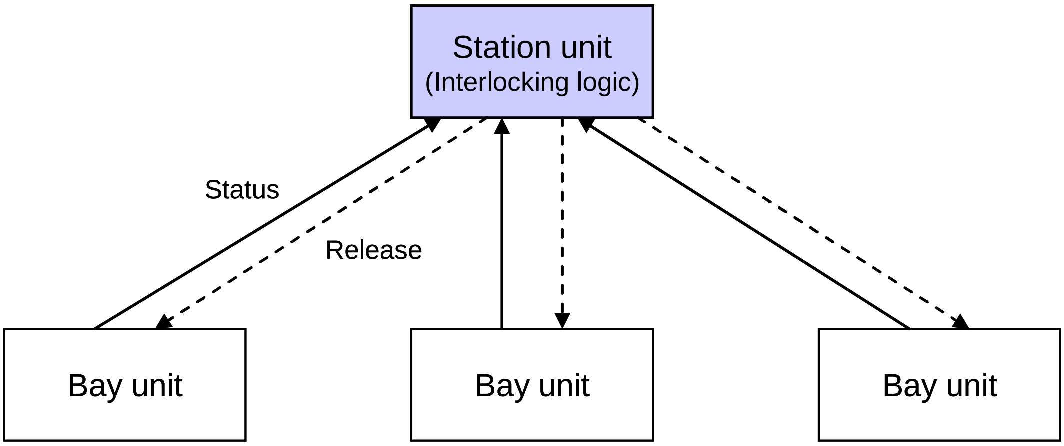


Fig. 9: Central interlocking in substation unit:

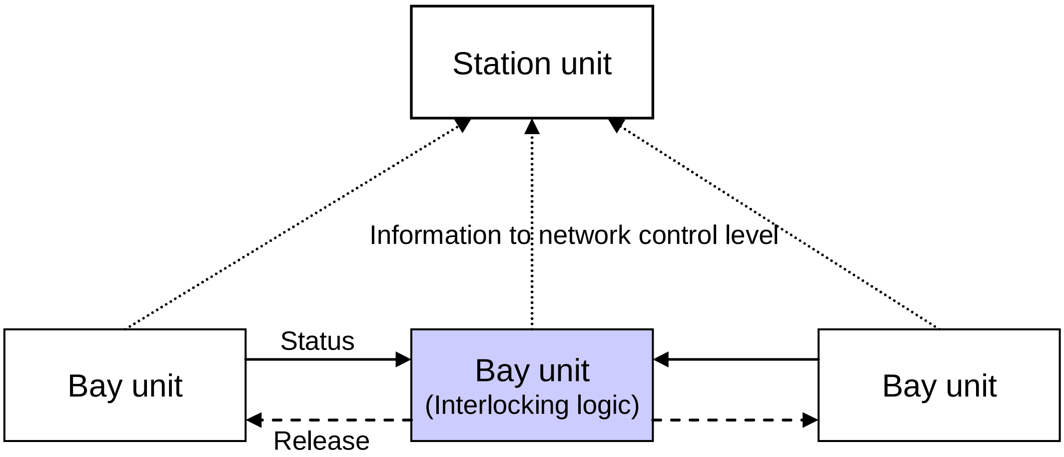


Fig. 10: Central interlocking in dedicated bay unit:

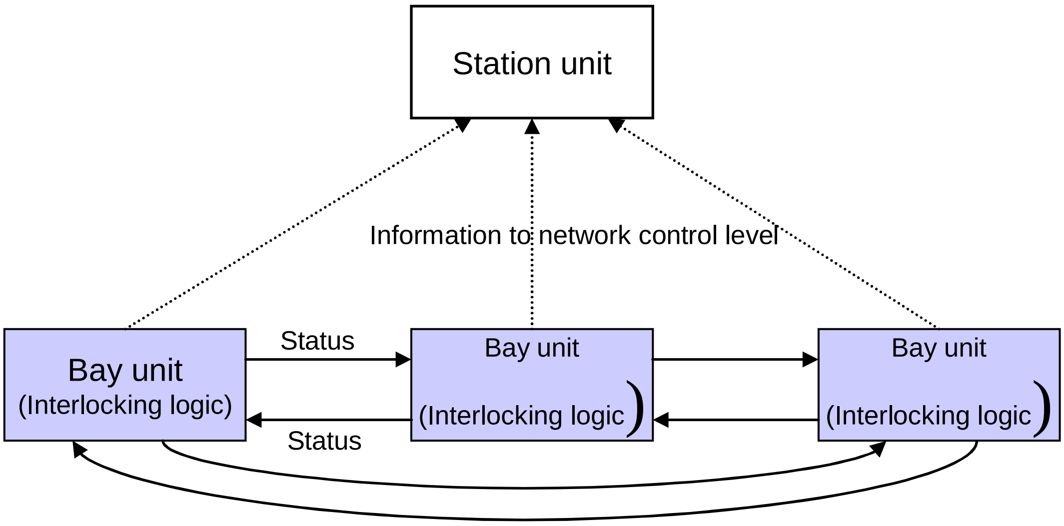


Fig. 11: Distributed interlocking in bay units

In the concepts “central interlocking in substation unit / in dedicated bay unit” (Fig. 9, 10) the interlocking logic is integrated in a central IED. The IED maintains a process image that comprises all information relevant for the bay-spanning interlocking conditions. To this end, the bay units transmit the relevant status information to the central IED. The release information calculated by the interlocking logic is sent to the corresponding bay units. This release information is the basis for executing or blocking a command output by the bay units.

The central substation interlocking again differentiates whether the substation interlocking is integrated in the interlocking logic of the substation unit or whether the bay-related interlocking logic is implemented in the bay unit itself.

With the concept of „distributed substation interlocking in bay units“ (Fig. 11), the bay-spanning interlocking logic is distributed among all participating bay units. The interlocking logic of each bay unit calculates both the interlocking conditions of the bay interlocking and the bay-specific interlocking. Moreover, each bay unit provides the status information required by other bay units for calculating the corresponding bay-spanning interlocking conditions.

4.2.3 Comparison of the concepts

The following table compares the implementation concepts with each other with regard to the criteria relevant for system and operation.

Criterion	Central concept / substation unit	Central concept / dedicated bay unit	Distributed concept
Interoperability	hardly given (a)	hardly given (a) given (b)	given (b)
Availability (N-1) / behaviour in the event of single faults	low	low	high
Influence of message bursts	high	high	low
Expandability	good	good	complex
Maintenance /service	good	good	complex
a. Client-server communication b. Multicast communication			

Table: Comparison of the implementation concepts

For the concept „central interlocking in the substation unit“ special procedure have to be defined that require additional information (e.g. release requests to the substation unit in case of a local command). An interoperable solution here requires a high configuration effort and presumes that the participating devices have the functions to support this procedure.

In comparison, less configuration effort is needed for the concepts using multicast communication (GOOSE). Furthermore, most of the device technology for bay units available today does not provide client functionalities. As a consequence, the interoperability of the interlocking applications based on multicast communication (GOOSE) is greater than that based on client-server communication (Reporting).

During a message burst, a great amount of information is sent from the bay units to the substation unit within very short time. The IEDs’ capacity to process information is usually limited. Since the substation unit must handle a greater volume of information than the bay units, the demands on the robustness of the interlocking logic in the face of message bursts are higher for the concept of “central interlocking in substation unit” than for the concepts with bay-level interlocking logic.

The ”availability” criterion is used in the following exclusively to designate the reliable availability of the interlocking function, the full availability of the communication connection is regarded as given.

As far as a component’s (IED) availability in the event of a failure is concerned, the corresponding arrangements in the interlocking logic have to be made for all concepts. A single fault can lead to the following results:

- Central interlocking concepts: Should the central interlocking logic fail, the entire bay-spanning interlocking functions will become unavailable.
- Only non-interlocked switching is possible for the central interlocking with integrated bay interlocking logic in the event of the connection being interrupted. Here control of the entire system is blocked.
- Central and distributed interlocking concept: If one bay unit fails, the bay-spanning interlocking function usually remains function with limitations. In some applications, however, the failed connection to a bay unit will entail blocking of the control for the entire system.

Substation expansions and maintenance or service work require modifications of the interlocking logic. When the substation is expanded, the new status information has to be added to the interlocking conditions. During maintenance or service the status information of the corresponding bay are usually updated in the interlocking logic. Different approaches are required for each interlocking concept:

- Central interlocking concepts: The expansion or updating only has to be carried out in the central interlocking logic.
- Distributed interlocking concept: The interlocking conditions or updating must be carried out in all bay units involved.
- For some substation units it is possible to freeze the present states for individual bay units (so-called bay blocking) to perform service work in the associated field.

4.3 Required object information (LN/DO/DA)

In order to map the substation interlocking, the status and release information have to be modelled using appropriate data objects. The list below shows the data objects exchanged among IEDs. Commands have to be configured as described in section 3.

A separate logical device is recommended for bay control functions. As a consequence, the corresponding logical nodes should be accommodated inside this logical device.

The list below shows which logical nodes, objects and data attributes should be used for substation interlocking.

4.3.1 Switchgear status messages

The positional information of the switchgear devices is to be modelled using the LNs XCBR and XSWI since these two represent the physical switchgear status without suppression of the intermediate position unlike CSWI.

LN	Data	CDC	Attributes	Values and Report Text	Comment
XCBR					Overall commands and messages
	Pos	DPC	stVal q t stSeld	0 - Intermediate 1 - off 2- on 3 – bad false, true	Switchgear status Switching operation In process
XSWI					Overall commands and messages
	Pos	DPC	stVal q t stSeld	0 - Intermediate 1 - off 2- on 3 – bad false, true	Switchgear status Switching operation In process

4.3.2 Release information from switchgear

The LN CILO shall be used to model the release information from switchgear units.

LN	Data	CDC	Attributes	Values and Report Text	Comment
CILO					Overall commands and messages
	EnaOpn	SPS	stVal q t	0 – False 1 – True	Indicates whether the target position “On” is released by the interlocking logic
	EnaCls	SPS	stVal q t	0 – False 1 – True	Indicates whether the target position “Off” is released by the interlocking logic

4.3.3 General status and release information

No special logical nodes are available to model derived and grouped release information (e.g. status via inserted busbar coupler). The LN GGIO can be used for such information.

LN	Data	CDC	Attributes	Values and Report Text	Comment
GGIO					Overall commands and messages
	Ind	SPS	stVal q t	0 – False 1 – True	General status and release information

4.3.4 Fault messages and measured values

To reproduce fault messages (e.g. communication interrupted etc.) and measured values (e.g. phase-to-earth voltages) the corresponding LNs should be used.

4.4 Time requirements

The command time (time lag between command output and switching or blocking the output circuits of the bay unit) should not exceed 500 ms.

It must be ensured that

- the process image on which the calculation is based reflects the physical process state at any time during the command time,
- changes of the physical process state or communication interruptions between the participating IEDs are registered and responded to during the command time to prevent inadmissible operating states.

Changes of the switching status caused by control operations, tripping of the circuit breaker or implausible switching states must be reported to the corresponding IEDs with a short delay, high priority (no overriding by other services) and high recording security.

4.5 Evaluation of the possible services

4.5.1 Central interlocking in substation unit

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Transmission of the status information						
Requirement for this application	***not required***	***not required***	***< 100ms***	***low***	***low***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied
Transmission of release information to bay units						
Requirement for this application	***required***	***not required***	<=1s	***low***	***low***	***not required***
Applicability of the possible services						
Control via request/response	satisfied	not satisfied	< 100ms	very low	low	not satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

4.5.2 Distributed interlocking in dedicated bay unit

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Transmission of the status and release information						
Requirement for this application	***not required***	***not required***	***< 100ms***	***low***	***low***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

4.5.3 Distributed interlocking in bay units

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Transmission of the status and release information						
Requirement for this application	***not required***	***required***	***< 100ms***	***low***	***low***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

4.6 Selected services

4.6.1 Services / interlocking function

The following services should be used according to section 0 depending on which implementation concept is used.

Implementation concept	Service
Central interlocking in substation unit	Client-server communication (reporting)
Distributed interlocking in dedicated bay unit	Multicast communication (GOOSE) or client-server communication (reporting)
Distributed interlocking in bay units	Multicast communication (GOOSE)

4.6.2 Services / messages in direction of substation and network control center

Client-server communication should be used to report status information such as positional indications, fault and warning messages to the substation operator terminal and the network control center.

4.7 Procedures

Fig. 12 shows the basic sequence of interlocking in a bay unit after command output. After input of a command by one of the control levels in the system (network control level, substation control level or bay control level), a control logic (CSWI) checks whether the target position is released (CILO). The release or blocking information is provided by the interlocking logic. Status and release information from within the bay as well as information from other bay units are included to calculate the interlocking result. Furthermore, the interlocking logic provides the calculated status and release information from other bay units.

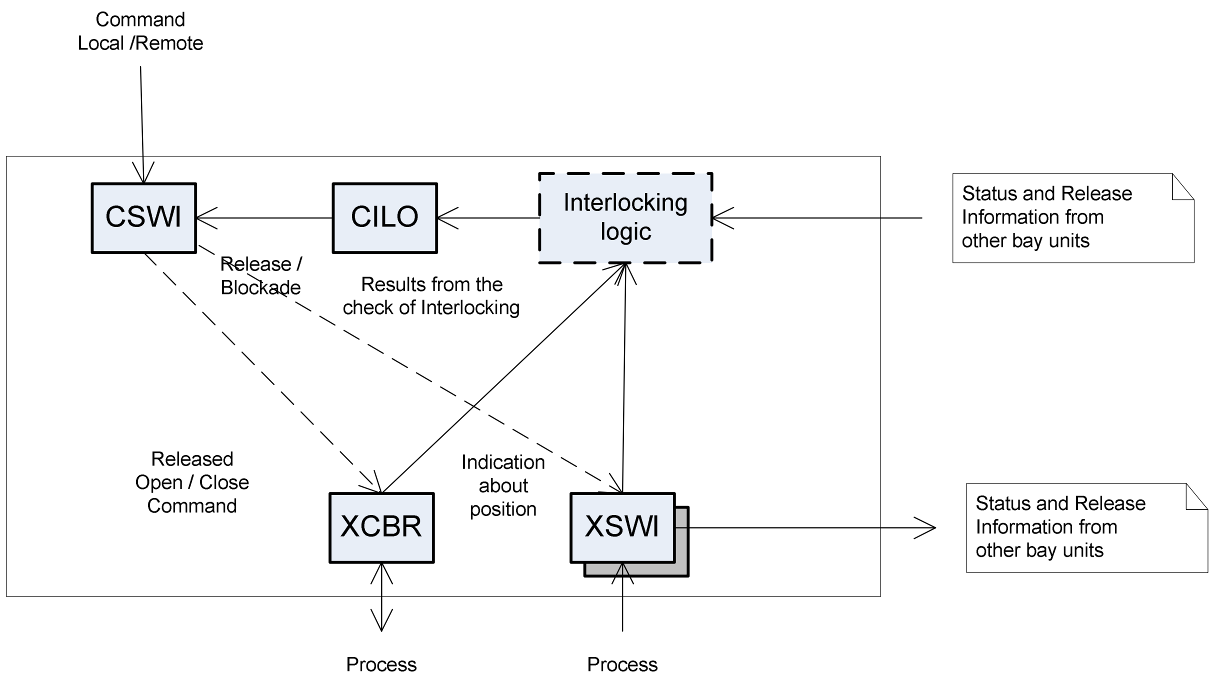


Fig. 12: Basic interlocking procedure in a bay unit

In case of a release, the command is output to the process; when blocked, no command is sent.

4.8 Marginal conditions

None

5 Switching with synchrocheck function

5.1 Application

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 Δ f < Δ fmax
- Difference of angles Δα < Δαmax

A comparison of the synchronism conditions can be performed by means of definitely applied voltages or by applying a voltage via relay during the runtime of the synchrocheck function.

The synchrocheck with application of the voltage is necessary e.g. for multiple busbars or in case of a failure of the coupling circuit breaker (backup circuit). The busbar voltage simulation function is usually used to provide a reference voltage. The synchrocheck with voltage application comprises the following partial functions:

- Applying the voltage
- Synchronous switching / parallel switching
- Voltage deselection

The synchrocheck with voltage application can be either central or distributed. With the central concept, a dedicated IED performs the synchrocheck function for the entire substation. With the distributed concept, the synchrocheck function is carried out by the IED of the bay to be connected.

5.2 Information and communication subscribers

5.2.1 Information

The following information is usually valid for all modes of the synchrocheck function:

- Information in command direction
    - o Closing the CB with synchrocheck function
    - o Closing the CB without synchrocheck function
    - o Abort of synchrocheck procedure
    - o Activating the synchrocheck function (only query of conditions)
- Information in message direction
    - o "synchrocheck running"
    - o “synchrocheck successful” or “synchrocheck unsuccessful”
    - o “synchronism condition violated”
    - o "synchrocheck faulted"
    - o "synchrocheck blocked"
    - o measured values of ΔU, Δf, Δφ

- messages of limit value violation of ΔU, Δf, Δφ
- "synchrocheck has not found a reference bay"
- "synchrocheck monitoring time expired"
- "synchrocheck rejected (e.g. no busbar section disconnector closed)"

5.2.2 Communication subscribers

The synchronization function can be activated by initiating a command locally, from the substation operator terminal or from the network control center. Fig. 13 shows the participating communication subscribers and the information flows as valid for all modes of the synchronization function.

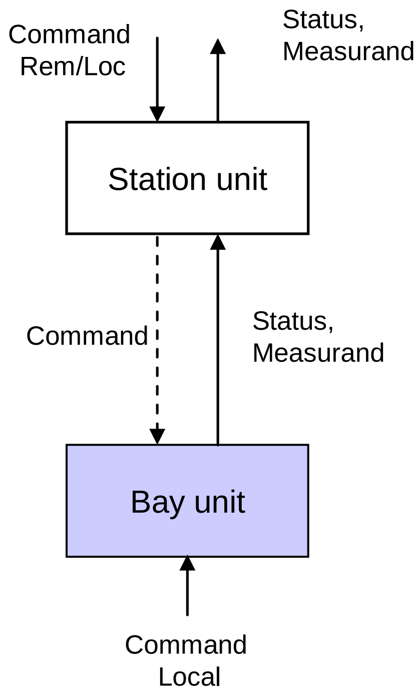


Fig. 13: Communication subscribers and information flows of the synchrocheck function.

5.3 Required object information (LN/DO/DA)

The status information of the synchrocheck function is shown in the table below.

LN	Data	CDC	Attributes	Values and Report Text	Comment
RSYN					Overall commands and messages
	Beh	INS	stVal q t	1 – On 2 – Blocked	Mode of the synchronisation function
	Health	INS	stVal q t	1 – OK 2 – Warning 3 – Alarm	Synchronization faulted
	Rel	SPS	stVal q t	0 – False 1 – True	Release close command
	VInd	SPS	stVal q t	0 – False 1 – True	Violation of voltage difference
	AngInd	SPS	stVal q t	0 – False 1 – True	Violation of angle difference
	HzInd	SPS	stVal q t	0 – False 1 – True	Violation of frequency difference
	SynPrg	SPS	stVal q t	0 – False 1 – True	Synchrocheck running
	DifVClc	MV	mag		Voltage difference
	AngVClc	MV	mag		Angle difference
	HzVClc	MV	mag		Frequency difference

5.4 *Time requirements*

The time requirements are uncritical. Antwortzeiten von ≤1 second is sufficient if the switching operation is triggered by an operator.

5.5 *Evaluation of the possible services*

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Initiation synchrocheck function						
Requirement for this application	***required***	***not required***	***< 100ms***	***very low***	***average***	***not required***
Applicability of the possible services						
Control via request/response	satisfied	not satisfied	< 100ms	very low	low	not satisfied

Feedback of the synchronism conditions						
Requirement for this application	***not required***	***not required***	***<=1s***	***very low***	***high***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE (with limitations only!)	not satisfied	satisfied	<20ms	average	high	not satisfied

5.6 Selected services

The client-server communication (reporting) should be used for the synchrocheck function. Transmission of the status information should be spontaneous, transmission of the measured values cyclical. The command for activating the synchrocheck function should be accomplished via Control per Request /Response and SBO with enhanced security.

5.7 Procedures

Picture 14 shows the basic sequence of synchrocheck function in a bay unit after a command. After input of a command by one of the control levels in the system (network control level, substation control level or bay control level), the synchrocheck function (RSYN) is activated after an existing interlocking check if necessary. The synchrocheck function is executed automatically. Status information and measured values are provided during execution and after completion of the synchrocheck function. If the conditions for synchronism have been checked successfully, the close command is released and carried out. If the check fails, the command is blocked and a corresponding message is generated.

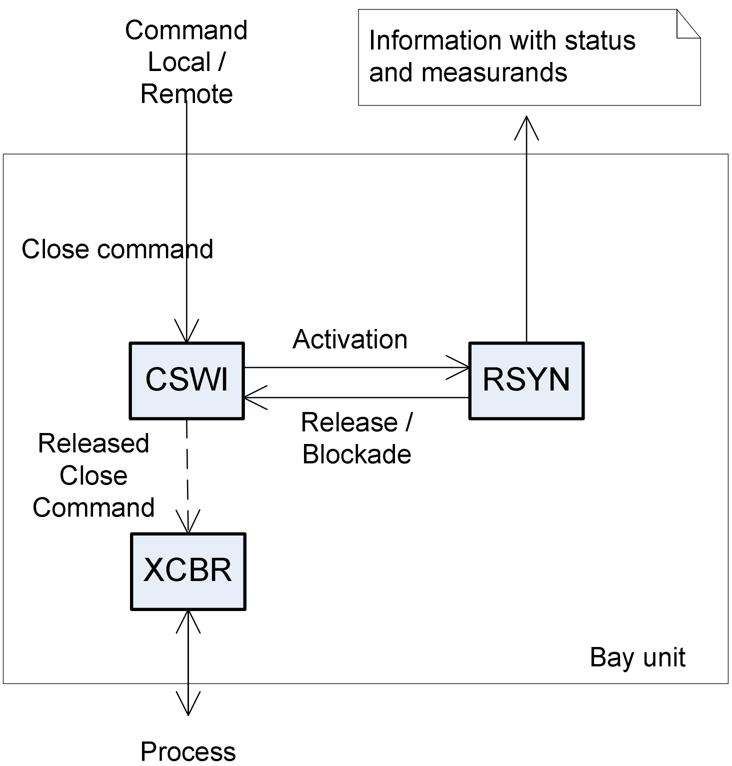


Fig. 14: Basic procedure of the synchrocheck function in a bay unit

5.8 Marginal conditions

None

6 Simulating the busbar voltage

6.1 Application

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 simulation” (BBS) 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 BBS in combination with the “distributed synchrocheck” function selects the reference bay whose voltage transformer circuits are connected galvanically to a ring feeder (or optical fibre) of the busbar section.

6.2 Information and communication subscribers

The following information is required for the BBS sequence:

- Status information
    - o Switchgear status messages
    - o Fault indications from auxiliary equipment that may initiate the abort of the BBS if no valid bay is found
- Voltage measured values
- Command to connect the voltage transformer circuits (BBS with synchrocheck)

The logic for the „busbar voltage simulation“ 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. When using the synchrocheck function with BBS, a command is sent to connect the voltage transformer circuits to the bay unit of the reference bay. Fig. 15 illustrates the information flows among the communication subscribers.

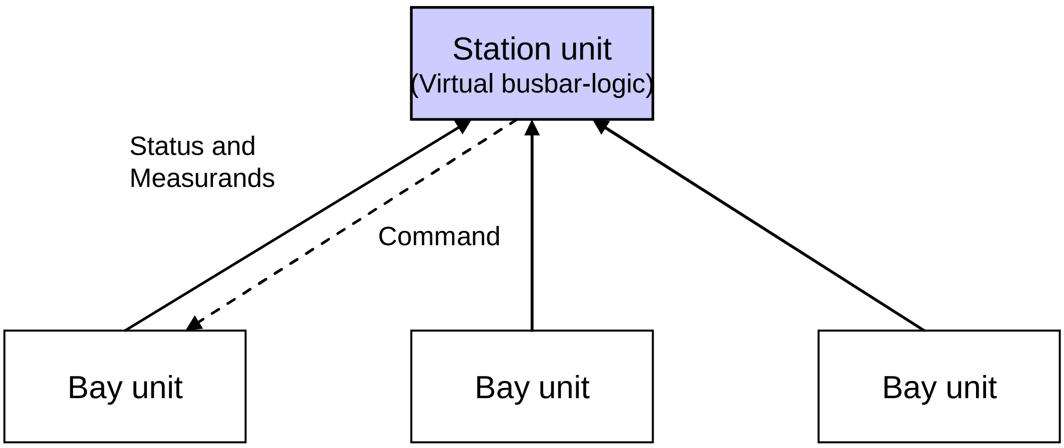


Fig. 15: Communication subscribers and information flows of the busbar voltage simulation

6.3 Required object information (LN/DO/DA)

The list below shows which logical nodes, objects and data attributes should be used for busbar voltage simulation.

LN	Data	CDC	Attributes	Values and Report Text	Comment
XCBR					Overall commands and messages
	Pos	DPC	stVal q t	0 - Intermediate 1 - off 2- on 3 - bad	Switchgear status
XSWI					Overall commands and messages
	Pos	DPC	stVal q t	0 - Intermediate 1 - off 2- on 3 - bad	Switchgear status

LN	Data	CDC	Attributes	Values and Report Text	Comment
MMXU					Overall commands and messages
	PPV	DEL	phsAB phsBC phsCA	Measured value	Phase-to-phase voltages
	PhV	WYE	phsA phsB phsC net	Measured value	Phase-to-earth voltages, displacement voltage

You should mostly use objects in the right context to simulate fault messages such as the fault message „voltage transformer mcb trip" in the LN TVTR. In cases where this is not possible, you can use generic objects like the LN GGIO.

LN	Data	CDC	Attributes	Values and Report Text	Comment
TVTR					Overall commands and messages
	FuFail	SPS	stVal q t	0 – False 1 – True	voltage transformer mcb tri

LN	Data	CDC	Attributes	Values and Report Text	Comment
GGIO					Overall commands and messages
	Ind	SPS	stVal q t	0 – False 1 – True	General status information
	Alm	SPS	stVal q t	0 – False 1 – True	General alarm information

Since no suitable logical node is available for the command to connect the voltage transformer circuits, the function can be simulated using the LN GGIO.

LN	Data	CDC	Attributes	Values and Report Text	Comment
GGIO					Overall commands and messages
	SPCSO	SPC	tlVal	0 – Off 1 – On	General status information

6.4 Time requirements

The updating time should not exceed 1 second.

6.5 Evaluation of the possible services

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Transmission of the status and measured value information						
Requirement for this application	***not required***	***not required***	***<500ms***	***low***	***low***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied
Transmission of the connection command:						
Requirement for this application	***required***	***not required***	<=1s	***low***	***low***	***not required***
Applicability of the possible services						
Control via request/response	satisfied	not satisfied	< 100ms	very low	low	not satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

6.6 Selected services

The client-server communication (reporting) should be used to implement the BBS. Transmission of the status information should be spontaneous, transmission of the measured voltage values cyclical. The command for connecting the voltage transformer circuits should be given via Control per Request / Response.

6.7 Procedures

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

6.8 Marginal conditions

Since the functions “substation interlocking” and “synchrocheck” share some identical objects and information, these should be transmitted together via the same service.

7 Commissioning and testing

7.1 Application

When information is processed in substations, it is necessary during certain inspection, test or service operations that recipients no longer receive information they usually receive during normal operation, or they have to be notified that the information does not reflect the normal status to derive corresponding reactions. For instance, unloading of switching lines during commissioning checks or removing test messages and test values not relevant for the evaluation from event logs.

It is equally important to deliberately block commands from external communication subscribers during check, test or service work.

Standard protocols like IEC60870-5-103 provide the so-called “message and measured value blocking” and the “command blocking”. This concept can not be used within the scope of IEC61850 since not only two communication subscribers (master and slave) but rather a multitude of controlling and monitoring communication subscribers (clients) can access the bay units (servers), as shown in Fig. 16.

The test concept of IEC61850 uses the following information:

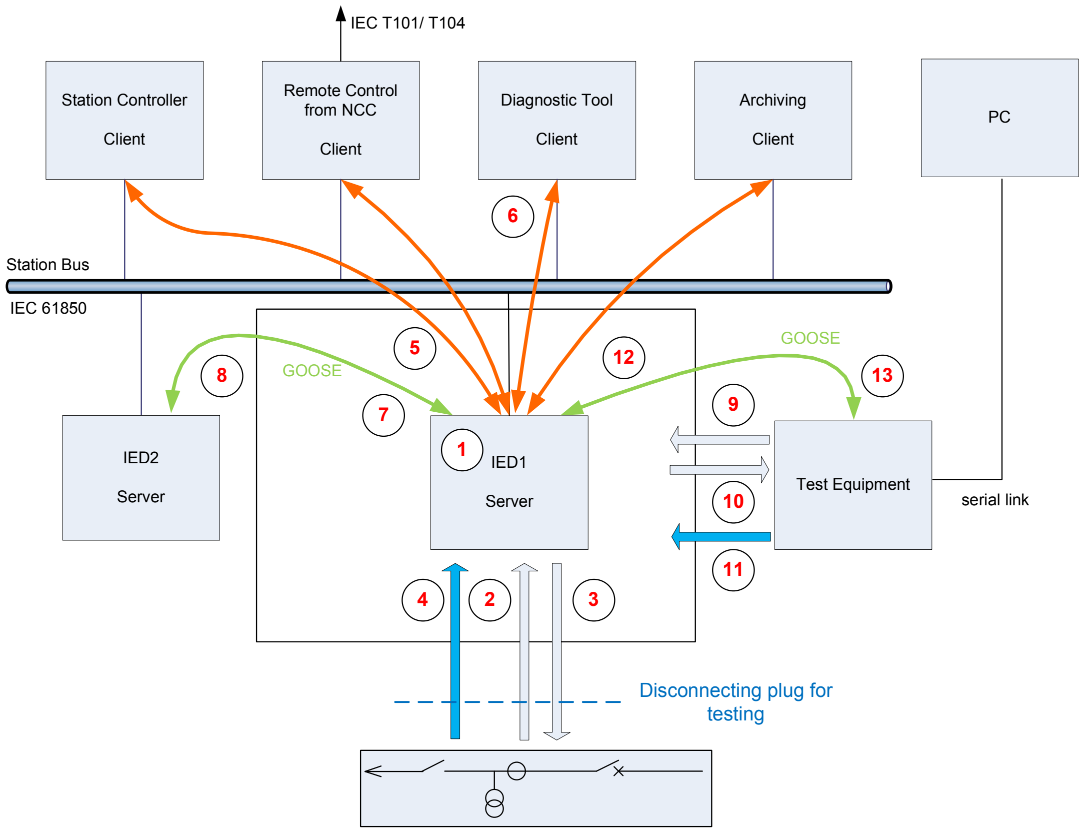
- The data objects Mod/Beh of the central node LLN0 for switching and signalling the test mode.
- The quality identifier of the data attribute .q (quality) contained in each data object for reporting and Goose.
- The service parameter “T” for executing a command from the client during test mode.

If the IED is switched as server in the test mode, the test bit is henceforth set in the attribute –q for each message to an external destination (e.g. reporting or Goose) so that all affected clients and GOOSE subscribers will now ignore this information or handle it separately.

A command coming from an external source is handled in the same way. An IED in test mode must ignore each command without test bit from a client or GOOSE publisher. The IED may only execute commands sent with set test attribute (service parameter „T“ or „q-Test“).

This ensures that all actions and reactions of the communication subscribers in the network can be clearly assigned to either the normal mode or test mode. This method is of special interest for bay-spanning checks since it allows the rather complex Goose structures to be included in or excluded from the test.

The application description of this chapter first looks at the substation configuration without process bus as is customary today, i.e. the primary system is generally connected to the secondary system via parallel wiring. Later, we will take a look at the test mechanisms for substations with process bus.



(1) Control on Device HMI
(2) Binary Input Control from the Process
(3) Binary Output to the Process
(4) Measured Values from the Process
(5) Control Command from Client
(6) Signals and Measurements to the Client
(7) Control Commands from GOOSE-Publisher
(8)
(9) Control Command from Test System (Binary Outputs)
(10) Signal to Test System (Binary Inputs)
(11) Measured Values from the Test System
(12) Control Command per GOOSE from Test System
(13) Signals and Measurements per GOOSE to the Test System

Fig. 16: Communication subscribers and information flows during commissioning and test

7.1.1 Overview for commissioning and testing

The following table provides an overview of the test scenarios that are typically encountered in practice and describes the anticipated behaviour of all affected communication subscribers.

The first column gives reference to the subsequent chapter including the detailed analysis. There an evaluation is carried out based on these criteria:

1. Target of the test
2. Possible test scenarios (if there is more than one)
3. Examples
4. Requirements

The test scenarios in the second column differentiate the type of disconnecting point for switching the connections between equipment under test and process. There is a separation of the measured value connection alone and a joint separation with the binary inputs/outputs towards the process. If a disconnecting point has been activated, the interface connected previously to the process is routed to a test system for signal simulation. Switching of the disconnecting point is usually effected directly at the bay.

The third column describes several options for launching the test scenario. The test mode at the IED can started either via local operation, a client (e.g. control equipment) or via binary input. The binary input is controlled via a contact directly from the disconnecting point or by a separate switch provided for this purpose.

Switching the IED into test mode is always done for an entire logical device (LD). Control is to be accomplished via the node LLN0/Mod of the corresponding LD. When activated via client, it is assumed that an authorization check is carried out at the control stations of the control system before sending the control command to the IED via IEC61850.

The client participating in the test mode can either be switched to test mode itself, or it can provide a special control section for sending appropriate commands with tagging of the test attribute. This client can thus switch individual IEDs into test mode in order to test it. The remainder of the substation can continue to run in normal mode so that no operational information is lost on the client side.

The fourth column describes the corresponding responses on the IEC 61850 interface following the initiation. It is limited to such information as is transmitted on the communication interface itself.

The fifth column shows that the equipment under test can remain in the normal mode throughout some test steps. Quite often, a detailed interface or function test is performed in test mode followed by a random check in normal mode. This is to ensure that the IED behaves identically in both operating modes.

The other columns contain the entries for 13 different action partners of the part under test while the test is executed. For a clearer overview, these are indicated with a number in Fig. 16.

The behaviour of the part under test anticipated for each test scenario is described by the text entry in the table. The legend is located below the table. The relevant differentiation is accomplished by handling or marking the test attribute and the interface switchover via the disconnecting point.

Chapter in Appl. Descr.	Testing Steps of IED as Server	initiated from	Used Service	IED Status Request	1 Control on Device HMI	2 Binary Input Control from the Process	3 Binary Output to the Process	4 Measured Values from the Process	5 Control Command from Client	6 Signals and Measurements to the Client	7 Control Commands from GOOSE-Publisher	8 Signals and Measurements to GOOSE-Subscriber	9 Control Command from Test System (Binary Outputs)	10 Signal to Test System (Binary Inputs)	11 Measured Values from the Test System	12 Control Command per GOOSE from Test System	13 Signals & Measurements per GOOSE to Test System
Chp.7.1.2	Normal Operation			Normal Mode	x	x	x	x	x oT	x	x oT	x	nv	nv	nv	nv	nv
Chp.7.1.3	Test of primary equipment and wiring every bay	a: Operator on device HMI b: Client sets LLN0.Mod = test c: Test plug in bay activated	LLN0.Beh.stVal = test	Test Mode	x	x	x	x	x mT	x mT	x mT	x mT	o	o	o	nv	nv
Chp.7.1.4	IED protection test (with measurement test plug only, typically with CB testing)	a: Operator on device HMI b: Client sets LLN0.Mod = test c: Test plug in bay activated	LLN0.Beh.stVal = test	Test Mode	x	x	x	x oP	x mT	x mT	x mT	x mT	x	x	x	x mT	x mT
	IED protection test (with measurement & I/O test plug)	a: Operator on device HMI b: Client sets LLN0.Mod = test c: Test plug in bay activated	LLN0.Beh.stVal = test	Test Mode	x	x oP	x oP	x oP	x mT	x mT	x mT	x mT	x	x	x	x mT	x mT
Chp.7.1.5	Commissioning test every bay (Wiring, functional test of whole cell, with measurement test plug only)	a: Operator on device HMI b: Client sets LLN0.Mod = test c: Test plug in bay activated	LLN0.Beh.stVal = test	Test Mode	x	x	x	x oP	x mT	x mT	x mT	x mT	x	x	x	x mT	x mT
	Commissioning test every bay (Wiring, functional test of whole cell, with measurement & I/O test plug)	a: Operator on device HMI b: Client sets LLN0.Mod = test c: Test plug in bay activated	LLN0.Beh.stVal = test	Test Mode	x	x oP	x oP	x oP	x mT	x mT	x mT	x mT	x	x	x	x mT	x mT
	Commissioning test every bay (Wiring, functional test of whole cell, with measurement & I/O test plug, IED in normal mode)	a: Test plug in bay activated	No reaction	Normal Mode	x	x oP	x oP	x oP	x oT	x	x oT	x	x	x	x	x oT	x
Chp.7.1.6	Commissioning test whole substation (bay interactive function, measurement test plug only)	a: Operator on device HMI b: Client sets LLN0.Mod = test c: Test plug in bay activated	LLN0.Beh.stVal = test	Test Mode	x	x	x	x oP	x mT	x mT	x mT	x mT	o	o	x	x mT	x mT
	Commissioning test whole substation (bay interactive function, with measurement & I/O test plug, IED in normal mode)	a: Test plug in bay activated	No reaction	Normal Mode	x	x oP	x oP	x oP	x oT	x	x oT	x	x	x	x	x oT	x
Chp.7.1.7	Communication LT, Archivrechner, NLT (mit MW&E/A-Trennstelle)	a: Operator on device HMI b: Client sets LLN0.Mod = test c: Test plug in bay activated	LLN0.Beh.stVal = test	Test Mode	x	x oP	x oP	x oP	x mT	x mT	x mT	x mT	x	x	x	x mT	x mT
	Bittest Communication Link to Substation OI, Archive System, Network System (with measurement & I/O test plug, IED in normal mode)	a: Test plug in bay activated	No reaction	Normal Mode	x	x oP	x oP	x oP	x oT	x	x oT	x	x	x	x	x oT	x

Legend:
x = unlimited in operation
x oP = operative, but not connected to the process
x oT = operative, when sent without test attribute
x mT = operative, when sent with test attribute
o = not connected/operative
N/A = not applicable

7.1.2 Normal operation

The description of the normal mode is required to allow differentiating the IED's behaviour from the test mode.

General requirements:

- The IED is only allowed to respond to data without test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose).
- All information from the IED (to clients and to other IEDs via Goose) must be sent without test bit in message direction.

The IED can also be tested during normal mode. To do so, the connection of the IED to the process is interrupted by means of a disconnecting point (test switch or test connector) and the IED is tested in "live" mode. The behaviour described above must not change in the process for as long as the IED is not switched to test mode.

7.1.3 Testing the primary equipment and wiring for each bay

Target of the test: Ensuring the correct functioning and wiring of a bay, especially all connections between IED and primary system.

Examples:

- Adjustments at primary devices (e.g. adjusting the checkback contacts for isolator drives)
- Testing device indications (e.g. SF-6 gas pressure indications for circuit breakers)

As a result, we obtain the following requirements:

- The IED is put into test mode (HMI, client or binary input).
- The primary device remains connected with the IED, all inputs and outputs of the IED are active without restrictions (no disconnecting point active).
- The IED is only allowed to respond to data with test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose). The IED only accepts switching commands entered at its front panel or received from authorized clients (substation controller, test/diagnostic tools) as command with the test bit set.
- All information from the IED (to clients and to other IEDs via Goose) is sent with test bit in message direction so that the recipient can decide how to process this information via its logic.

IED test devices are not used in this case.

7.1.4 Testing the protection system

Target of the test: Ensuring correct wiring and functioning of the protection equipment of a bay.

The IED (e.g. protection device or combination device) is tested, the primary system can be out of operation or in operation[1].

The commissioning test or regular inspection checks the wiring, the correct response of the IED to input information (commands, binary inputs, measured values, Goose

[1] Owing to the high availability demands on the network equipment it may not be possible in many cases to switch off lines or transformers in order to perform regular inspections of the secondary system or to remedy faults. Hence, protection devices have to be tested during service when at least two independent protection systems exist.

messages) with regard to valid, invalid or missing information or states. When checking the bay-related protection, the test includes the bay-spanning functions in the IED which are organised in a distributed way, e.g. pickup or tripping of the switch backup protection.

Possible test scenarios:

- Protection check (only with MV disconnecting point, typically with circuit breakers)
- Protection check (with MV&I/O disconnecting point)

Examples:

- Commissioning tests or regular inspections of each protection system in interaction with primary devices (e.g. circuit breakers, disconnectors)
- Commissioning tests or regular inspection alone for each protection system

The IED is put into test mode (HMI, client or binary input) or normal mode depending on the test concept and the condition of the system. The modes described in the table are presented in the test mode, but they can also be carried out in normal mode. The requirements remain the same.

Requirements:

- The primary system is disconnected from the IED at a disconnecting point. Either the measured values are disconnected here or additionally the binary inputs and outputs, too.
- The IED is only allowed to respond to data with test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose). Commands (e.g. switching the AR function, changeover of setting groups) are only accepted by the IED when they are entered at the front display or received from authorized clients (substation controller, test/diagnostic tools) as command with the test bit set.
- All information from the IED (to clients and to other IEDs via Goose) is only sent with test attribute in message direction so that the recipient can decide how to process this information via its logic. This also applies to the fault records.
- The tests require the use of IED testing equipment. The information necessary for the function is simulated by the testing device. For instance, messages (e.g. CB, disconnector feedback for AR, switch backup protection, protection signal transmission) and measured values (current, voltage) are created and injected at the disconnecting point (test switch or connector) for the IED to be tested. The IED's reactions are verified by the testing device. It must be possible to run the testing device in normal mode and in test mode.
- The testing device can exchange binary information for the testing process with the IED via binary inputs/outputs and via Goose communication. In case of Goose, the test attributes enables recognizing simulated or real process information.
- Measured values generally require a disconnection to inject test values in order to check functions running in the protection system, e.g. short-circuit breaking.

7.1.5 Commissioning test per bay

Target of the test: Ensuring correct wiring and functioning of an entire bay (primary and secondary system). The commissioning test checks the wiring, the correct response of the IED to input information (commands, binary inputs, measured values, Goose messages) with regard to valid, invalid or missing information or states. When checking the bay, the bay-spanning functions, which are organised in a distributed way, e.g. interlocking, are tested, too.

Possible test scenarios:

- Commissioning checks per bay (function of the entire bay, only MV disconnecting point)
- Commissioning checks per bay (function of the entire bay, with MV&I/O disconnecting point)
- Commissioning checks per bay (function of the entire bay, with MV&I/O disconnecting point, IED in normal mode)

Examples:

- Test of the bay interlocking
- Wiring check for initial commissioning
- Testing bay-related synchrocheck facility

The IED is put into test mode (HMI, client or binary input) or normal mode depending on the test concept and the condition of the system.

As a result, we obtain the following requirements:

- The primary system is disconnected from the IED at a disconnecting point. Either the measured values are disconnected here or additionally the binary inputs and outputs, too.

  Test mode:

  - The IED is only allowed to respond to data with test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose). The IED only accepts switching commands entered at its front panel or received from authorized clients (substation controller, test/diagnostic tools) as command with the test bit set.
  - All information from the IED (to clients and to other IEDs via Goose) is only sent with test bit in message direction so that the recipient can decide how to process this information via its logic.

  Normal mode:

  - The IED behaves as in normal mode and is only allowed to respond to data without test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose).
  - In message direction, the IED behaves as in the normal mode. All information from the IED (to clients and to other IEDs via Goose) is sent without test bit.

- IED test devices are not used in this case. The information required for the function from the participating partners is either generated by the real process or they are simulated by the testing device. The reaction is also verified.
- The testing device can exchange binary information for the testing process with the IED via binary inputs/outputs and via Goose communication. In case of Goose, the test bit enables recognizing simulated or real process information.
- Measured values alternatively provide a disconnection to inject test values in order to check functions running in the bay, e.g. synchrocheck, even when the substation is de-energized.

7.1.6 Commissioning tests per substation

Target of the test: Checking bay-spanning functions which are organized centrally and require measured values. Checking the exchange of information during normal operating conditions as final acceptance.

Possible test scenarios:

- Commissioning checks per substation (bay-spanning function, only MV disconnecting point)
- Commissioning checks per substation (bay-spanning function, with MV&I/O disconnecting point, IED in normal mode)

Examples:

- Checking the substation interlocking
- Testing central synchrocheck facility
- Checking automatic changeover functions

The IED is put into test mode (HMI, client or binary input) or normal mode depending on the test concept and the condition of the system.

As a result, we obtain the following requirements:

- The primary system is disconnected from the IED at a disconnecting point. Either the measured values are disconnected here or additionally the binary inputs and outputs, too.

  Test mode:

  - The IED is only allowed to respond to data with test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose). The IED only accepts switching commands entered at its front panel or received from authorized clients (substation controller, test/diagnostic tools) as command with the test bit set.
  - All information from the IED (to clients and to other IEDs via Goose) is only sent with test bit in message direction so that the recipient can decide how to process this information via its logic.

  Normal mode:

  - The IED behaves as in normal mode and is only allowed to respond to data without test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose).
  - In message direction, the IED behaves as in the normal mode. All information from the IED (to clients and to other IEDs via Goose) is sent without test bit.

- IED test devices are not used in this case. The information required for the function from the participating partners is either generated by the real process or they are simulated by the testing device. The reaction is also verified.
- The testing device can exchange the information required for the testing process with the IED via binary inputs/outputs and via Goose communication. In case of Goose, a direct simulation by the testing device can not be implemented according to the current state of the standard.
- Measured values alternatively provide for a disconnection to inject test values in order to check functions running in the bay, e.g. synchrocheck, even when the substation is de-energized.

7.1.7 Checking the communication to the control center, archiving computers, network control center

Target of the test: The connected diagnostic devices, control units, archives etc. are checked here as to whether the information arrive and are processed as defined in the parameterisation. The Goose communication is checked within the scope of the bay or substation relation function check and is not considered anymore at this point.

Possible test scenarios:

- Checking the communication to the control center, archiving computers, network control center (with MV&I/A disconnecting point)
- Checking the communication to the control center, archiving computers, network control center (with MV&I/A disconnecting point, IED in normal mode)

Examples:

- Testing the data transmission between IED and their communication subscribers

The IED is put into test mode (HMI, client or binary input) or normal mode depending on the test concept and the condition of the system. Depending on the concept, there are more or less clients and rules where a message is to be transmitted in the special case under consideration.

As a result, we obtain the following requirements:

- The primary system is disconnected from the IED at a disconnecting point. The measured values are disconnected here and the binary inputs and outputs.

  Test mode:

  - The client involved in the test must be able to generate information with test bit and process these for this test.
  - The IED is only allowed to respond to data with test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose). The IED only accepts switching commands entered at its front panel or received from authorized clients (substation controller, test/diagnostic tools) as command with the test bit set.
  - All information from the IED (to clients and to other IEDs via Goose) is only sent with test bit in message direction so that the recipient can decide how to process this information via its logic.

  Normal mode:

  - The client involved in the test must be able to generate information without test bit and process these for this test.
  - The IED behaves as in normal mode and is only allowed to respond to data without test bit from neighbouring bays or from the higher-ranking control center (server-client or Goose).
  - In message direction, the IED behaves as in the normal mode. All information from the IED (to clients and to other IEDs via Goose) is sent without test bit.

- IED testing devices are not used in this case. The information required for the function from the participating partners is either generated by the real process or simulated by the testing device. The reaction is also verified.
- The testing device can exchange binary information for the testing process with the IED via binary inputs/outputs and via Goose communication. In case of Goose, a direct simulation by the testing device can not be implemented

according to the current state of the standard.

Measured values alternatively provide for a disconnection to inject test values in order to check functions running in the bay, e.g. synchrocheck, even when the substation is de-energized.

7.1.8 Restrictions

IEC61850 offers many more options to perform device and system checks. We have deliberately chosen the test employing a test switch or connector as the disconnecting point between bay device and primary system for this application. This kind of test is used very frequently today.

Other testing concepts, e.g. test via testing device with Ethernet interface for injecting analog and digital quantities directly over the bus or checking substations with a digital process bus according to IEC61850-9-2 will be dealt with later.

7.2 Information and communication subscribers

The requirements of the various testing scenarios are covered by disconnecting the IED from the process and/or configuring a test mode in the IED.

The test mode in the IED is always configured completely for all logical devices:

- by a special command from a client (test/diagnostic tool, control center, front display at the device if this can be implemented as client)
- via direct operation at the local control (binary contact)

Controlling the mode (to test and back) must be secured via a special authorization (key-operated switch, password, access to local control cabinet). Each modification is logged in the event list.

7.3 Required object information (LN/DO/DA)

Changing the data object Mod (= TEST) in the LLN0 of all logic devices (LD). The entire IED is switched to test mode as a result.

The following information is required by modifications of the Mod in the entire LD:

LN	Data	CDC	Attributes	Values and Report Text	Comment
LLN0					
	Mod	INC	ctlVal stVal q t ctlModel	on, test on, test direct-control-with-normal-security	Control of the logical node (the structure of the service parameters for ctlVal is defined by part 8-1) Status of the logical node Control method of the logical node

The message is accomplished in this case via the datum “Beh” over the communication interface:

LN	Data	CDC	Attributes	Values and Report Text	Comment
LLN0					
	Beh	INS	stVal q t	on, test	Status of the logical device

7.4 Time requirements

There are no special time requirements. But it should be assured that the test mode is activated virtually simultaneously in all LDs in the IED and logged only once for the entire IED.

7.5 Evaluation of the possible services

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Activation/deactivation of the test mode						
Requirement for this application	***required***	***not required***	***<=1s***	***low***	***low***	***not required***
Applicability of the possible services						
Control via request/response	satisfied	not satisfied	<=1s	very low	low	not satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied
Status report of the test mode						
Requirement for this application	***not required***	***not required***	***<=1s***	***low***	***low***	***not required***
Applicability of the possible services						
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

7.6 Selected services

<u>Insertion via Mod modification in LLN0 for the entire LD:</u>

Control model for activating / deactivating the substation control unit (client):

- Direct-Control-with-normal-security (is entered as the control model for Mode in LLN0 of the GAK15 substation)
- Direct-Control-with-enhanced-security

The following services result:

- Operate (Oper)
- CommandTermination (CmdTerm, only for enhanced-security)

Logging to substation control unit:

- Buffered / Unbuffered Reporting (with trigger options: data-change, quality-change, general-interrogation).

7.7 Procedures

The procedure for changing the mode is to set the value Mod of LLN0 of all logic devices (LD) to “TEST“.

If direct-control-with-normal-security is used for activation the Command_termination line is not applicable.

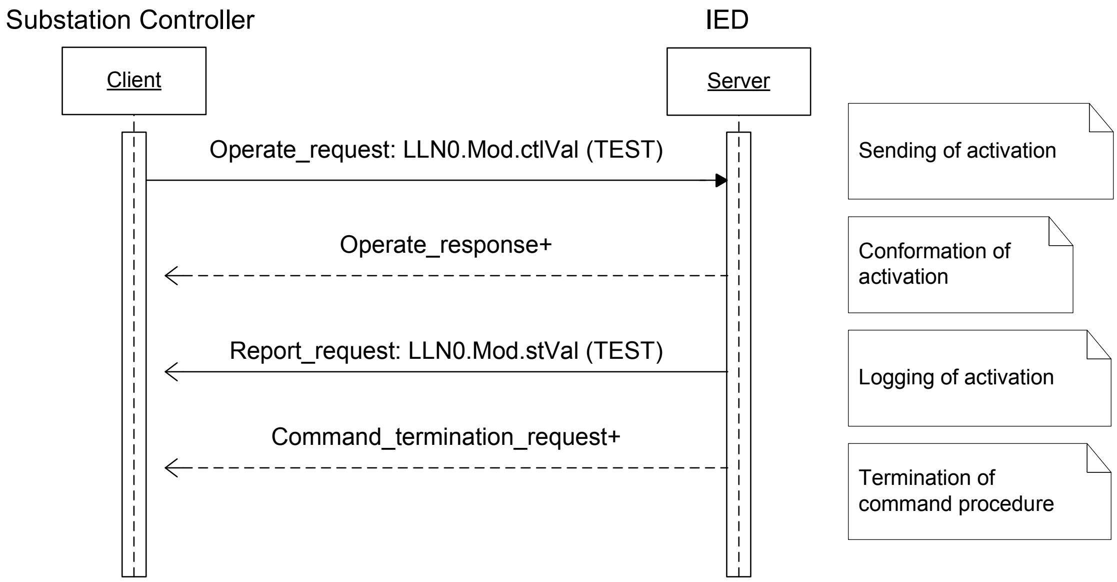


Fig. 19: Sequence of activating the TEST mode

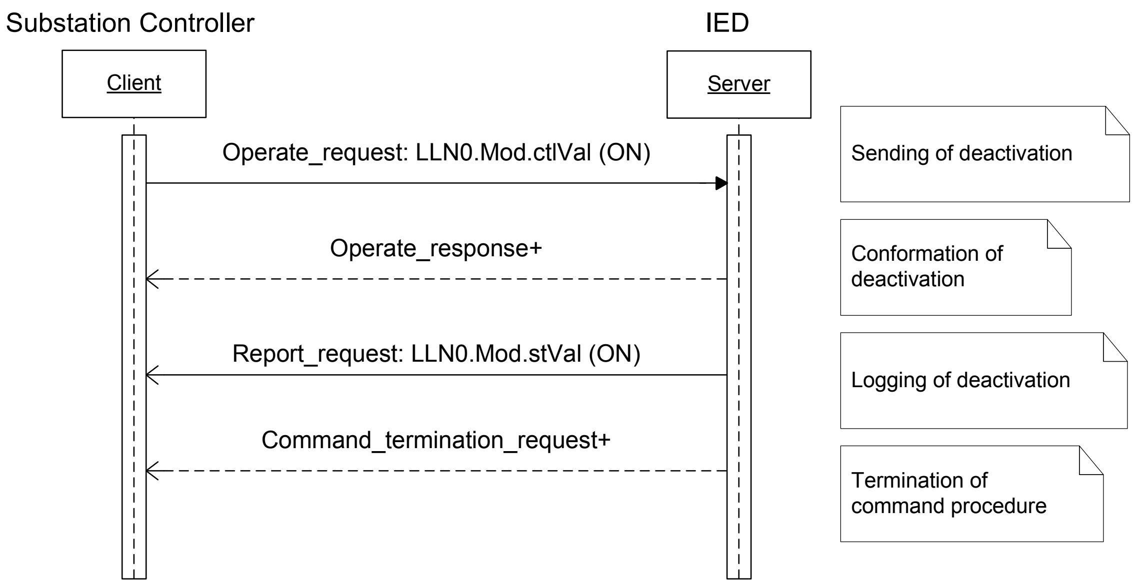


Fig. 20: Sequence of deactivating the TEST mode (back to ON mode)

7.8 Marginal conditions

none

8 Remote/local operation

8.1 Application

Switching between local and remote operation is controlling the switching authority between substation level and bay level in the bay device. The authorization, i.e. assigning and checking access rights for operating high-voltage switches, is thus implemented. The remote control status of the bay unit allows the local control from the operator terminal of the substation control device and the remote control from a network control center via a substation device gateway. The separation of the switching authority of these two control stations is integrated as an internal function in the substation control unit.

Switching between remote and local control on bay level is always induced via a key-operated switch (binary contact) or operation at the bay controller.

In case of local control, there are other operating modes like:

- LOCAL Local control via service control location, e.g. at the display of the bay device, with interlocking via bay/substation interlocking
- EMERG Emergency control via the emergency control elements of the individual bays, the control is without interlocking and without logged command output in the control center
- OFF Control not possible

8.2 Information and communication subscribers

The activation via communication is not possible because local/remote switchover is accomplished using key-operated switches or operation at the device. The information flow refers to the logging of the local/remote switchover.

- A local/remote switchover is activated via operation at the bay device or via a binary contact (key-operated switch) (no communication).
- The activation of the local/remote switchover is done in the device and logged on the higher-ranking substation control level via message transmission where it has to be acknowledged.
- All control commands arriving in the bay unit are rejected with a negative acknowledgement (BF-) for as long as local control is activated.

But no control commands should be sent to the bay unit in the first place since the output should have been blocked already by the substation control unit (evaluation of the feedback of remote/local switchover).

8.3 Required object information (LN/DO/DA)

Remote/local switchover:

Using IEC61850, the status indication for the remote/local switchover is accomplished via the data object Loc that is especially designed for this purpose:

LN	Data	CDC	Attributes	Values and Report Text	Comment
LLN0					Overall commands and messages
	Loc	SPS	stVal q t	ORTSTEU / NAHSTEU	Indication of control level

This data object will be reported centrally in the logical node LLN0 and in other logical nodes of the individual control functions.

Fig. 21 shows the basic set-up. Only the overall remote/local switchover is modelled in the GAK15 substation (LLN0.Loc; e.g. there is only one key-operated switch for the entire bay unit), not the selective switchover of the individual switchgear devices (XCBR.Loc). But the message of the Loc is mandatory for switchgear devices XCBR and XSWI and is thus also reported separately when the status changes.

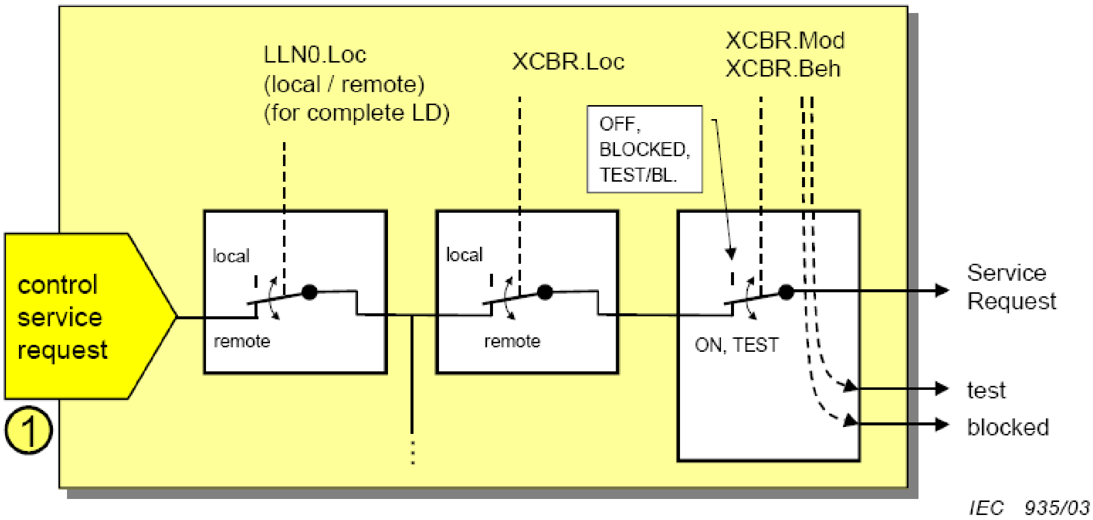


Fig. 21: Status message for remote/local control

8.4 Time requirements

The message indicating the status change from remote/local control should occur no later than after 1 second.

8.5 Evaluation of the possible services

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Activation/deactivation of the switchover						
Requirement for this application	***required***	***not required***	***<=1s***	***low***	***low***	***not required***
Applicability of the possible services						
Control via request/response	satisfied	not satisfied	<=1s	very low	low	not satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied
Status report of the switchover						
Requirement for this application	***not required***	***not required***	***<=1s***	***low***	***low***	***not required***
Applicability of the possible services						
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied

No service can be recommended at present for activating/deactivating of the client side (only options listed).

8.6 Selected services

Logging to substation control unit:

- Buffered / Unbuffered Reporting (with trigger options: data-change, quality-change, general-interrogation).

Rejection of control commands: Select before Operate with enhanced security

The following services thus result for the control command to be rejected:

- SelectWithValue
- Cancel
- Operate
- CommandTermination

8.7 Procedures

Fig. 22 depicts the procedure for sending the status information after a remote control block was set.

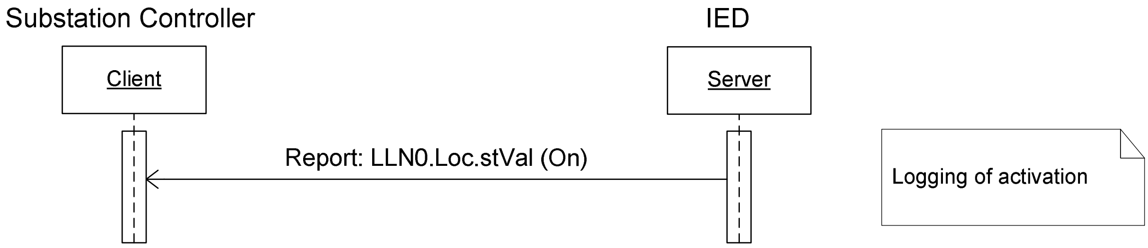


Fig. 22: Logging the status of remote/local switchover

Fig. 23 shows the sequence when a control command is rejected.

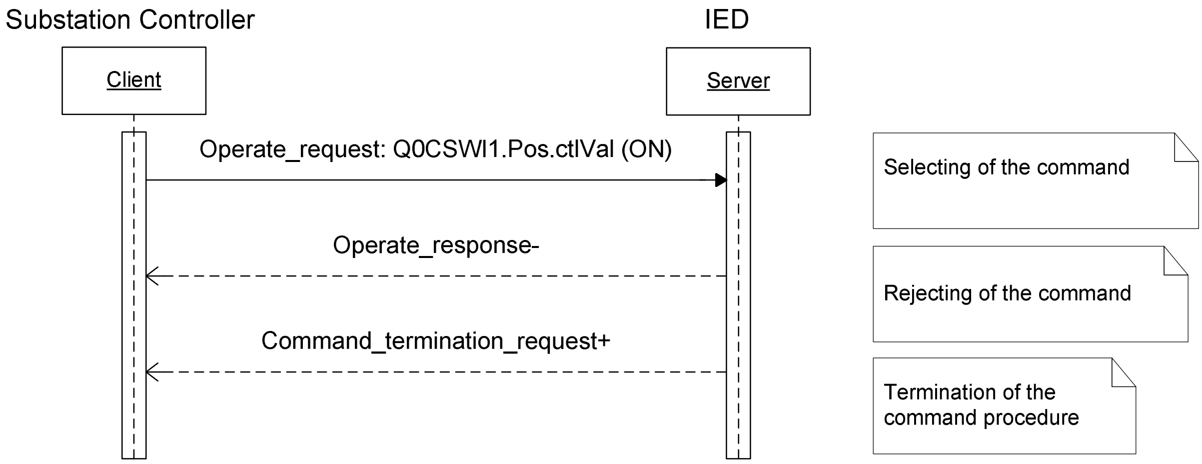


Fig. 23: Sequence for a rejected control command

8.8 Marginal conditions

None

9 Transmitting fault recordings to an archiving computer

9.1 Application

The fault recording function serves to detect and save instantaneous values of analog measured quantities and of binary signals. The fault recording function is usually an integral function of today's bay controllers and protection devices. These devices are capable of storing multiple recordings and transmit these to higher systems via a communication interface.

Fig. 24 shows a typical configuration. The bay units are connected to a substation unit via a communication medium.

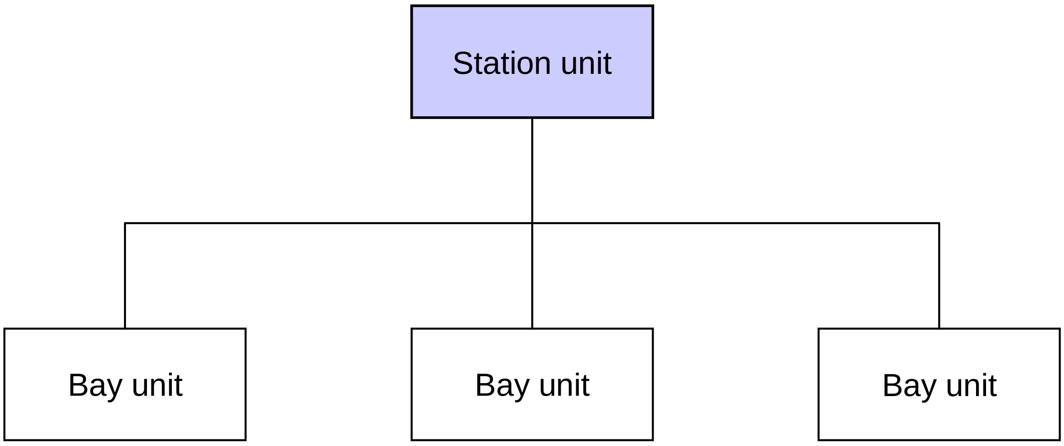


Fig. 24: Configuration

The participating IEDs (bay and substation units) assume the following tasks and functions:

- o Bay units:
  - o Fault recording
  - o Storing the fault records
  - o Indication of the status of the fault recordings
  - o Transmission of the fault recordings over the communication interface
- o Substation unit:
  - o Aggregating the fault recordings of the bay units
  - o Failsafe storing of fault records with high memory depth
  - o Format conversion of the fault records if required
  - o Transmission to remote systems
  - o Providing for service computers

9.2 Information and communication subscribers

The following information is required for transmitting fault records:

- Status information on fault records
- Fault records in COMTRADE format

Fig. 25 gives a basic overview of the communication subscribers and possible data flows.

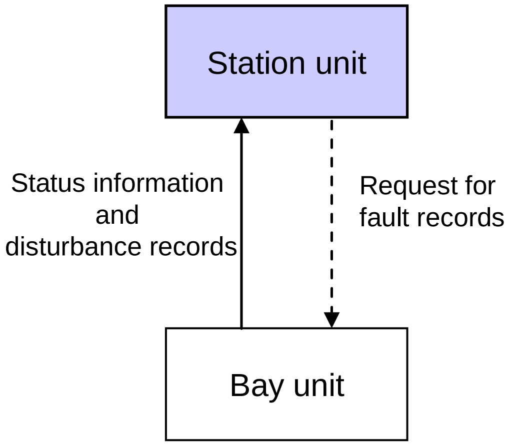


Fig. 25: Communication subscribers and data flows

9.3 Required object information (LN/DO/DA)

9.3.1 Logical device

The standard provides for the use of a special logical device (LD) to simulate the fault recording function.

This approach is recommended since in most devices the fault recording is treated as an independent device function.

9.3.2 Logical nodes

The standard provides the logical node RDRE (Disturbance Recorder function) for recording faults in the detection device:

LN	Data	CDC	Attributes	Values and Report Text	Comment
RDRE					Acquisition of fault data on bay and process level
	RcdMade	SPS	stVal q t	0 – False 1 – True	Fault recording executed
	FltNum	INS	stVal q t net	Number	Fault number

Additionally, the following logical nodes can be used:

- RDRS: Disturbance Record Handling, management of fault data on substation level
- RADR: Disturbance Recorder Channel Analogue, analog fault data channel
- RBDR: Disturbance Recorder Channel binary, binary fault data channel

The use of the logical nodes RADR and RBDR requires that the detection device supports manipulation of the fault records (Comtrade format). Using the LN RBDR is intended for clients (substation units, gateways and fault data concentrators).

Since the requirements mentioned above are not always satisfied, there should be at least one LN RDRE with the mandatory data objects in the acquisition device (protection device, control unit, non-conventional transformer) to provide general and essential support.

9.4 Time requirements

The time requirements are as follows:

- Transmission of the status information: < 500 ms
- Transmission of the fault records > 1 s, < 1 min

9.5 Evaluation of the possible services

Service used	**Returning a reception acknowledgement**	**Reception of several clients (multicast)**	**Time critical information exchange**	**Continuous data traffic**	**System load directly after event**	**Sending buffered data after a communication interruption**
Transmission of the status information						
Requirement for this application	***not required***	***not required***	***<500ms***	***low***	***low***	***not required***
Applicability of the possible services						
GetDataValues (Polling per Request / Response)	satisfied	not satisfied	<500ms	low	low	not satisfied
Unbuffered Reporting	satisfied	not satisfied	< 100ms	low	average	not satisfied
Buffered Reporting	satisfied	not satisfied	< 100ms	low	average	satisfied
GOOSE	not satisfied	satisfied	<20ms	average	high	not satisfied
GSSE	not satisfied	satisfied	<20ms	average	high	not satisfied
Transmission of the fault recordings						
Requirement for this application	***not required***	***not required***	***> 1s***	***average***	***very high***	***not required***
Applicability of the possible services						
File transfer	not satisfied	not satisfied	> 1s	very low	very high	not satisfied

9.6 Possible services

The following services should be used to support the transmission of fault records:

- o Reporting to transmit spontaneous status information
- o IEC-61850 file transfer to transmit the fault records

9.7 Procedures

The following sequence diagram depicts the process recording a fault and transmitting the fault record and the associated information flows between server and client. Optional actions are indicated by dotted lines.

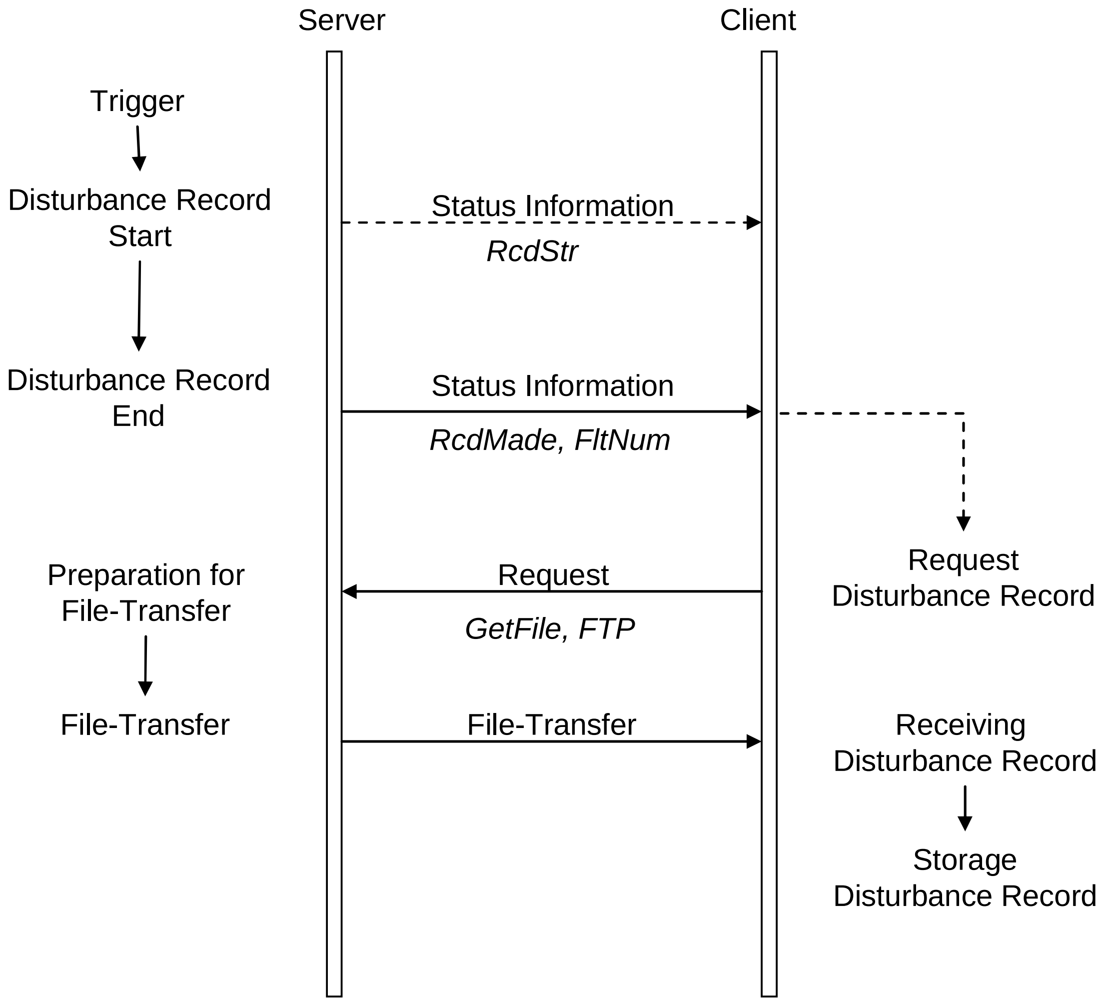


Fig. 26: Sequence diagram of fault recording and transmission of fault records

The action of fault recording encompasses the following activities:

- The fault recording in the server device is initiated by a trigger signal.
- Fault recording is started. If supported, the server spontaneously sends the message “Recording Started” (RDRE/RcdStr) to the client.
- After completion of the fault recording, the server spontaneously sends the information “Recording Made” (RDRE/RcdMade) and “Fault Number” (RDRE/FltNum) to the client.

The action of fault recording transmission encompasses the following activities:

- The transmission of the fault record is initiated in the client by an external signal (command from network control system) or automatically by the server according to preceding information.
- The client requests a certain or all fault records via the File Transfer service (IEC 61860-8-1).
- The server sends all the requested data to the client.
- The client saves the fault recordings.

9.8 Marginal conditions

The following points have to be settled in order for the transmission of the fault recordings to be successful:

- Authentication mechanisms (login, password)

- Extend of the transmission (single / all fault records)
- Activation mode (automatic / on command)
- Filing structure in the client (common / several folders, designations)
- Handling of the fault records in the server after successful transmission (delete, overwrite, etc.)
- Transmission to the network control center

10 Recommendations for selecting the services

10.1 Motivation for these recommendations

The IEC 61850 communication standard was defined as an open standard, i.e. it was deliberately not tailored to the applications commonly used in substations. Rather, an option was included in the standard that allows the free data modelling of all object types customary today and a variety of possible communication services. This enables the standard to be developed further without limitations and to be extended to various fields of application. However, the drawback is that there is a certain ambiguity or lack of clear definitions when implementing an application. This is where IEC 61850 differs from other communication standards like e.g. IEC 60870-5-103 in the form of a fixed type/inf assignment. This is exactly the challenge when implementing applications in substations. To enable full “interoperability”, it becomes either necessary to implement the entire scope of services of the standard into all devices or to define certain restrictions or adjustments to determine which services are reasonable to implement which application. This adjustment can be used by manufacturers as the basis for device implementation so that all important services will be made available in the future in all device types commonly used in substations today. Therefore, the committee has been immersed in a detailed analysis and developed this application description.

10.2 Results

Following an in-depth analysis of the individual steps required for each application the following services where selected to enable a best possible implementation based on what we know today.

Reverse interlocking

Transmission of the interlocking information: GOOSE

Controlling switchgear

Activation (central): Control via request/response

Supervision of the switching status (central/distributed): Unbuffered/Buffered Reporting

Central interlocking in substation unit

Transmission of status information: Unbuffered Reporting

Transmission of release information to bay units: Control via request/response

Distributed interlocking in dedicated bay unit

Transmission of the status and release information: GOOSE

Distributed interlocking in bay units

Transmission of the status and release information: GOOSE

Switching with synchrocheck function / automatic synchronization

Initiation synchrocheck function: Control via request/response

Feedback of the synchronism conditions: Unbuffered Reporting

Simulating the busbar voltage

Transmission of the status and measured value information: Unbuffered Reporting

Transmission of the command: Control via request/response

Commissioning and testing

Activation/deactivation of the test mode: Control via request/response

Status report of the test mode: Buffered/Unbuffered Reporting

Remote/local operation

Activation/deactivation of the switchover: Control via request/response

Status report of the switchover: Buffered/Unbuffered Reporting

Transmitting fault recordings to an archiving computer

Transmission of the status information: Buffered/Unbuffered Reporting

Transmission of the fault recordings: File transfer

10.3 Final remarks

The extent of the applications selected in this document does not by far include all applications customary in substations today. Therefore, the committee has resolved to add further applications after this document has been published.

Not all of the recommended services present a sufficient solution to cover the multitude of different applications. In several cases, we have conducted intensive talks with the editors of the standard to expand missing objects and improve existing object specifications. These talks have revealed how important this committee is for the future elaboration of the standard despite its consisting of national participants only.