Research Project InterOP

Investigating Interoperability of IEC 61850 Technology

Test Report

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Abstract

This document presents the Test Report of project InterOP (Interoperability of IEC 61850) featuring

- an overview about project setup (section 1),
- test findings encountered during the tests and derived solutions for fixing (section 2),
- a summary outlining conclusions (section 3)

The objective of communication standard IEC 61850 is the implementation of interoperable station automation systems with IEDs from various manufacturers. Interoperability is a property referring to the ability of diverse components in a system to work together based on common exchange of information.

The aim of project InterOP was to verify the current status of interoperability based on available IEDs for control, protection and supervision from different suppliers. The verification was made through executing interoperability tests which were defined according to typical substation functions in InterOP Test Specification [INTEROP_TS]. The InterOP project investigated the interoperability based on present, certified devices and standard definitions.

Results of investigation confirm the interoperability of devices on communication and application level. Restrictions and limitations exist for engineering of communication and implementations of functions. The restrictions due to specific implementations do not oppose to the aim of the standard to support interoperable systems. It shows the intention of IEC 61850 to avoid that function implementations and function allocations in systems become part of the standard as this would reduce flexibility in system solutions. Furthermore the intention is to support innovation and competition between suppliers for developing the best solutions. Findings show the importance to clarify such flexible aspects of standard in early project phases. It is essential to have a common understanding about the application and its implementation based on the standard.

The findings are sketched out in this report. Taking these as a basis recommendations were derived for project execution, engineering and standardisation. Further a guideline was defined for system engineers to ease setup of multi-vendor system engineering.

Usually different ways of setting up a specific function exist and sometimes users already have a preferred solution in mind. If not, the Functional Specification [INTEROP_FS] shows interoperable ways for typical functionalities used in substation automation. While not preferring another solution we recommend to use the investigated ways as depicted in the Functional Specification.

While this project focused on investigating interoperability the principle way of how to set up a specific function is seen to be part of standardisation bodies such as current efforts on application part of IEC 61850. The outcome of this project might give some valuable input on basis of the Functional Specification.

1 Introduction

1.1 InterOP Project Scope

One central goal of the standard IEC 61850 is to provide comprehensive interoperability in substation automation systems between control, protection and station level devices from different suppliers. Interoperability means the ability of two or more IEDs from the same vendor, or different vendors, to exchange information and use that information for correct execution of specified functions [IEC-5], ch. 3.8. In order to investigate the challenges that emerge from the requirement to provide interoperability, to support standardisation activities and to derive recommendations to ease future engineering processes the research project InterOP has been initiated defining, executing and analysing concrete interoperability test cases of IEC 61850 devices in a co-operative research effort. The scope of the project is limited to IEC 61850 Edition 1 application.

The aim of the research project was to investigate how the present standard supports the implementation of interoperable systems. Usage of compliant devices is necessary but not sufficient to achieve interoperable systems. Additionally there is a need for defining system-wide aspects concerning communication and engineering. The result of the project is a set of recommendations to be taken into account for achieving interoperability.

In a first step, a Functional Specification [INTEROP_FS] giving an abstract description of the test cases was set up. It is based on typical applications and examples used in substations of large electric grids taking into account parts of the DKE IEC 61850 substation model of DKE AK 952.0.15 "GAK 15" (Release Feb. 2006) [DKE_MODEL]. The following test cases were defined:

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

While the Functional Specification gives an abstract description of the test case functionality the Test Specification [INTEROP_TS] depicts the test case setup concerning IEDs and the interaction to further equipment and explicitly describes the information flow between devices.

Following the specification stages an engineering stage has been performed to set up the comprehensive substation configuration description (SCD file) for describing the functionality and communication of the test system. Tools from different vendors involved in the project were used to perform the engineering which involved an exchange of ICD/CID files between tools and vendors. System engineering was executed by three independent system configurators. For setting up the system-wide communication configuration of reporting and data flow was defined before starting SCL engineering.

Finally, the testing phase was carried out based on the test scenarios defined. The tests were executed at FGH e.V. facility in Mannheim, Germany, where a test infrastructure was built up. During these tests all encountered issues have been noted down and are outlined in this Test Report.

1.2   System Description

InterOP research activities are based on tests running on a real physical system environment as shown in Figure 1-1. For setting up and executing tests on practical and common applications the project partners agreed on using a topology based on the resulting substation model of DKE AK 952.0.15 "GAK 15" (Release Feb. 2006) [DKE_MODEL].

According to the necessary substation-structure for carrying out all scheduled tests of the Test Specification, the "GAK 15" substation model was modified. It is not designed for representing a complete substation but for representing typical functionalities used in substation operation.

All IEDs involved in the tests are shown in the figure and have an unambiguous naming according to the bay. E.g. an IED named "IED 1.1" which provides both protection and control functionality is identified by its unambiguous ID "E1Q1FP1". Intentionally each test involved a specific constellation of IEDs from different vendors which are referenced in the basic test descriptions of the Test Specification.

Figure 1-2 shows the principle test communication system environment as used for executing the tests. The network consists of three switches. Switch 1 and switch 2 directly connect all server devices and switch 1 provides a mirror port which represents all traffic on all ports, the communication between all servers as well as to and from all clients via an uplink connection to switch 3.

To the mirror port a single analysing PC with an appropriate interface was connected, in order to capture the entire traffic of the system for post analyses, taking into account not only the traffic between the servers but also between servers and clients.

Switching devices and analogue as well as digital signalling were simulated by external equipment.

Via switch 3 HMIs and equipment like an SNTP server were connected. A VPN remote access provided general accessibility of devices for engineering purposes or exchanging configurations, setup and log files.
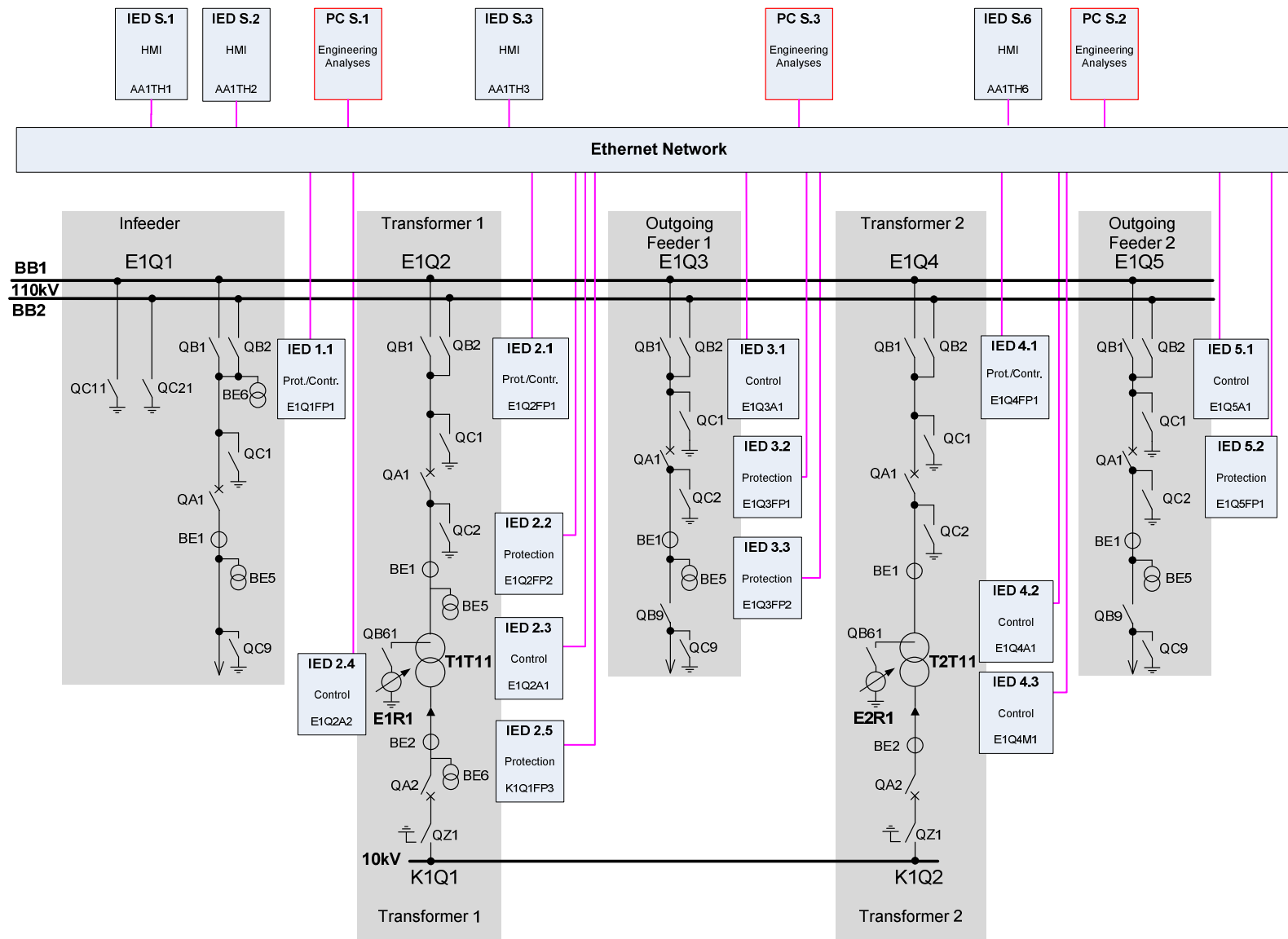
Figure 1-1 **Substation Topology for InterOP Test**

FGH e.V. – Research Project InterOP
Network Architecture

F G H

1..n Remote Client PCs

www VPN Tunnel

SNTP Server

VPN Server

1..n HMIs

Switch 3
24 el. Ports 100 MBit + 2 el. Ports 1 GBit

FGH Engineering
and Test PC with
Analysing Tools

Gbit   Uplink

Analysing and Capture PC

Switch 1
12 el. Ports (100 Mbit)
4 op. Ports (ST) (100 Mbit)
3 el. GBit Ports

Simulator Device

1 GBit Mirror Port

Switch 2
6 el. Ports (100 Mbit)
3 op. Ports (ST) (100 Mbit)

IEDs
of various suppliers

IED | IED | IED | IED | IED

IED 1   IED 2   ...   IED n-2   IED n-1   IED n

Simulations,Triggers, Measurements

— LAN infrastructure

Figure 1-2   Network Architecture Scheme

1.3   Definition of Conformance, Interoperability and Interchangeability

In order to have a common understanding a definition of the following terms is given as defined in the standard IEC 61850:

Conformance[1] test: the check of data flow on communication channels in accordance with the standard conditions concerning access organization, formats and bit sequences, time synchronization, timing, signal form and level, reaction to errors. [IEC-4], ch. 3.16

Interoperability: the ability of two or more IEDs from the same vendor, or different vendors, to exchange information and use that information for correct execution of specified functions. [IEC-5], ch. 3.8

Interchangeability: the ability to replace a device supplied by one manufacturer with a device supplied by another manufacturer, without making changes to the other elements in the system. [IEC-5], ch. 3.7

1.4   Abbreviations

Table 1-1   Abbreviations

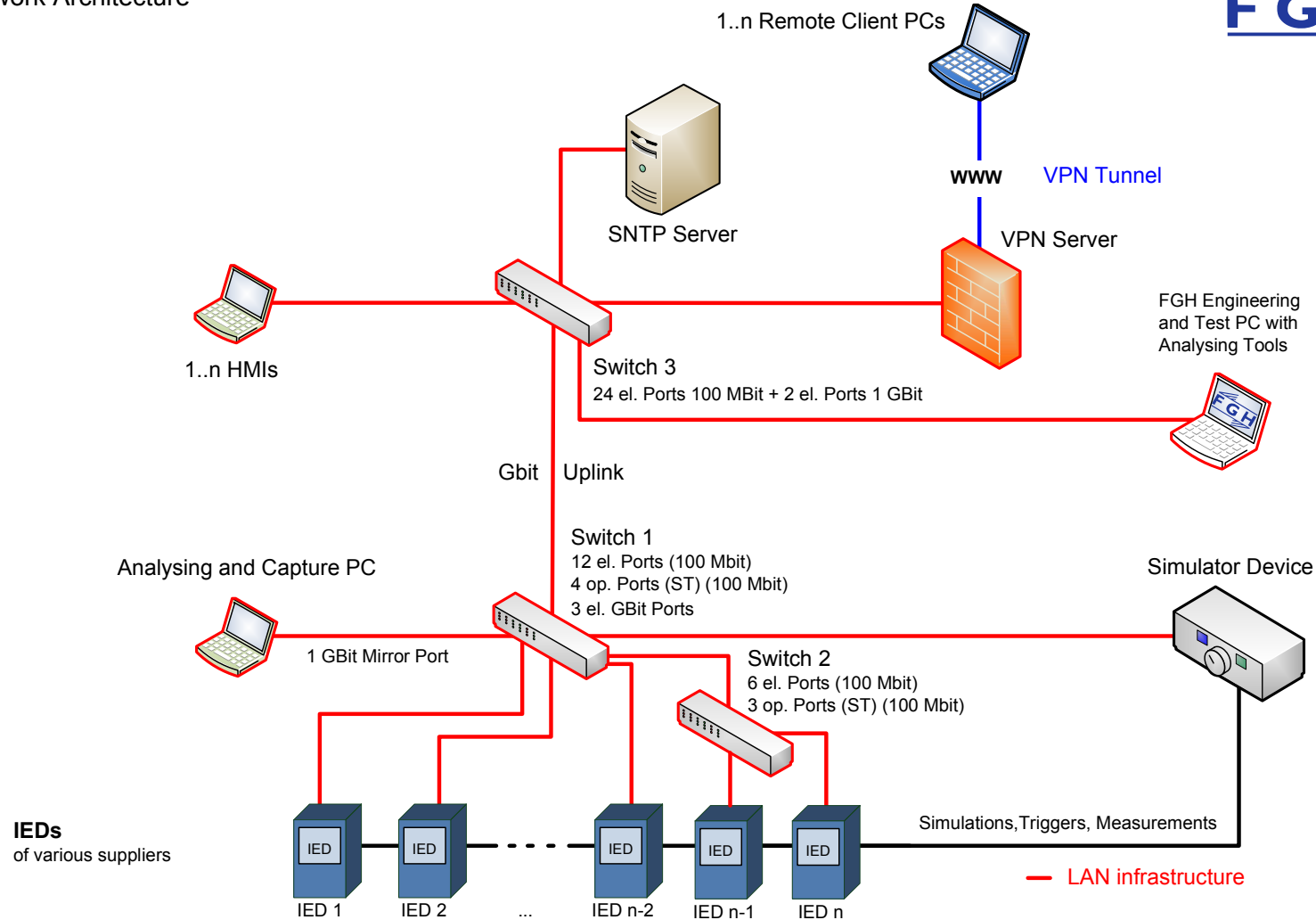| Abbreviation	Explanation
CB	Circuit Breaker
CID	Configured IED Description
COMTRADE	IEEE Standard Format for Transient Data Exchange acc. to IEC Standard IEC 60255-24 (DIN EN 60255-24)
DKE	DKE German Commission for Electrical, Electronic & Information Technologies (hosts counterparts to the IEC, CENELEC and ETSI bodies)
GOOSE	Generic Object Oriented Substation Events
HMI	Human-Machine Interface
ICD	IED Capability Description
IED	Intelligent Electronic Device
MMS	Manufacturing Message Specification
OLTC	On-Load Tap Changer
PIXIT	Protocol Implementation Extra Information
RCB	Report Control Block
SBO	Select Before Operate
SNTP	Simple Network Time Protocol
TICS	Tissue Implementation Conformance Statement
TISSUE	Technical Issue
VPN	Virtual Private Network

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[1] Since the Standard IEC 61850 Ed. 1 does not define conformance solely but conformance test [IEC-10], the definition for conformance test is given. Nevertheless this indicates the meaning of conformance.

1.5 References to Standards and Specifications

Table 1-2 References to Standards and Specifications

[IEC-1]	IEC 61850-1: Communication Networks and Systems in Substations. Part 1: Introduction and overview (2003-04)
[IEC-4]	IEC 61850-4: Communication Networks and Systems in Substations. Part 4: System and project management (2002-01)
[IEC-5]	IEC 61850-5: Communication Networks and Systems in Substations. Part 5: Communication requirements for functions and device models (2003-07)
[IEC-6]	IEC 61850-6: Communication Networks and Systems in Substations. Part 6: Configuration description language for communication in electrical substations related to IEDs (2004-03)
[IEC-7-1]	IEC 61850-7-1: Communication Networks and Systems in Substations. Part 7-1: Basic communication structure for substations and feeder equipment – Principles and models (2003-07).
[IEC-7-2]	IEC 61850-7-2: Communication Networks and Systems in Substations. Part 7-2: Basic communication structure for substations and feeder equipment – Abstract communication service interface (ACSI) (2003-06)
[IEC-7-3]	IEC 61850-7-3: Communication Networks and Systems in Substations. Part 7-3: Basic communication structure for substations and feeder equipment – Common Data Classes (2003-05)
[IEC-7-4]	IEC 61850-7-4: Communication Networks and Systems in Substations. Part 7-4: Basic communication structure for substations and feeder equipment – Compatible logical node classes and data classes (2003-05)
[IEC-8-1]	IEC 61850-8-1: Communication Networks and Systems in Substations. Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3 (2004)
[IEC 60255-24]	IEC 60255-24: Electrical Relays - Part 24: Common Format for Transient Data Exchange (COMTRADE) for Power Systems
[IEC-10]	IEC 61850-10: Communication Networks and Systems in Substations. Part 10: Conformance Testing (2005-05)
[DKE_MODEL]	DKE952.0.1: Modelling Guideline and Sample Modelling using SCL (2008, Version 1.0), http://www.vde.com/en/dke/DKEWork/NewsfromtheCommittees/Pages/Modelling_of_a_combined_high_and_medium_voltage_substation_with_IEC_61850.aspx
[DKE_APPLICATIONS]	DKE952.0.1: Applications using the Services of IEC 61850 (2008, Version 1.0.)
[INTEROP_FS]	InterOP Functional Specification for Testing (Version 1, 2009-03-16)
[INTEROP_TS]	InterOP Test Specification for Testing (Version 1.0, 2009-08-12)
[TISSUES]	IEC 61850 Tissue website, http://www.tissues.iec61850.com
[UCAIUG]	Website of UCA International Users Group, http://iec61850.ucaiug.org/

2 Test Findings and Recommendations

Having executed the tests specified in the InterOP Test Specification [INTEROP_TS], interoperability on communication and application level was achieved.

Interoperability according to definition in section 1.3 can be interpreted in two different ways. The first interpretation focuses on communication solely. The second interpretation includes both application and applied communication.

The scope of the project was focused on interoperability of communication also including the setup of functionality and involved engineering as far as needed. A detailed investigation of engineering tools, related functionality aspects and engineering workflow was not in the scope of the project. These aspects might be part of a possible future phase of the InterOP research project.

In order to ease the engineering process and to give recommendations for setting up interoperable system environments, this section describes following aspects per finding:

- Case description
- Deduced recommendation
- Relevance for documentation, project execution and standardisation
  All recommendations are aimed at specific types of documents, such as:

    - Requirements specification
    - Standard
    - System design
    - Tools

To get an interoperable system all definitions and requirements should be defined as early as possible in the project phase. The **requirements specification** has to be defined carefully and unambiguously. For some findings it is recommended to find an unambiguous definition in the **standard** itself because it was sometimes not possible to agree on a common understanding of the current formulation in the standard. Some issues are rooted in the **system design** itself. They occur with specific setups and could be avoided by choosing alternative designs or handling the design specifically. Furthermore the requirements for the engineering **tools** should be defined so that the configuration can be executed seamlessly.

The identified findings are clustered into the three groups **application**, **engineering** and **system coordination**.

The first group concerns findings connected to **application**. To support interoperability from the functional point of view every IED has to support a certain functionality in order to achieve a system-wide functionality. IED-specific implementations can cause restrictions. Group **application** includes all findings showing such restrictions.

The second group deals with findings connected to **engineering**. For setting up the system environment and configuring a system-wide functionality of devices in the entire system, ancillary conditions and common definitions have to be agreed upon. Group **engineering** describes these conditions and gives recommendations on the definitions.

The third group describes findings concerning the **system coordination**. Specific issues have to be taken into account to get a reliable and stable system environment.

2.1   Application Findings

2.1.1   Event-Driven Disturbance Record Transfer

Case description

It was defined to support event-driven disturbance record upload from servers.
In order to achieve the system-wide functionality the server has to support spontaneous reporting of disturbance record completion via *RcdMade* (Disturbance recording complete) in LN RDRE [IEC-7-4], ch. 5.5.2. The client has to evaluate this DO and upload the disturbance record event-driven.
Some clients did not support evaluation of DO *RcdMade* and event-driven upload. In this case system-wide event-driven upload was not possible.

Deduced recommendation

The standard does not define which approach of disturbance upload (event-driven / cyclic / polling) has to be supported by the client implementation. It is up to the vendor to decide which method is supported by the client. In the project specification phase the user needs to define the requirements for disturbance upload and to verify this against the method offered by the client. In case of non-supported event-driven upload a possible solution could be to change the disturbance record transfer to cyclic upload.

Relevance for documentation, project execution and standardisation

Support of event-driven disturbance upload has to be defined in the **project specification** and has to be clarified before project execution.

2.1.2   Specific File Storage for Disturbance Records

Case description

It was defined to upload disturbance record files in COMTRADE file format from server to client. According to the standard COMTRADE files have to be stored in a directory named "COMTRADE" on the server [IEC-8-1], ch. 23.1. One server stored the files in addition to the COMTRADE directory in a directory with a different name, which is not excluded by the standard. The content of this directory was identical to the COMTRADE directory. One client read the disturbance record files from both directories and interpreted the files as two separate disturbance records although the files were identical in content and timestamp.

Deduced recommendation

It is recommended to use a directory named COMTRADE only for retrieving disturbance records. For the project it was accepted to receive each disturbance record twice, the original one from COMTRADE directory and a duplicate from an additional directory.

Relevance for documentation, project execution and standardisation

It is recommended to define in the **standard** that disturbance records should be uploaded from the COMTRADE directory only.

2.1.3   COMTRADE Directory Access

Case description

To upload disturbance records from a server two possibilities of accessing files inside the COMTRADE directory were used by clients. Both possibilities are conformant to the standard.
The first one is to request the file with the complete directory structure directly, i.e. request "/COMTRADE/filename.zip". The second one is to change to the COMTRADE directory and then request the disturbance record only by "filename.zip".
It was found that a server did support only one possibility of COMTRADE directory access. The file handling behaviour of the client was adapted to match the requirements of the server.

Deduced recommendation

Client should be adaptable to the file handling of the server.

Relevance for documentation, project execution and standardisation

It should be documented in the project **requirements specification** which way of COMTRADE upload is supported by the server and therefore should be supported by the client. It should be discussed in the **standardisation** committees whether the way of addressing should be defined in the PIXIT of the server. Since it could happen that different servers supporting different ways are used in the system it should be discussed where to document the individual support for each server from the client. As an alternative it should be discussed whether it makes sense to restrict the access to the COMTRADE directory to one way in the standard.

2.1.4   Direct Control

Case description

It was defined to switch equipment from clients by direct control in contrast to Select-Before-Operate (*SBO*). One client did not support direct control and was not able to operate the equipment. To be able to switch the equipment another client which supported direct control was used.

Deduced recommendation

If equipment should be operated by direct control it should be checked if the clients support it and it should be defined in the project's requirements specification.

Relevance for documentation, project execution and standardisation

Support for direct control should be defined in the **requirements specification**. Support of direct control by clients should be verified.

2.1.5   Interpretation of File Creation Date

Case description

A server and a client interpreted file creation dates differently. One interpreted the date as UTC (Universal Time Coordinated), the other one as local time. The creation date was transmitted in local time by the server. The client received the file, interpreted the timestamp as UTC and added the offset for local time again. As a result the file creation date was off by the difference between UTC and local time zone.

Deduced recommendation

There was no solution to this finding.

Relevance for documentation, project execution and standardisation

It is recommended to define unambiguously in the **standard** whether timestamps of file creation or modification should be UTC or local time.

2.1.6   Indication of *RcdMade* (Disturbance Recording Complete)

Case description

RcdMade = TRUE means "Disturbance recording complete" [IEC-7-4], ch. 6 and is a mandatory DO. It was defined to initiate a disturbance record file upload with *RcdMade* as indication that new disturbance files are present. After a server sent *RcdMade* = TRUE a client requested upload of disturbance record files. When the upload was finished the server sent another *RcdMade* = TRUE, which was caused by the finished upload. This cycle repeated infinitely. It was solved by updating the implementation of *RcdMade* of the server.

Deduced recommendation

The standard does not define the handling of *RcdMade* for the defined application. Handling between server and client needs to be coordinated properly.

Relevance for documentation, project execution and standardisation

The **standard** should define the handling for setting and resetting *RcdMade***.**

2.1.7   Separate Selection Command of *Select-Before-Operate (SBO)* Sequence

Case description

It was defined to execute a test if a selection attempt from a control point failed because switchgear was already selected by another client. Switching by *Select-Before-Operate (SBO)* was used. The test execution showed that the first client indicated selection of the switchgear, but the selection attempt from the second client was not blocked. It was found that the first client did not send the selection request to the switchgear controlling device (i.e. send the command over the communication network), but only indicated a successful selection in the user interface. The selection command was sent immediately before the operate command as automatic *SBO* sequence, when the switching was executed. No separate selection command was received.

Deduced recommendation

It was necessary to send a separate selection command to successfully pass the defined test. Another client than the originally planned one was used to pass the test. The functionality of the first client is entirely conformant to the standard, which does not define this specific defined case of separate selection from command execution from a client.

Relevance for documentation, project execution and standardisation

It should be considered in the **system design** if the functionality of a separate selection command, independent of the execution command is required. Security of switching operations is not affected if commands are sent by the client either as separate commands or as concatenated commands. It must be ensured that the server state machine is blocking a second command originated by another client. If the SBO functionality is required this should be defined in the **requirements specification**.

2.1.8   *AddCause* (AdditionalCauseDiagnosis) Values

Case description

The value of *AddCause* as a part of the variable *LastApplError* indicates why the last command could not be successfully executed. 18 different values are currently defined. It was found that one server did not support all *AddCause* values specified in the standard and could not send the defined value of the test case.

Deduced recommendation

It should be defined before project execution which values of *AddCause* are required in system. It should be checked if the devices support all required values (supported values are listed in PIXIT documents). This can be a subset of all defined values in the standard.

Relevance for documentation, project execution and standardisation

All required values of *AddCause* should be defined in the **requirements specification**.

2.1.9   Support of *stSeld*

Case description

It was found that one IED did not support evaluation of DA *stSeld* of DO *Pos* of switchgear equipment. *stSeld* indicates if the switchgear is in the status *selected* when operating a switch with *SBO*. It was not possible to implement system-wide interlocking functionality.

Deduced recommendation

It should be checked if the IEDs that are required for interlocking functionality support evaluation of *stSeld*. The functionality could be implemented by upgrading the IED's firmware.

Relevance for documentation, project execution and standardisation

Support for DA *stSeld* should be defined in the **requirements specification**.

2.1.10 Specific Prefixes/Instances of LNs

Case description

It was found that one client only interpreted the prefixes but not suffixes of LNs of the server to unambiguously differentiate between these LNs. This client in the project only interpreted LN prefixes in order to distinguish application based mapping to primary processes and expected this to be sufficient. This is a limiting definition which jeopardizes interoperability in the system and limits the use of IEDs. The intended test case could not be executed with this client as planned since it did not support the full flexibility given by the standard.

Deduced recommendation

Support for distinction between LN instances based on prefixes and suffixes should be checked for all IEDs before project execution as well as flexible naming of LNs for applications. A client therefore should not show any constraints concerning naming and support any communication based on the data model of the standard. One is free to choose any server IED according to IEC 61850 and can expect the client to support any communication.

Relevance for documentation, project execution and standardisation

In project specification phase it has to be clarified which constraints concerning LN-naming exist. The consequences of such constraints have to be evaluated and respected in the **system design**.

2.1.11 Format of Data in GOOSE Messages (Structure or Separate Variables)

Case description

According to the standard the *GOOSEData* part of GOOSE messages can contain all types of *CDCs* [IEC-7-2], ch. 15.2.3.11 including *DataObjects* and *DataAttributes*. It was found that some subscribers could not evaluate data of GOOSE messages which were *DataObjects*. Quality attributes of the data of GOOSE messages were always indicated as invalid by the subscriber regardless of the actual content. The subscribers could not be used to implement application functionalities that required the data of GOOSE messages with *DataObjects*. Other subscribers were able to evaluate the *GOOOSEData*. The issue could be solved by changing the publishers to send the contents of *GOOSEData* as separate *DataAttributes*.

Deduced recommendation

It should be verified before project execution if all publishers and subscribers support requested DO- and DA-handling of *GOOSEData* in GOOSE messages[2]. As the quality information of any sent indication is required for subscribers to determine its validity and react in a defined way, support of quality information is mandatory for GOOSE publishers.

Relevance for documentation, project execution and standardisation

The limitation to evaluate data only on *DataAttribute* level should be described in the product documentation. The approach of organizing *GOOSEData* in the system should be considered in the **system design** and should be defined before project execution. This should also be defined in the **requirements specification**.

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[2] For coming 2nd Edition of the standard only the *DataAttribute* approach is recommended.

2.2   Engineering Findings

2.2.1   IED Name Length

Case description

Within the engineering of the system it turned out that a client did not support an *IEDName* length of more than 8 characters. Therefore it could not connect to servers named with more than 8 characters. According to the standard *IEDName* respectively *LDName* can be theoretically up to 32 characters long [IEC-7-2], ch. 19.2. A limitation to a fixed character length may reduce interoperability and cuts the flexibility for user oriented object designations.

According to IEC 61850 Edition 1 the object designation which contains *IEDName* has a limitation of 63 characters. Dependent on the implemented data model of IEDs, it may be the case that the device specific hierarchy and *LDInst*, Prefix and Suffix naming reduce the number of available characters for *IEDName*. E.g. "*IEDName*.Mannheim110kVBayE01Meas.CurrentMMXU1.PPV.phsAB.instCVal.mag". This object designation allows only 8 characters for *IEDName* in order to avoid exceeding the maximum value of 63 characters.

Deduced recommendation

Unlimited flexibility in *IEDName* length is the preferred IED feature. Therefore in the project specification phase it should be identified if the designated project IEDs (servers and clients) support the required *IEDName* length. In case of a limitation of at least one IED, it is recommended to fix the *IEDName* of all IEDs to the minimum length in order to avoid conflicts and to ensure interoperability.

Relevance for documentation, project execution and standardisation

The limitation of *IEDName* length should be described in the product documentation. Existing limitations, if any, should be part of the **requirements specification**.

2.2.2   Different System Engineering Approaches

Case description

System engineering tools from different vendors were used for engineering the substation system. Two different approaches were used for engineering the system. Both approaches could be used successfully to achieve a complete configured system.

Approach A is based on a vendor independent system configuration tool which defines the system-wide data-flow. Based on the ICD file import from IED configuration tools it generates a SCD file which is used for final server and client configuration. This SCD file is complete concerning servers, clients, reporting and GOOSE definition.

Approach B does not use a vendor independent system configuration tool. ICD files from IED configuration tools are imported directly to vendor specific client configuration tool which defines the data flow. The IED configuration tool or client configuration tool provides the functionality of generating an incomplete SCD file for documentation. Missing components in the incomplete SCD file could be 3rd party client and server configuration.

Deduced recommendation

Users should evaluate which process matches their requirements best. In case of multi-vendor systems it is recommended to use a complete SCD file according to the standard.

Relevance for documentation, project execution and standardisation

System design usually is done by a vendor who also provides a client for a system, nevertheless it should be possible to import and use all information given in any SCD file. The standard intends to lead to common SCD files which describe a substation comprehensively and in a vendor independent way. Any system engineering tool should offer to import and export such a file and use all given information for configuring devices for the system. The required engineering approach should be defined in the **requirements specification**.

2.2.3 GOOSE Engineering – Configuration Limitation for GSE/*APPID* (Unsigned16)

Case description

According to the standard [IEC-8-1], Annex C, the reserved value range for GOOSE GSE parameter *APPID* is 0x0000 to 0x3FFF. If no *APPID* is configured, the default value shall be 0x0000. For one configuration tool there was no possibility to set a value of the full range of allowed values from 0x0000 to 0x3FFF. This required to limit the range system-wide to the values supported by this configuration tool.

Deduced recommendation

It is strongly recommended by the standard to have an unambiguous, source-orientated GOOSE *APPID* within a system [IEC-8-1], Annex C. Engineering tools should allow the full range of values defined by the standard to be set for a device. For filtering purposes it makes sense to indicate a specific category of functionality of a GOOSE by defining a system-wide unambiguous *APPID*.
It should be verified if the *APPID* has to be entered as decimal or hexadecimal value in the engineering tool to ensure that the correct value is set. *APPID* in SCL is always a hexadecimal value.

Relevance for documentation, project execution and standardisation

The GOOSE setup is part of the **system design** and should be defined in an early engineering stage to achieve a system-wide consistent approach.

2.2.4 GOOSE Engineering – Unambiguous Identification of GOOSES

Case description

It was found, that one IED did not distinguish and unambiguously identify GOOSEs by interpreting the *GSEControl/appID* but used a combination of *GSE*/MAC-Address and *GSE/APPID* instead. It became necessary to define a system-wide schema for addressing *GSE*/MAC-Address and *GSE/APPID* per IED. According to the standard this is not the intention of using *GSE*/MAC-Address and *GSE/APPID* where it is stated that it shall be possible to use *GSEControl/appID* as an unambiguous system identification for the application that is issuing the GOOSE [IEC-7-2], ch. 15.2.1.

Deduced recommendation

GSEControl/appID solely should be sufficient for IEDs to distinguish system-wide application associations. For performance reasons it is beneficial to consider MAC-Address filtering and therefore assign unambiguous MAC-Addresses for each application in GOOSE engineering.

Relevance for documentation, project execution and standardisation

It should be verified whether any IED is requiring interpretation of *GSE*/MAC-Addresses in order to unambiguously identify GOOSES system-wide. If so this should be documented in the **system design.**

2.2.5 GOOSE Engineering - *AppID*[3] (VISIBLESTRING65)

It is worth to be mentioned that **AppID** (in SCL defined to be *appID*) is intended be renamed *GoID* from Edition 2 on. It must not be mistaken for GSE/*APPID* (see 2.2.3).

Case description

It was found that an empty value was assigned to *AppID* in the GOOSE Control Block (*GoCB*) in some CID files. As a consequence one configuration tool was not able to configure the subscription of the respective GOOSE messages for the IED. Therefore they were indicated as missing by the non-configured IED.

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[3] According to Edition 1 of the standard *AppID* is used where according to coming Edition 2 *GoID* is used instead. Regardless this change on ACSI level in [IEC-7-2], in SCL the tag *appID* is kept for backward compatibility reasons and typically defined to adapt the *GoCBRef*.

Deduced recommendation

The standard provides the flexibility to leave *AppID* empty in SCL engineering or define own values [IEC-7-2], Table 28. In case *AppID* is left empty IED configuration tools should automatically configure *GoCBRef* for *AppID*. The standard allows to use an adequate assignment to the application issuing the GOOSE [IEC-7-2], Table 28. So the user has the flexibility to define a system-wide unambiguous *AppID* for GOOSE messages.

Relevance for documentation, project execution and standardisation

The GOOSE setup is part of the **system design** and should be defined in an early engineering stage to a system-wide consistent approach.

2.2.6   TPAA Connection Parameters

Case description

For setting up a client-server TPAA the parameters OSI-AP-Invoke, OSI-AE-Qualifier, OSI-AE-Invoke are optional [IEC-8-1], ch. 25.1.1.1. Some clients did not support a configuration of these parameters. Their connections to the server were not possible. One should also be aware of the possibility to deny specific IP-addresses for accessing a server which denies access also in case of correct parameterisation. In this case the server internal blocking of specific IP-addresses needs to be switched off in order to allow all clients in the sub-network to connect.

Deduced recommendation

It is recommended to verify that clients, such as diagnosis tools, HMIs, gateways are able to adapt to servers. The configuration information given in the PIXIT document of devices should be used to configure TPAA connection parameters in the clients appropriately.

Relevance for documentation, project execution and standardisation

It should be verified that clients can be configured according to TPAA connection requirements of the servers in the system. Engineering tools should support configuration of TPAA connection parameters of clients. All required connection parameters of used devices should be defined and documented in the **system design**.

2.2.7   Assignment of Primary Process to Logical Nodes

Case description

For substations with separately engineered and delivered IEDs from different suppliers it is needed to have a cross reference of the LN data model against the primary components for unambiguous understanding of application. It is not defined in the standard how the assignment between primary process naming and naming of corresponding Logical Nodes of applications should be documented in CID files. It was found that CID files did not sufficiently describe the application depending assignment of LNs to the primary process objects. Primary process oriented LN-naming was not supported by all devices, the assignment finally was made by setting up an additional reference sheet.

Deduced recommendation

Additional documentation is necessary to be able to define an unambiguous assignment. Three ways of how to document assignment of LNs to the primary process are possible:
A first way is to have a complete identification in LN-naming within the structure of LD, LN-Prefix and LN-Instance. This way requires the support of flexible product naming for adaption to the actual primary process.

Two alternative ways without identification by LD, LN-Prefix and LN-Instance name require additional documentation:
- One way is to assign LNs by additional documentation within external files like Excel-sheets,
- Another way is to track this extra information in the substation part of SCL files.

The user has to define his requirements according to the possibilities described above and supported by the intended devices for the system. It is highly recommended to use a possibility for assignment to the primary process according to the means of the standard.

Relevance for documentation, project execution and standardisation

The assignment of the primary process objects to LN applications should be defined in the **system design**. It is recommended to **standardisation** committees to define a solution for having a complete description in device oriented engineering.

2.2.8   Engineering Tool Compatibility to Enhancements of the Standard

Case description

It was found that one system engineering tool had not implemented an approved Tissue provided by [TISSUES]. The data of one DO in an ICD file could not be interpreted by this tool for engineering the system since it did not support this Tissue. To overcome this Tissue the database of the system engineering tool was updated in order to support the Tissue. In principle it can occur that IEDs and tools have different states of implementations of the standard. Edition 1 of the standard is enhanced in some specific parts by the Tissues and Edition 2 is a further enhancement of the standard. Tools should align with the status of Tissues and the IEDs used in the system.

Deduced recommendation

It should be verified before project execution that foreseen configuration tools align with implemented Tissues in devices and support importing of according ICD files as well as export of SCL file, such as CID- or SCD-file. Tissues and enhancements of the standard do not generally have an effect on interoperability. Therefore it is not necessary to support the same set of Tissues by involved devices. Typically only very specific parts are changed which sometimes do not influence the intended system setup at all. However, supporting a same set of Tissues eases the process of getting quickly an interoperable system. An up-to-date engineering tool is recommended and ensures to set up the systems without constraints according to Tissues potentially used for communication and application setup in the system.

Relevance for documentation, project execution and standardisation

The system integrator is in charge of checking and ensuring the alignment of Tissues according to considered devices and system-wide functionality setup. The alignment of considered tools and devices for the system setup should be documented in the **system design.**

2.2.9   Handling of *ConfRev*

Case description

It was found that the provided communication description in a CID file did not align with the actual communication supported by the IED application. The inconsistency could not be detected since the *ConfRev* was not changed in the IED. Inconsistency check on the receiver side therefore did not work. As a consequence the communication based application on receiver side failed.
According to the standard, the parameter *ConfRev* contains the configuration revision to indicate insertion, deletion or reordering of members of a *DATA-SET* as well as a change of the value in the *DATA-SET* reference (attribute *DatSet*) [IEC-7-2], ch. 14.2.2.7. According to the standard the updated *ConfRev* should be detected by the receiver and the change of configuration should be adopted.

Deduced recommendation

It is mandatory to keep *ConfRev* consistent system-wide in internal implementations of devices and their corresponding representation to the outside (CID-file). This should be respected for all kinds of revision indication, such as revision number for distinguishing SCL-files, revision numbering of parameter changes and revision numbering *ConfRev* for indication of changed *DATA-SET*s. A receiver (subscriber to GOOSE) should be able to rely on indication of revision management set by parameters such as *ConfRev*. In case of modifications revision indication needs to be set consistent to the outside and in the internal implementation of devices.

Relevance for documentation, project execution and standardisation

The handling of *ConfRev* is part of the engineering. Based on means of the standard a consistent engineering of the system has to be ensured. This should be supported by appropriate **tools**.

2.2.10 Handling of Revision of CID Files

Case description

It was found that the revision number in a CID file of a server was increased without updating the IED description on the client side via export of the CID file. The result was a mismatch between the configuration revision of the data model in the server and the configured configuration revision on client side. While starting up one client a cross-checking according the configuration revision indicated a mismatch. The client refused communication association to the server due to mismatch of the revision number. The standard does not define rules for handling revision number.

Deduced recommendation

The revision number in an IED and according CID file should always be consistent and be published to all system partners. There is a need for a clear common understanding of revision handling by all system components e.g. reasons for changing revision number, validity criteria for consistent revision numbers.

Relevance for documentation, project execution and standardisation

Revision handling should be defined before project execution in the **requirements specification**. It should be checked if the configuration **tools** support file revision handling. Appropriate rules for revision handling by tools should be discussed within the standardisation committees in order to provide a maximum support of system-wide consistency checking.

2.3   System Coordination Findings

2.3.1   Multi-Client Systems with Clients from Various Vendors

Case description

According to the standard each server has to reserve one individual instance of a Report Control Block (RCB) for every client that allocates this RCB [IEC-7-2], ch. 14.2.1. Clients connect to RCBs in different ways. Within the project two ways could be found, depending on the access strategy of the client. Some clients connected to a specific instance of a RCB, for example they always request the RCB instance predefined by the client. Other clients tried to connect to the first available **free** instance of the RCB.
It was found that some clients were not able to connect to their fixed RCB instances because they were already enabled by another client. A stable connection between server and client could not be established. A simple solution was to have just one client connected to the system. To be able to connect all clients simultaneously a coordinated access of the clients to the servers' RCBs had to be defined. First a client which always explicitly connected to the first RCB was switched on, followed by those which allowed engineering of the instance number, finally remaining clients which used the first **free** RCB.

Deduced recommendation

It is recommended to define an unambiguous allocation of clients to RCBs. Clients have to support the configuration of accessing fixed RCB instances. If clients are used which explicitly connect to the first instance of a RCB, a specific start-up sequence has to be defined. As start-up sequences can hardly be performed in unmanned substations after a power-down, this approach does not seem to be applicable. Additionally there is the need to also allow client tools to connect to RCBs temporarily.

Relevance for documentation, project execution and standardisation

Support for multi-client systems and unambiguous allocation of clients to RCBs should be defined in the **system design**. If predefined start-up sequences of clients cannot be avoided, they should be part of the project specification. It is also recommended to provide recommendations and definitions for multi-client systems in the **standard** on how to arrange the reservation process on RCBs successfully for all cases in order to avoid the need for predefined start-up sequences.

3 Conclusions

Functions for testing the multi-vendor system were engineered according to the Functional Specification [INTEROP_FS] and were tested according to the Test Specification [INTEROP_TS]. Based on the Functional Specification and current conformance-tested devices certified by accredited test laboratories according to Edition 1 of IEC 61850 standard, a comprehensive interoperable system was set up in the InterOP project. However, the project was faced with difficulties to achieve application interoperability. In certain cases specific engineering was needed to design and implement proper solutions for passing the tests.
The findings causing problems are described in chapter 2.
Supporting interoperability while avoiding restriction of flexibility was identified to be the main reason for discovered findings. Sometimes this results in different approaches applied by vendors. The output of the InterOP project helps to clarify the current situation and provides guidelines to support the setup of multi-vendor systems.

The discovered findings described in chapter 2 can be assigned to the following categories which represent the root causes for the finding. A detailed overview listing which finding is assigned to which category can be found in the annex.

- **Lack of detail in the standard**
- **Degree of implementation in IED**
- **Vendor specific restrictions to the standard**
- **Different system engineering approaches**

Depending on the kind of category specific conclusions are derived and specific measures for handling are recommended. It is recommended that generally all findings and the guidelines in chapter 4.1 should be taken into account by system suppliers and users when setting up and executing a project. Recommendations how to handle findings of specific categories are presented below.

Findings of category "**Lack of detail in the standard**" occurred since specific aspects are not defined in an unambiguous way in the standard. Either specific definitions can be interpreted in different ways or the definitions for specific aspects are missing completely. This lack can lead to mismatching assumptions and therefore result in different implementations in devices. That is why it is needed to improve the standard towards a common unambiguous definition of application functionality while at the same time maintaining flexibility. Findings that have their root cause in "**Lack of detail in the standard**" will be addressed to the standardisation committee. The mismatches could be solved in the InterOP project by adapted engineering or redesign of the system solution.

The following findings belong to this category:

- Specific File Storage for Disturbance Records
- Interpretation of File Creation Date
- Indication of *RcdMade* (Disturbance Recording Complete)
- Separate Selection Command of *Select-Before-Operate (SBO)* Sequence
- GOOSE Engineering - *AppID* (VISIBLESTRING65)
- Assignment of Primary Process to Logical Nodes
- Handling of *ConfRev*
- Handling of Revision of CID Files
- Multi-Client Systems with Clients from Various Vendors

Findings of the category **"Degree of implementation in IED"** occured since IEDs supported different degrees of implementation of functions. The standard defines both, basic mandatory parts as well as various optional aspects. Based on this approach the standard permits user specific degrees of implementations starting with basic small solutions for simple requirements and ending with high-level solutions for sophisticated requirements. Solutions with a lower degree of implementations are fully standard conformant in the same way as solutions with a higher degree are, although they might not be able to support specific functions. It has to be verified in the project specification which degree of implementation is needed for the actual project. If

optional parts of the standard have to be used then additional measures may have to be taken into account in order to achieve interoperability.

Findings of category "**Degree of implementation in IED"** are indications for users and suppliers to verify project requirements against the supported functionality by IEDs. Generally it is recommended for vendors to increase the degree of implementation in IEDs in order to provide more comprehensive solutions to the market.

The following findings belong to this category:

- Event-Driven Disturbance Record Transfer
- COMTRADE Directory Access
- Direct Control
- *AddCause* (AdditionalCauseDiagnosis) Values
- Support of *stSeld*
- Format of Data in GOOSE Messages (Structure or Separate Variables)
- TPAA Connection Parameters
- Engineering Tool Compatibility to Enhancements of the Standard

Findings of category **"Vendor specific restrictions to the standard"** occurred since some vendor specific implementations introduced constraints for communication. These constraints have system-wide consequences which reduce the flexibility for setting up the system. Such constraints limit the choice of devices for setting up interoperable systems. They might prevent users from selecting IEDs which are not tolerant to the specific constraints although they are conformant to the standard.

It is recommended to prevent any "**Vendor specific restrictions to the standard"** in order to ensure the best system solution for the user. All devices should support the full range of values defined in the standard. Possible restrictions have to be considered system-wide, i.e. for all devices and in the engineering phase to ensure interoperability.

The following findings belong to this category:

- Specific Prefixes/Instances of LNs
- IED Name Length
- GOOSE Engineering - Configuration Limitation for GSE/*APPID* (Unsigned16)
- GOOSE Engineering - Unambiguous Identification of GOOSES

IEC 61850 is the first communication standard for substation automation which defines also the engineering of communication based on SCL language besides the basic definition of communication aspects. As a new aspect, system configuration for IEC 61850 systems is needed to establish the data flow between server and client (Reporting, Control) and between the servers (GOOSE). This data flow engineering as part of the system configuration in the project was made by various project parties. All parties contributed to system engineering but based on **"Different approaches for system engineering"**. One approach was based on standard definition according to [IEC-6] providing a complete SCD file which was used for both system engineering and system documentation. In another approach ICD files were used for direct configuration of clients and servers. This approach did not provide a comprehensive SCD file. This SCD file could be used for limited documentation purposes only.

It is recommended to use the **system engineering approach** which provides complete SCD files according to the standard. The complete substation description should be available in one file. This file could be used to configure all clients and servers including communication. It provides complete substation documentation for future enhancements and amendments.

The following finding belongs to this category:

- Different System Engineering Approaches

The annex contains a set of guidelines a system engineer should consider in order to face an efficient way of system-wide interoperable engineering of a multi-vendor system constellation of devices.

4 Annex

4.1 User-Guidelines for Setting up IEC 61850 Multi-Vendor Projects

The following rules were derived from the best practices identified during the project. Naturally a thorough preparation is one of the major success factors of a multi-vendor project. Nevertheless a well and coordinated test and commissioning will support an efficient project conclusion.

A) Specify Application Functions and Communication Requirements

Look for proven multi-vendor project specifications

A good starting point is the use of specifications, which have been successfully applied in accomplished multi-vendor projects or have been developed by dedicated expert groups. Ask your vendors for those specifications. National and international standardisation or user groups might also be able to provide helpful guidelines and recommendations [DKE_APPLICATIONS, UCAIUG].

Describe application functions and expected behaviour

List all the application functions which you want to be implemented by the substation automation system. Describe in detail the concepts and expected behaviour especially of those applications which require the interaction of several components (IEDs), e.g. substation interlocking or synchrocheck.

Describe communication functions and data exchange

If the application function requires data exchange, describe what type of communication is necessary, what are the involved communication actors and what data is exchanged between the actors.

Describe essentially required IEC 61850 objects and services

For each application identify those IEC 61850 objects (Logical Nodes incl. Data Object and Data Attribute) which are essential for function realisation. Describe which information (Data Attribute) and which communication IEC 61850 service should be used for data exchange. Guidelines from vendors or expert groups provide assistance in the identification of reasonable objects and services.

Specify information flow between IED

In order to get a comprehensive overview of the information flow within the substation automation system compile all required IEC 61850 objects and services from an IED perspective.

B) Select Capable IEDs and Document IEC 61850 Objects

Select IEDs according application functions and communication capabilities

Ensure that IEDs fulfil the functional requirements and are capable to provide required IEC 61850 objects and services. Consult the PIXIT documentation for detailed descriptions and possibilities of the communication implementation.

Document signal designations of IEC 61850 objects

Different signal designations of the used IEC 61850 objects due to IED specific naming are quite usual (e.g. different prefixes and suffixes of circuit breaker Logical Node XCBR). Here a cross-reference table as basis for testing and commissioning has proved itself in practice.

C) Test and Start-up Step-by-Step

Use handy and device independent test and diagnosis IEC 61850 tools

Handy test and diagnosis tools facilitate identification and localisation of failures or misconfiguration. Especially in case of multi-vendor projects the use of device independent tools is recommended in order

to limit the number of tools. "Device independent" means supporting IEC 61850 compliant interfaces. The use of the tool is not restricted to a specific IED. It does not mean a mandatory use of third party tools.

Communication commissioning: from simple to sophisticated

Begin with the start-up of simple communication functions. Reporting of measurements and status information are a good choice. Proceed with control commands. After successful start-up of reporting and control proceed with GOOSE communication.

4.2   Categories for findings

Category / Finding	Lack of detail in the standard	Degree of implementation in IEDs	Vendor specific restrictions to the standard	Different system engineering approaches
Application Findings				
Event-Driven Disturbance Record Transfer		X		
Specific File Storage for Disturbance Records	X			
COMTRADE Directory Access		X		
Direct Control		X		
Interpretation of File Creation Date	X			
Indication of *RcdMade* (Disturbance Recording Complete)	X			
Separate Selection Command of *Select-Before-Operate (SBO)* Sequence	X			
AddCause (AdditionalCauseDiagnosis) Values		X		
Support of *stSeld*		X		
Specific Prefixes/Instances of LNs			X	
Format of Data in GOOSE Messages (Structure or Separate Variables)		X		
Engineering Findings				
IED Name Length			X	
Different System Engineering Approaches				X
GOOSE Engineering – Configuration Limitation for GSE/*APPID* (Unsigned16)			X	
GOOSE Engineering – Unambiguous Identification of GOOSES			X	
GOOSE Engineering - *AppID* (VISIBLESTRING65)	X			
TPAA Connection Parameters		X		
Assignment of Primary Process to Logical Nodes	X			
Engineering Tool Compatibility to Enhancements of the Standard		X		
Handling of *ConfRev*	X			
Handling of Revision of CID Files	X			
System Coordination Findings				
Multi-Client Systems with Clients from Various Vendors	X			

End of document