GE

Grid Solutions

New Insights into **IEC 61850** Interoperability and Implementation

White Paper

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imagination at work

Abstract

The IEC 61850 standard has been released for more than 10 years. Electrical utilities have made considerable effort to apply the IEC 61850 engineering process and technology in their substations. Intelligent electronic device (IED) vendors and third parties have provided many tools to help such customers implement this transformation.

While a bottom-up approach using IED vendor tools has been widely used in utilities, a top-down approach using vendor-neutral tools is gradually being used. Tools provided by specific IED vendors are not optimal and do not always work in a multi-vendor environment, while so-called System Configuration Tools are far from mature. Grid automation engineers need be trained for a wide range of tools to get the job done. Interoperability in IEC 61850 still focuses on the device level. So there are many challenges in interoperability at the system level.

The purposes of adopting the standard are to realize the interoperability of IEDs within multi-vendor substation systems, to reduce engineering efforts, and to reduce maintenance costs for utilities. To achieve these goals, there are still many challenges.

This white paper outlines the interoperability of IEC 61850. Our understanding of the standard is included. Our practices, with a number of use-cases, for interoperability within a multi-vendor environment are analyzed and our thoughts and insights regarding interoperability are discussed. The architecture/process for interoperability at the device level and system level is proposed too. Recommendations to implement IEC 61850 interoperability are provided.

1. Introduction

Many IEC 61850-compliant substations have been built and are in operation around the world since IEC 61850 was released in 2005. The configuration of IEC 61850-based substation automation systems with multi-IED vendors using a set of configuration tools still has been a challenge. No single tool can realize the whole process of configuration. The claimed benefits of the IEC 61850 standard, such as reducing engineering efforts and maintenance costs, have not been fully realized due to the lack of a practical System Configuration Tool. IEC 61850 Edition 2 has addressed many issues regarding interoperability, but many projects will combine Edition 1 IEDs with Edition 2 IEDS.

Configuration of an IEC 61850 substation at the system level is a complicated and comprehensive engineering process. It not only involves IED Configuration Tools from different vendors and a System Configuration Tool from one of the IED vendors or an independent third-party, but also requires correct understanding of the configuration process and data flow. The majority of work for interoperability has been focused on the IED level since IEC 61850 was released. IED vendors and utilities have gained a lot of experience on IED-level interoperability. The current key issue that affects the engineering process is the compatibility and interoperability of IED Configuration Tools and the System Configuration Tools. In other words, interoperability at the system level is a major concern.

Recently, GE Grid Solutions conducted a comprehensive study on IEC 61850 interoperability within a multi-vendor environment. With state-of-art devices, device configuration tools, and system configuration tools, the interoperability and compatibility at device and system levels have been fully tested. There are many valuable findings during the practice. These findings brought us to think more and in depth on the interoperability. In the following sections of this paper, these findings are discussed.

In Section 2, two different IEC 61850 engineering methods (top-down and bottom-up) are studied and compared. This section discusses the necessary tools for each method, as well as the compatibility issue of these tools and various IEC 61850 Substation Configuration Language (SCL) files.

Section 3 introduces the concepts of Dataset, GOOSE Control Block, and Report Control Block. It explores how these concepts play a role in interoperability.

Section 4 outlines implementation of interoperability. IED configuration tools and system configuration tools are discussed in depth and some important matters that affect interoperability are highlighted.

Section 5 addresses field deployment/commissioning testing. The unique requirements of testing a multi-vendor IEC 61850 system, such as GOOSE message isolation, IED simulation and test mode under Edition 2 are discussed. This section proposes some conceptual testing tools to monitor the GOOSE messages.

Section 6 outlines findings and recommendations.

2. IEC 61850 engineering process, tools, and interoperability

IEC 61850 is a standard that provides methodology and modelling of substation automation systems towards a full digital solution. Within IEC 61850, the substation automation system is modeled using the object-oriented method. Each device/equipment has its corresponding object. The relationships of these objects are also well defined. The standard lays a solid foundation for a digital substation system, as well as a smart grid.

The following figure illustrates object-oriented models of IEC 61850.

Application of IEC 61850 brings a new engineering process to utilities. With the assistance of suitable software tools, the ideal engineering process is automated as much as possible.

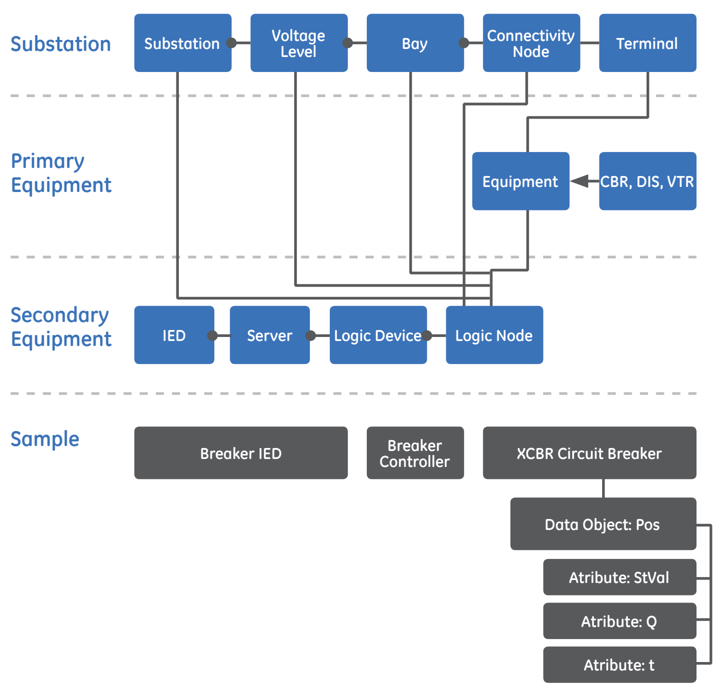
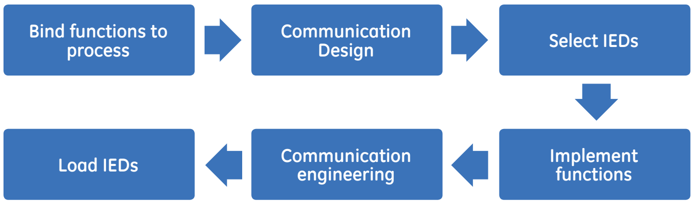


Figure 1: SCL-based model of substation

2.1 Top-down approach

The engineering process that IEC 61850 recommends is the top-down approach. It starts with the specifications of a substation system. The figure illustrates the general process.



The process completes three major tasks: System Specification, System Configuration and Integration, and IED Configuration. One item to be noted here is the data within this process. One of advantages of IEC 61850 is that it defines a unified language to describe system specification, system configuration, and IED configuration. That is the Substation Configuration Language (SCL). SCL is a configuration description language defined by IEC 61850-6 to describe/specify in a way understandable by configuration tools of different manufacturers the capabilities and configuration of IEDs and communication systems. SCL acts as a data description language and provides the same data format to these three tasks. Therefore, the standard ensures that IEDs use the syntax and semantics that allow them to understand the transmitted data and information and interoperate. The following figure demonstrates the mission and data flow of the top-down approach.

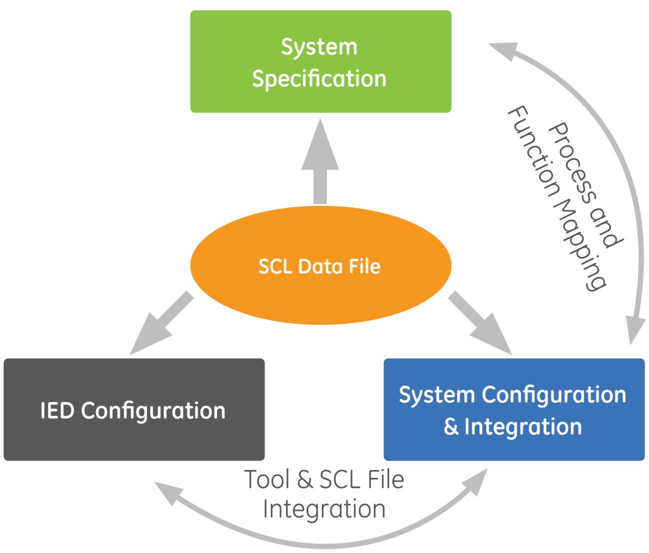


Figure 3: Mission of top-down approach

2.1.1 Tools and language

The Substation Configuration Language (SCL) includes several formats, as follows:

SSD - System Specification Description

SCD - Substation Configuration Description

ICD - IED Capability Description

CID - Configured IED Description

IID - Instantiated IED Description

SED - System Exchange Description

In actual applications, the engineering process is realized through three kinds of tools: IED Configuration Tool, System Configuration Tool, and System Specification Tool. Each tool completes one specific task, as illustrated in Figure 4, which shows the interoperability of the tools. The System Configuration Tool also includes integration, documentation, and monitoring tools.

Each tool deals with a different SCL data format. Figure 5 gives an overview of tools and SCL data.

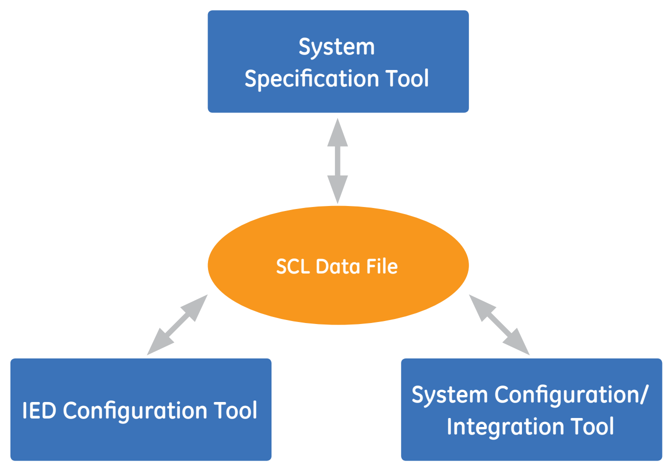
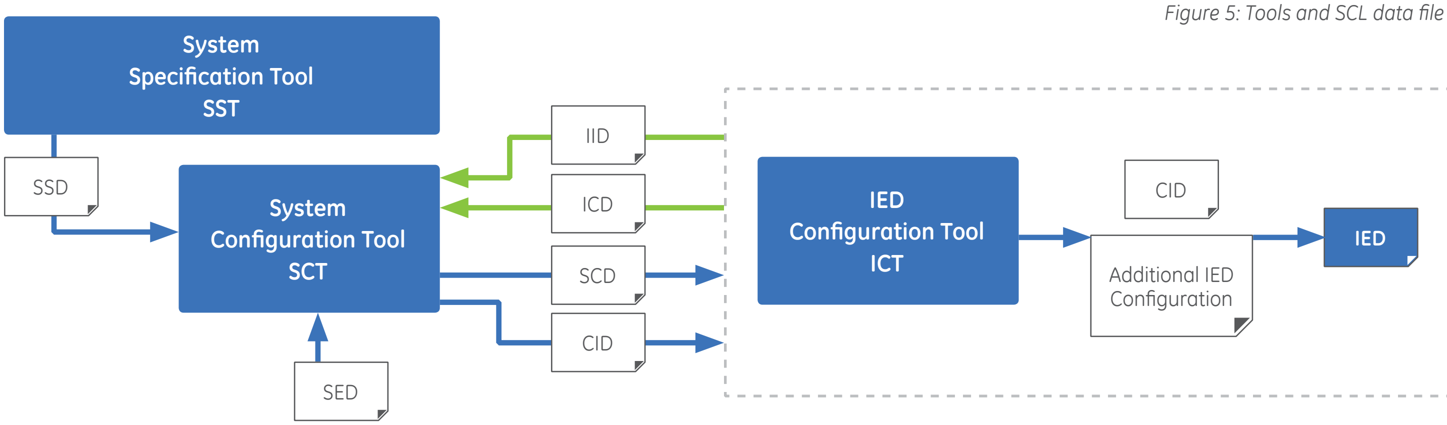


Figure 4: Tools with top-down approach

Figure 5: Tools and SCL data file



2.1.2 System configuration and integration

In the top-down approach, the most important step is to integrate all IEDs that will be used in the substation according to the CID/IID file of each IED and the SSD file of the substation, and to generate the SCD file. The following are major steps in the system configuration:

1. Collect capabilities of devices (through ICD/IID files) and the system specification (using an SSD file when available).
2. Import these files in the SCT.
3. Configure the IEC 61850 capabilities of the system for all devices, including datasets, control blocks, and GOOSE messages
4. Connect all IEDs to the network – set IP addresses and Network Access Points.
5. Export the resulting SCD file to import into device configuration tools

In actual application, the top-down approach is mainly used in a small project with a single IED vendor for pilot purposes. It has not been widely used due to a lack of mature System Configuration Tools.

2.2 Bottom-up approach

The bottom-up approach has been used in utilities due to IEC 61850 being well supported in IED Configuration Tools. This approach starts with IED, as shown in the following figure.

In this approach, all know-how is bound to the IED and stored in vendor-specific tools. All settings, including IEC 61850 settings, are handled in a vendor specific manner.

2.3 Interoperability

IEC 61850 Edition 2 defines the roles of the tools more clearly and precisely compared to Edition 1. The functionality of IED Configuration Tools and the System Configuration Tools are gradually being enriched. Interoperability is becoming more possible.

Interoperability in the IEC 61850 world is addressed at two levels: device (IED) level and system level. The interoperability at system level is realized during the substation configuration, while interoperability at device level occurs when devices communicate in real time.

The system interoperability is to verify whether the System Configuration Tool and the IED Configuration Tool can work together through the SCL language. For example, the following are some typical questions to consider when dealing with interoperability:

1. Can the System Configuration Tool accept an ICD/IID file from every vendor IED?
2. Can the System Configuration Tool configure GOOSE transmission, GOOSE reception, and reporting for each vendor IED?
3. Can the System Configuration Tool handle private information (for example, protection information) for each vendor IED?
4. Can the System Configuration Tool handle a mix of Editions of IEC 61850?
5. Can the IED Configuration Tool accept an SCD/CID file from the System Configuration Tool?
6. Can the IED Configuration Tool send a CID file generated by the System Configuration Tool to the IED?

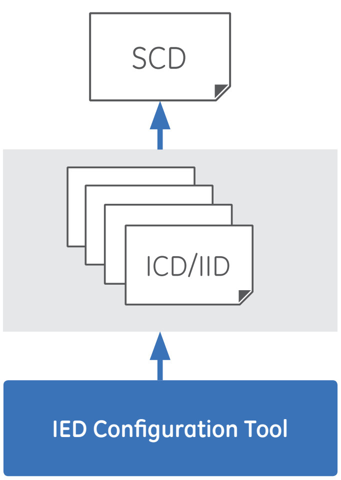


Figure 6: Bottom-up approach

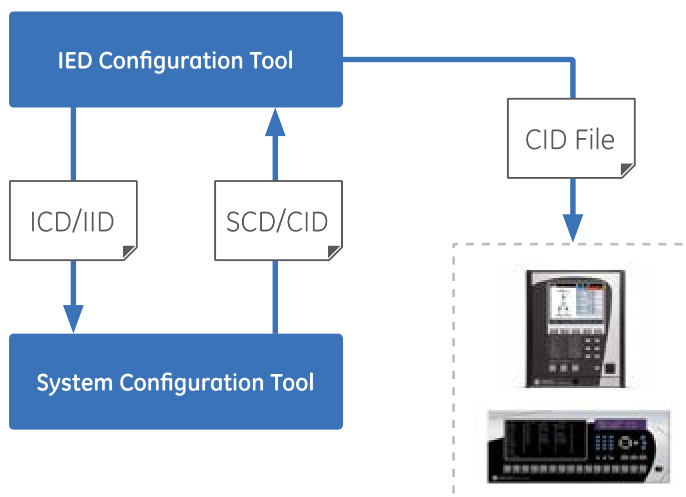


Figure 7: Interoperability of tools at the system level

3. Principles of interoperability in multi-vendor system

An IED's data and information are modeled in a classified and hierarchical manner in the IEC 61850 standard. All Data Attributes (DA) that collectively provide the information of a certain function (for example pickup, timestamp, quality) are collected as a Data Object (DO). The combination of Data Objects that contain the information of a specific application (such as phase instantaneous overcurrent) is categorized under a Logical Node (LN). Logical Nodes that provide a general service (such as Protection, Control) can be grouped as a Logical Device (LD). Finally, a Server provides a representation of the behavior of the IED, based on the aforementioned data categories, to the entities outside the IED.

In order to provide the means for IED interactions, other entities need to be defined and modeled to facilitate the exchange of data among the IEDs. IEC 61850 has defined several models and classes that operate on the data of the IED. Specifically DataSet, substitution, setting group control, Report Control and Logging, Control Blocks for generic substation event (GSE), Control Blocks for transmission of sampled values, control, time and time synchronization, File system and Tracking are the models defined in IEC 61850 for this purpose. Structuring the IED information based on the hierarchical system and using these models, IEC 61850 introduces various services that can be utilized, based on the IED capabilities, to facilitate the information exchange among IEDs. The introduced services and models are intertwined and cannot be considered as separate concepts. The process of the information exchange is conceptually independent of the IED manufacturer and the proprietary implementation of the IED. Rather, it is solely based on the capabilities of the IEDs to provide these services.

An IED, to satisfy interoperability requirements, should be able to interact and exchange information with other IEDs, based on its capabilities, using these services. Highlights of the models and services are explained in the following sections.

3.1 DataSet

DataSet is an ordered collection of Data Objects and Data Attributes that are not necessarily categorized under one Logical Node. DataSets allow a user to conveniently group certain Data Objects and Data Attributes that are required in their application and therefore help the user to efficiently utilize the communication bandwidth of the substation network and reduce the complexity of the configuration. DataSets are important for several models and services, such as Report and GOOSE Control Block, since they define the transmitting data structure.

3.2 Report control block and log control block

Report and Log Control Block models provide IEDs with the means to either report events of the system to clients or log the events internally. Reporting utilizes notification-based mechanisms rather than polling to save time and network bandwidth.

Report and Log make use of DataSets to contain the list of data points to monitor. As soon as an event is detected by detecting data change, quality change, or data update in a DataSet, a notification is generated. The notification starts an internal sequence of actions to prepare the report content that is sent eventually to the client. Moreover, it is expected for a client to initiate a General Interrogation (GI) at any time. GI requests from the server a set of data values in order to synchronize with the current state of the server.

Two types of Report Control Blocks are defined in IEC 61850 standards.

- **Buffered Report Control Block (BRCB)** — A buffered report can be buffered, based on the IED capability, in case the report is not sent due to communication issues or other problems. This type of report ensures that no report is lost and can be retransmitted as soon as the issue is resolved.
- **Unbuffered Report Control Block (URCB)** — An unbuffered report is sent immediately after an event. However, if a report is not transmitted due to communication issues or other problems, it is not buffered and data can be lost.

3.3 GOOSE control block

The Generic Object Oriented Substation Event (GOOSE) control block allows fast and reliable exchange of data from one IED (Publisher) to several peer IEDs (Subscribers) in order for the IEDs to perform a distributed action. A GOOSE control block makes use of DataSets to organize the required data that needs to be monitored and published in each GOOSE message. As soon as the value of a DataSet member changes, the GOOSE message is published. The publisher/subscriber mechanism of the GOOSE message allows any IED in the system to subscribe to a specific published message without requiring any modification in the configuration of the publisher.

3.4 Control

The Control model is defined for changing the state of the units based on a client command. The client sends a command to the process and receives the response from the process. There are four types of behaviors defined for the control model that can be used based on the capabilities of the IED and the process: direct control with normal security, select before operate (SBO) control with normal security, direct control with enhanced security, and SBO control with enhanced security.

3.5 IEC 61850 in substation automation systems

Substation automation systems (SAS) require certain functions in order to monitor, control, and protect the system. These functions are distributed among the IEDs based on their responsibilities in the system. The following figure presents the communication diagram of a substation example. The diagram consists of three local bays that are responsible for protection, control, and monitoring three parts of the system: local 230 kV line, 230/115 kV transformer, and 115 kV line. IEC 61850 clients, station human-machine interface (HMI), and SCADA system are utilized for monitoring and control of the entire system from the station level. Finally, communication means are provided to establish communication to the remote 230 kV line in order to facilitate performing functions that require the involvement of the remote end of the 230 kV line.

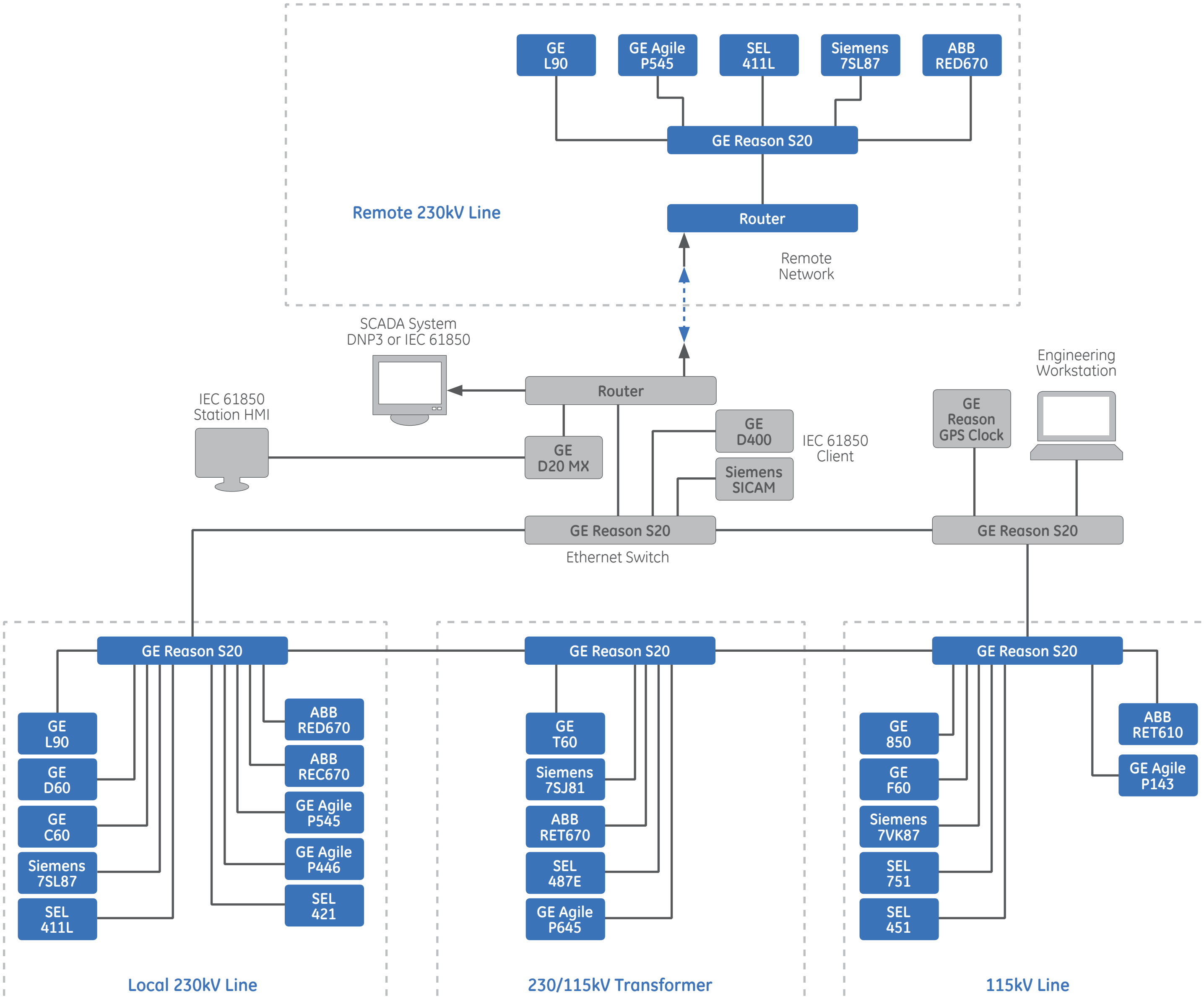


Figure 8: IEC 61850 substation communication architecture

The following communication interfaces are expected to perform the required functions: interfaces to transmit analog and control data from the process to the bay IEDs; interfaces to transmit data among the IEDs within a bay; interfaces to directly exchange information between bays; interfaces to convey control and protection data between bay and station level clients and IEDs; interfaces to transfer data among the station IEDs; interfaces to communicate control data and information from station IEDs to remote substations and bays; and interfaces to exchange data between the local and remote bays.

The next figure presents an example of a distributed function, scattered between two IEDs. IED 1 is responsible for protection and metering while IED 2 controls and monitors the breaker. IED 1 and IED 2 contain some Logical Devices, as follows:

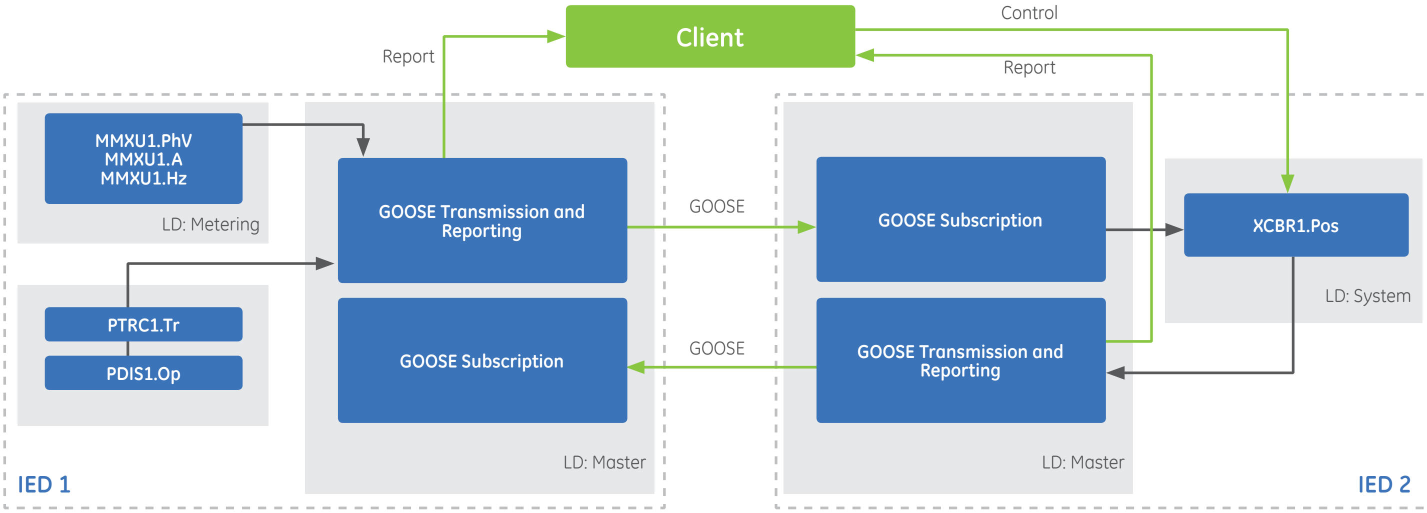


Figure 9: Distributed function example implemented with IEC 61850

- Protection logical device in IED 1 has two Logical Nodes, these being an instance of Distance protection logical node (PDIS1) and an instance of Trip Bus logical node (PTRC1). The Operate (Op) data attribute of the distance element is used as the input of the trip bus. If the distance element detects any fault, it transmits the information to the trip bus. Trip bus is mapped to send the Trip (Tr) command to GOOSE and Reporting services in order to send the necessary command to IED 2 for controlling the breaker and report to the client
- Metering logical device in IED 1 has an instance of the measurement logical node (MMXU1) that provides the metering information, such as Phase Voltage (PhV), Current (A), and Frequency (Hz) to GOOSE and Reporting service
- Master logical device in IED 1 is responsible for providing the information exchange services such as GOOSE and Report services in order to facilitate the communication with other IEDs and the client
- System logical device in IED 2 contains an instance of Breaker Control (XCBR1) logical node in order to control and monitor the position (Pos) of the breaker

Upon occurrence of a fault, the status of IED1Protection\PDIS1.Op changes from false to true. This parameter is transmitted to the PTRC1 logical node and causes a status change of IED1Protection\PTRC1.Tr data object. This change triggers GOOSE and Report services; a GOOSE message is transmitted to IED 2 and a report is sent to the client. IED 2 receives the GOOSE message. The change in the status of the received GOOSE message prompts IED2System\XCBR1.Pos to change the status of the breaker and isolate the faulted line. A GOOSE message containing the new status of the breaker is sent back to IED 1 and a report is also sent to the client for monitoring and data recording purposes. When the fault is cleared, the client can close the breaker by sending a direct Control command to IED2System\XCBR1.Pos data object.

In this scenario, the manufacturer and type of IEDs is not important as long as the IEDs are capable of performing the depicted protection and control functions. A metering logical device can be part of IED 2 and the metering values can be reported via IED 2. The data reference of the transmitted GOOSE messages and Reports are fixed and there is no need for configuring and defining communication addresses for transmitted messages.

It is evident that IEC 61850 has created a solid foundation in realizing interoperability in communication networks for power utilities. However, there are a few areas in which the standard is silent or has not provided a concrete solution to avoid confusion and ambiguities. These unclear scenarios stand out when IEC 61850 is interpreted with different suppliers and the developed IEDs are not fully capable of handling all possible interoperability scenarios, as it is not mandated by the standard. A fully interoperable IED requires accepting all basic and complex types of data when DataSets are configured. Moreover, it requires receiving and handling the values of DataSets that contain members with all possible data types. A GOOSE message, for example, that transmits a DataSet with members of different types and structures, such as INT32, Float, Quality, Timestamp and so on, should be possible to configure in the transmitting or receiving IED. Publishing and reception of structured GOOSE also plays an important role in communication among IEDs that needs to be considered in the list of IED capabilities. In addition, IEDs should be able to handle structured GOOSE messages by interpreting data attributes, quality bits, and timestamp in the message. Moreover client/server communication should be established by limiting restrictions on the server IEDs since the capabilities of IEDs in the fields may be limited.

It is recommended that suppliers implement feature sets to handle all possible data and information types and packages and convert them to types that can be interpreted and utilized within the proprietary section of the IEDs. The way that clients initiate communication with servers needs to be as flexible as possible. Missing optional logical nodes, longer object names, and various optional fields' selections of buffered and unbuffered reports, for example, should not prevent the client from communicating with IEDs or receiving reports.

4. Implementation of interoperability in a multi-vendor system

IEC 61850-6 Edition 2 adds a new section called "Tool and project engineering rights" in which it defines the IED Configuration Tool and System Configuration Tool engineering responsibilities and roles.

For a project with IEDs from multiple vendors, the top-down approach is shown in the next figure. It involves a selected System Configuration Tool (SCD) and all IED Configuration Tools (ICTs) from the vendors.

There are a lot of challenges for this solution to be successful even though this is the premium configuration method promoted by the standard. There can be compatibility and interoperability issues among the System Configuration Tool and the IED Configuration Tools. The ICD file or IID file from the IED Configuration Tool can fail the validation by the System Configuration Tool, and the SCD or CID file created by the System Configuration Tool can be rejected by the IED Configuration Tool. The conformance testing of IEC 61850 tools requires coordination from all parties involved.

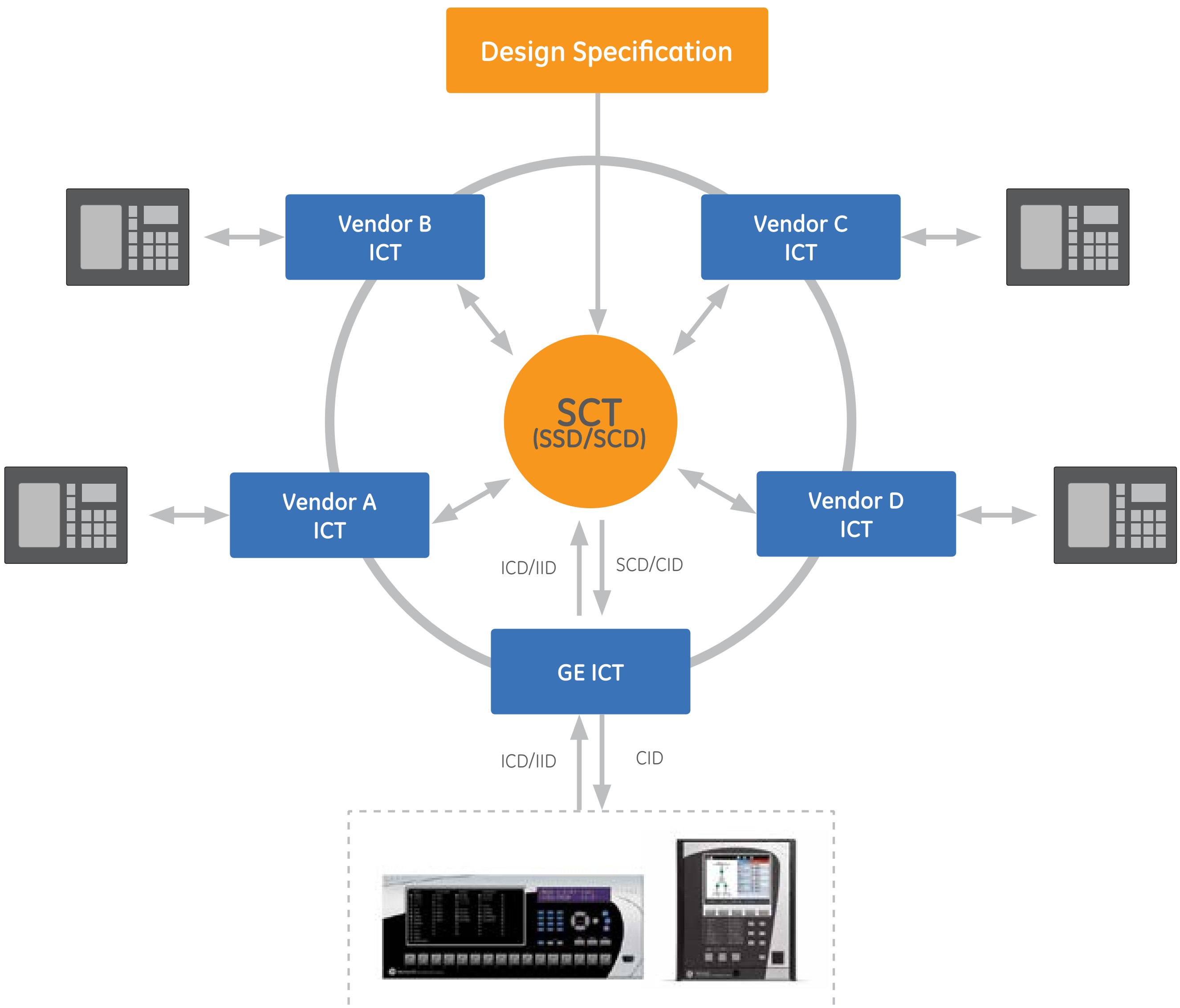


Figure 10: Interoperability within the top-down approach

4.1 IED configuration tool

The IED Configuration Tool or IED Configurator is manufacturer-specific and can be used to

- Generate an ICD template file or instantiated IED Description (IID) file, which is a project-specific configuration and IED capabilities file
- Import a SCD/CID file to configure the IED with final IED instance configuration before loading the IED instance
- Bind GOOSE messages from other IEDs as defined within an imported SCD/CID file to internal signals, for example by means of the SCL Input section
- Upload /download the CID file from/to the IED

The IEC 61850-6 Edition 2 clause 9.3.13 "Binding to external signals" provides an IED internal address field called "intAddr" that is used for binding the external signals to the internal IED addresses. For some IEDs that have the fixed internal IED addresses for the reception of GOOSE messages, the internal IED addresses can be predefined in the ICD file so that the System Configuration Tool can actually bind the external signals to those addresses and complete the GOOSE message configuration. However, for some IEDs, the internal IED addresses may not be available in the ICD file and the binding of external signals to those IED addresses may not be practical for the System Configuration Tool. Therefore the IED Configuration Tool is better able to complete the task before sending it to the IED. It is also important to know that it is the IED tool's role to fill in the 'inAddr' field in both cases, and the System Configuration Tool always preserves this field unchanged. The interface between the System Configuration Tool and IEC Configuration Tool is not easily tested due to the involvement of multiple companies. Therefore, there are still a lot of challenges for successful configuration of GOOSE subscription at the system level.

When importing an SCD/CID file generated from a System Configuration Tool, the IED Configuration Tool checks the input section, verifies the "ExtRef" fields, and provides an interface to bind the external signals if the "intAddr" fields are empty before sending it to the IED instance unless the IED uses predefined internal IED addresses. The following code is an example of predefined internal IED addresses inside an ICD file and the fully configured input sections.

```
<Inputs>
   <ExtRef intAddr="Ind001" desc="RxG Bool1">
</Inputs>
<Inputs>
   <ExtRef intAddr="Ind001" desc="RxG Bool1" serviceType="GOOSE" iedName="TS01_SEL451_55CF" srcLDInst="G
   srcPrefix="" srcLNClass="LLN0" srcCBName="GooseDSet13" ldInst="G" prefix="" lnClass="GGIO" lnInst="1"
   doName="Ind001" daName="stVal" />
</Inputs>
```

Figure 11: SCL code of predefined internal IED addresses

4.2 System configuration tool

The System Configuration Tool or System Configurator is an IED- independent, system-level tool that is used to:

- Create an SSD file from a system specification, such as single line diagram, protection, and control functions
- Import multiple ICD, IID files and create an instance of IEDs inside the project
- Assign communication parameters to each IED in the project, such as the IP address, network mask, and gateway IP
- Create DataSet and Control Blocks for GOOSE transmission
- Create dataflow and Control Blocks for client and server communication
- Engineer the data flow between the IEDs, assign addresses to them, and bind the Logical Nodes to the primary system. The System Configuration Tool only needs to create IED input sections from the system engineering point of view, however without binding to IED internal signals.
- Reorganize the DataTypeTemplate section
- Create SCD or (possibly) CID files that can be used by the IED Configuration Tools for the final configuration of IEDs
- Handle proper information transfer between projects via the SED files

Most of the vendor IEC 61850 tools in the market play roles of both the IED Configuration Tool and partially the System Configuration Tool. The system configuration functions mainly focus on the vendor's own IEDs, such as configuration of GOOSE message exchange between IEDs. When coming to the IEDs from other vendors, it allows the import of those IEDs via an ICD/IID/CID/SCD file for configuring the GOOSE message subscription for their own IEDs. The configuration of other vendor's IEDs is limited and not tested with the other vendor's IED Configuration Tool. Therefore, it is common to result in errors when importing back to other IED Configuration Tools. However, the tool allows the configuration of their own IEDs for GOOSE reception from other vendors. This feature allows the IEC 61850 configuration for the bottom-up approach. When using the bottom-up approach, each IED is configured initially using its own IED tool for the following:

- Communication parameters
- DataSet and Control Blocks for GOOSE transmission and client communication

Figure 12 illustrates this bottom-up approach, where ICT refers to the IED Configuration Tool. The partially configured SCL files are then exchanged between IEDs from different vendors for GOOSE reception configuration and input bindings using IED tools. Each IED tool is responsible for configuring its own IED reception of the GOOSE messages from other vendors.

After the GOOSE message reception configuration, no more SCL file exchange among the vendor tools is required and each IED tool is responsible to load the SCL file to the IED instance of its own. This approach requires minimal SCL validation and compatibility. However, the documentation of the IEC 61850 project is difficult and there is no single SCD file available for the project. The user can end up using a traditional way of documenting the message exchange among IEDs. If vendors have separate settings file and the IEC 61850 SCL file for a single IED, the user has two files to manage for each IED—a proprietary setting file and a CID file.

The third-party tools, however, can only be the System Configuration Tool since it focuses on the system integration of IEDs from different vendors. It is important to understand the capabilities of System Configuration Tools and IED Configuration Tools to support Edition 1 and Edition 2 of the Standard. It also is important to understand how thoroughly the device files and SCT configuration tool have been tested together. Some errors encountered when using the SCD/CID files generated by the SCT as an input to the IED Configuration Tool or gateway configurator cannot be fixed without manual manipulation of configuration files.

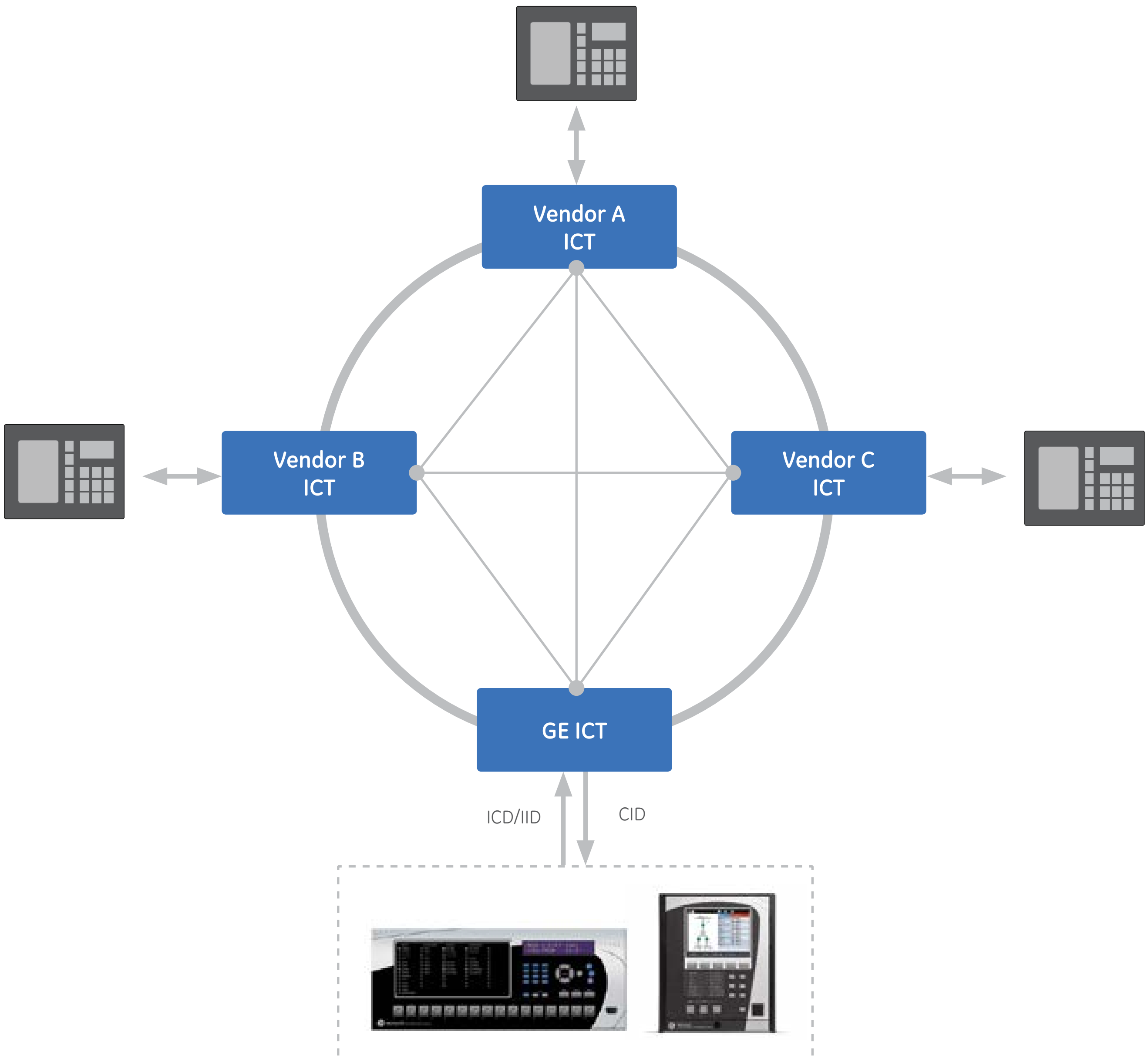


Figure 12: Interoperability with the bottom-up approach

4.3 GOOSE message publication and subscription

The GOOSE message configuration includes configuring the DataSet and GOOSE Control Block.

DataSet items can include only status, analog value, or both. A GOOSE DataSet can contain the Data Object (DO) (CDC) and Data Attribute (DA). The DO can contain the structured DAs and their quality and timestamp. Not all IEDs in the market support the DOs in the GOOSE messages. Therefore, it is recommended to use structured GOOSE only if all recipients can subscribe to structured GOOSE messages.

What follows is an example of the DataSet that can be used for a GOOSE message where the first item in the data set only contains the doName, which means it is a structured CDC data object. The second item contains the daName "general," which means it is a DA item. Item 3 is an analog DA. Figure 13 is the SCL code of this GOOSE message. Figure 14 demonstrates this configuration process.

```
<DataSet name=”GOOSE1” desc=””>
   <FCDA ldInst=”850” prefix=”phs” lnClass=”PIOC” lnInst=”1” doName=”Op” fc=”ST”/>
   <FCDA ldInst=”850” prefix=”phs” lnClass=”PIOC” lnInst=”2” doName=”Op” daName=”general” fc=”ST”/>
   <FCDA ldInst=”850” prefix=”” lnClass=”MMXU” lnInst=”1” doName=”TotW” daName=”instMag” fc=”MX”/>
</DataSet>
<GSEControl name=”gcb01” desc=”” datSet=”GOOSE1” confRev=”1” type=”GOOSE” appID=”850_GOOSE1”>
   <Private type=”GoEna”>true</Private>
</GSEControl>
```

Figure 13: SCL code of GOOSE publication

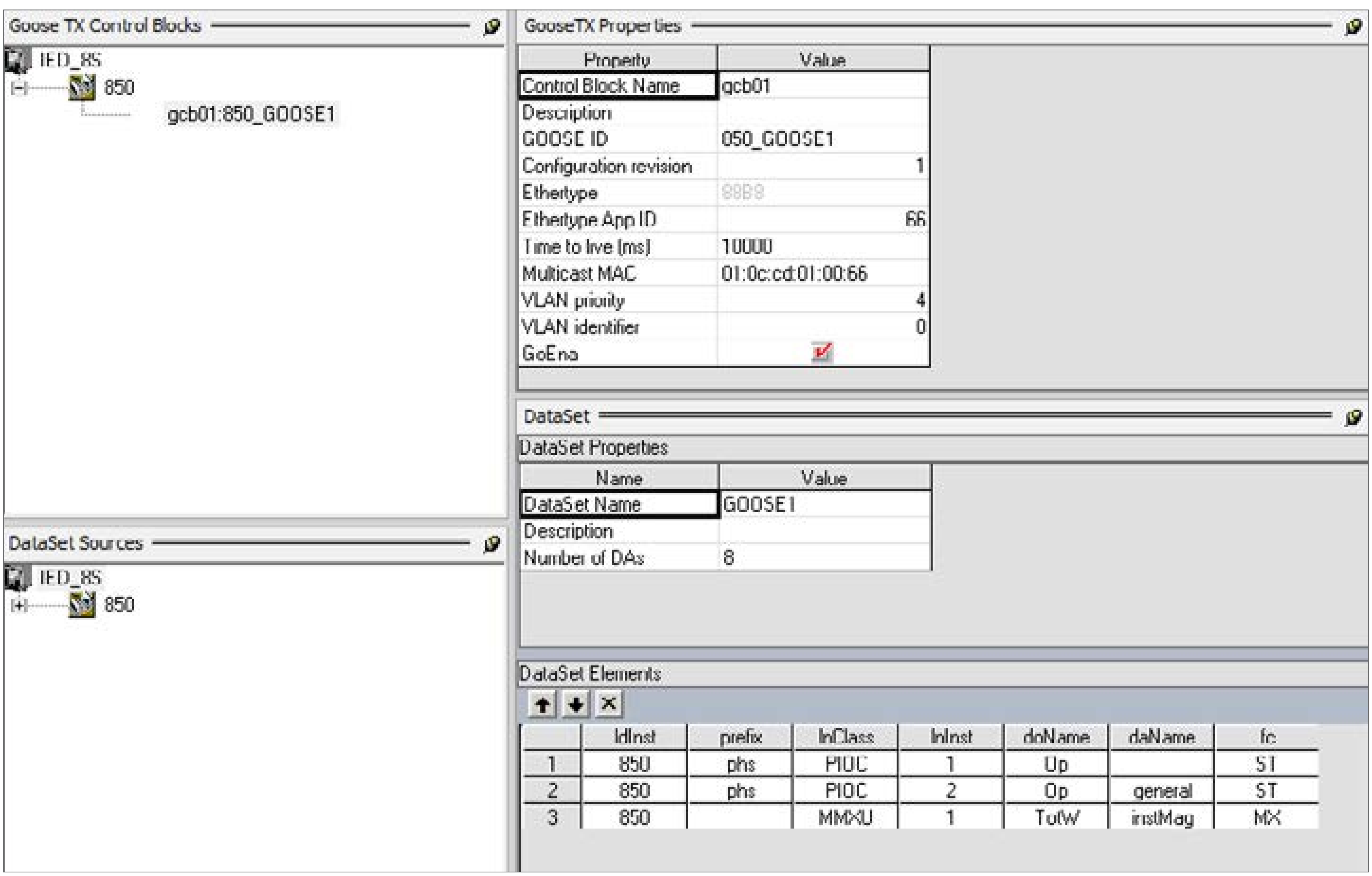


Figure 14: Configuring a GOOSE message for publication

Figure 15 is some SCL code for a GOOSE subscription message. Figure 16 shows one of the subscription methods of the above GOOSE message. When the GOOSE message item is a CDC data object, it will list all the data attribute for binding to IED internal addresses. The quality bits can be mapped separately to individual bits depending on application needs.

The binding of external messages is shown as follows.

```
<Inputs>
   <ExtRef iedName=”IED_8S” ldInst=”850” prefix=”phs” lnClass=”PIOC” lnInst=”1” doName=”Op” intAddr=”850_GOOS
   E1|66|01:0c:cd:01:00:66|{Bool,Bool,Bool,Bool,BVstring13,Utctime}(general,phsA,phsB,phsC,q,t)|0,0x0,,Ind1.
   stVal,0;4,0x400,,Ind2.stVal,0”/>
   <ExtRef iedName=”IED_8S” ldInst=”850” prefix=”phs” lnClass=”PIOC” lnInst=”2” doName=”Op” daName=”general”
   intAddr=”850_GOOSE1|66|01:0c:cd:01:00:66|Bool|0,0x0,,Ind3.stVal,0”/>
   <ExtRef iedName=”IED_8S” ldInst=”850” prefix=”” lnClass=”MMXU” lnInst=”1” doName=”TotW” daName=”instMag”
   intAddr=”850_GOOSE1|66|01:0c:cd:01:00:66|Float”/>
</Inputs>
```

Figure 15: SCL code of GOOSE subscription

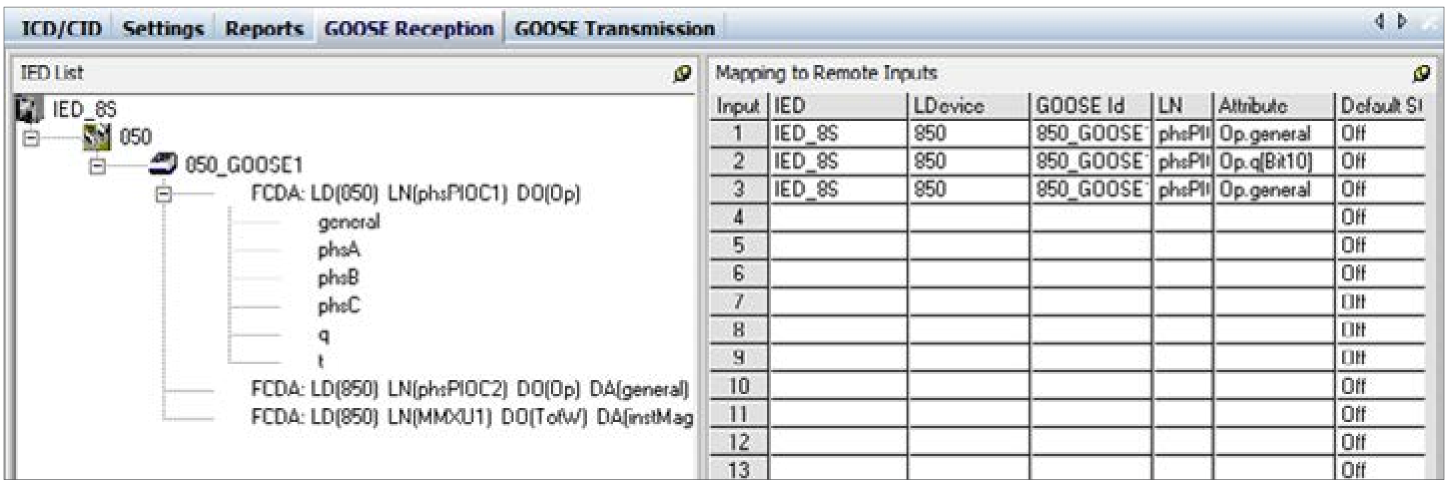


Figure 16: Configuring a GOOSE message for subscription

4.4 Report publication

Buffered and unbuffered reports can be configured using the IED tool or third-party System Configuration Tool. Figure 17 shows the configuration of buffered report brcb00_1 with an IED tool. The report urcb00_1 is the configured unbuffered report. The corresponding SCL code is shown in Figure 18. The maximum number of clients for the buffered report is one, while for the unbuffered report the configuration is four clients for this example.

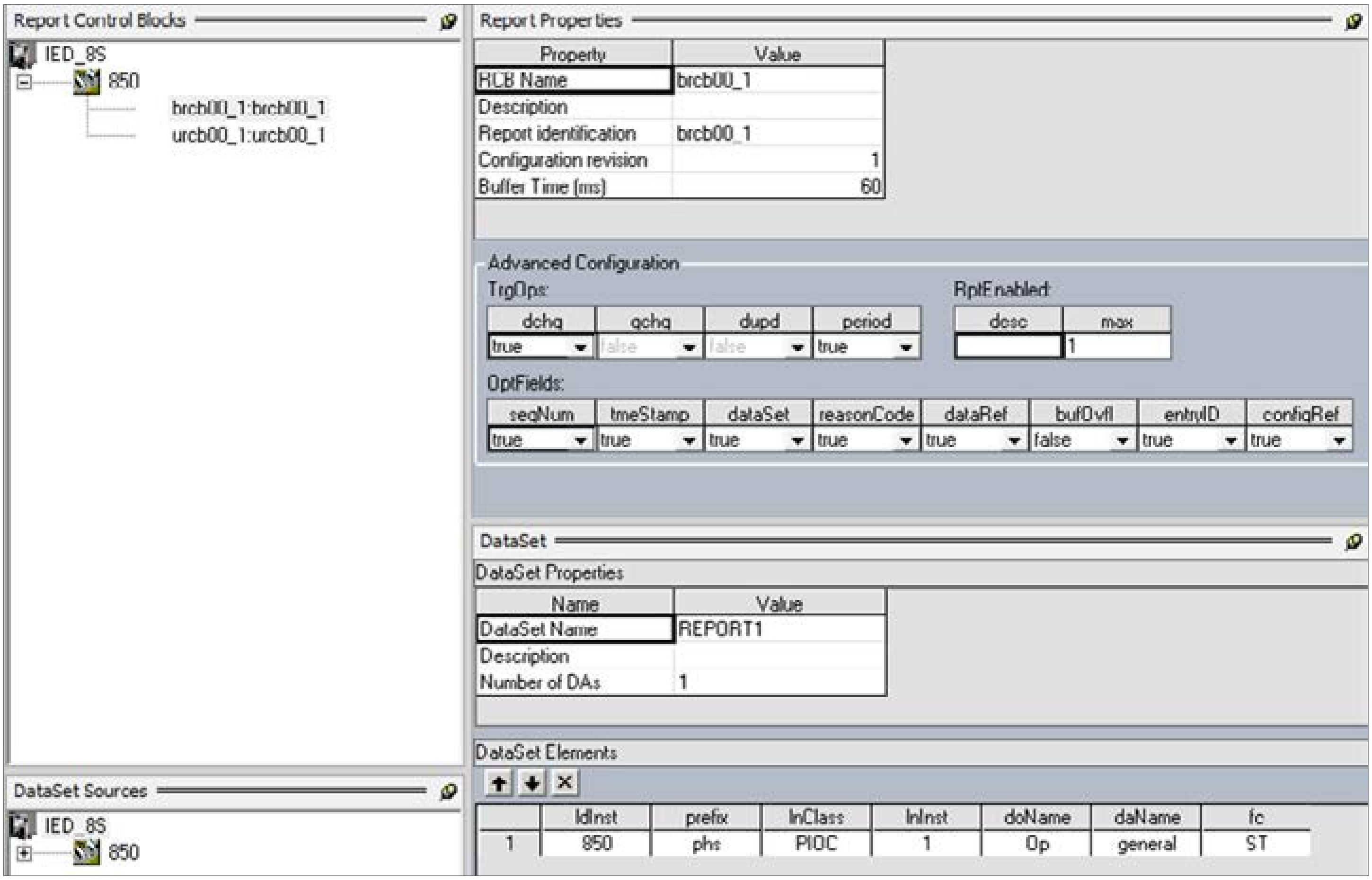


Figure 17: Configuring buffered and unbuffered reports

```
<DataSet name="REPORT1" desc="">
   <FCDA ldInst="850" prefix="phs" lnClass="PIOC" lnInst="1" doName="Op" daName="general" fc="ST"/>
</DataSet>
<ReportControl name="brcb00_1" desc="" rptID="brcb00_1" datSet="REPORT1" confRev="1" buffered="true"
   bufTime="60">
   <TrgOps dchg="true" qchg="false" dupd="false" period="true"/>
   <OptFields seqNum="true" timeStamp="true" dataSet="true" reasonCode="true" dataRef="true" entryID="true"
   bufOvfl="false" configRef="true"/>
   <RptEnabled max="1"/>
</ReportControl>
<ReportControl name="urcb00_1" desc="" rptID="urcb00_1" datSet="REPORT1" confRev="1" buffered="false"
   bufTime="0">
   <TrgOps dchg="true" qchg="false" dupd="false" period="true"/>
   <OptFields seqNum="true" timeStamp="true" dataSet="true" reasonCode="true" dataRef="true"
   configRef="true"/>
   <RptEnabled max="4"/>
</ReportControl>
```

Figure 18: SCL code for buffered and unbuffered reports

4.5 Handling of Edition 1 and Edition 2 IEDs in the same project

The IEC 61850 Standard has evolved to over time to improve specific portions to better provide interoperability. The revised version of the Standard is generically known as "Edition 2". This version changes the SCL schema, expands reference names for Logical Devices and Logical Nodes, and increases the number of Logical Node groups, Logical Nodes, and Common Data Classes. Legacy devices may only support the original ("Edition 1") version of the Standard, while newer devices will support Edition 2 of the Standard. In projects, it may be necessary to combine devices of both types. Interoperability is possible between these devices. However, this increases the complexity and uncertainty of the integration process using the System Configuration Tool and IED Configuration Tools. For such a project, proof of concept testing is a good choice before selecting the IEDs for the real project. The focus of the testing is on the interoperability of IED Configuration Tools and System Configuration Tool.

There can be some ambiguity on how to support the compatibility when coming to actual implementation. During lab testing of the mixed IEDs, we have noticed the following:

- The GOOSE message exchange among the IEDs of Edition 1 and 2 at the device level does not encounter any problem. Some IEDs with Edition 1 do not support structured GOOSE, therefore the use of structured GOOSE can be a limitation.
- The IED Configuration Tool with Edition 1 IEDs do not always not support importing SCL files of the Edition 2 IEDs from other vendors. Therefore the GOOSE subscription configuration using the IED Configuration Tool becomes challenging for some IEDs.
- A substation gateway that supports Edition 2 is required. A substation gateway that can be configured using an SCD file, individual CID files, or online configuration is preferred, as this provides the most flexibility in configuration.
- The SCD file generated using a System Configuration Tool is a hybrid Edition 1 and Edition 2 SCL file that contains both Edition 1 and 2 IEDs. The resulting SCD files generated with two different System Configuration Tools were rejected by the IED Configuration Tools and the substation gateway configurators. This requires manual manipulation of the device files to be successful.

5. Field deployment/commissioning testing

When deploying an IEC 61850 system, there will be inevitable changes to the SAS engineering process and documentation. New tools and testing methods are needed for system commissioning. This section discusses the impacts that IEC 61850 brings to SAS documentation and IED testing.

5.1 SAS engineering documentation

The substation configuration description SCD file is the core document in an IEC 61850 substation. It contains the inter-device communication configuration information of the entire substation. Therefore, it is kept as part of the substation engineering documentation record, along with schematics drawings, wiring diagrams, and IED setting files.

Visualization of the communication links configured in the SCD file is essential in field commissioning and troubleshooting. Engineers and technicians need a diagram that shows where the GOOSE messages originate and where they go. Though the IEC1850 standards do not define how the SCD is visualized, the visualization tool needs to be able to extract these configurations from the SCD file and generate such diagrams.

5.2 IEC 61850 testing

IEC 61850 interoperability brings changes to how the IEDs are tested. For example, the methods and tools that are used in hard-wired IED I/O testing cannot be used on the GOOSE message testing. There are three basic operations to test an IED: IED isolation, simulation, and output monitoring. The principles in these operations do not change but there are new requirements in the IEC 61850 era, as follows:

- **IED isolation** — Isolate the IED outputs from the rest of the system so that they do not cause inadvertent undesired operation. For an IEC 61850 system, there is need to isolate the outgoing GOOSE messages.
- **Simulation** — Applied simulated signals, such as AC voltage/current injection, to test IED configured functions. For an IEC 61850 system, this includes simulating IEC 61850 SMV or GOOSE messages.
- **Outputs monitoring** — Monitoring the IED outputs with the simulated signals. For IEC 61850, this includes monitoring the GOOSE status and the reporting.

The following sections focus on IEC 61850 testing methods in these three areas.

5.2.1 GOOSE isolation

IEC 61850 Edition 2 defines a quality test bit to facilitate IED testing. Each Logical Node is to contain a Data Object called Mod that can be set in test mode, which sets the quality test bit of all the data within the Logical Node to TEST. At the GOOSE subscription IED, if the data accepting LN Beh.stVal is not set in "test," then the incoming data is to be "processed as invalid" if its quality test bit is TEST. This function can be used to isolate the GOOSE messages by setting all the LNs in the GOOSE publishing IEDs to the "test" mode. Note that while some IEDs have a "test mode" feature, this "test mode" is functionally different from the IEC 61850 LN Mod in "test," and this is not discussed here.

"Process as invalid", defined by the IEC 61850 standard, means that the incoming GOOSE data is to fall back to the default or the last received status, as defined by the GOOSE subscription IED configuration. Our test results show that not all IEDs automatically perform this operation when the incoming GOOSE data quality test bit is TRUE. Some IEDs leave it to the application level, that is, the user programmable logics to decode the quality bit and to decide how to use the data when its test bit is on.

IEC 61850 Edition 2 allows the Mod data object to be set at both the Logical Node and Logical Device level. Setting the Mod at the Logical Device level forces the Mod of all the Logical Nodes within it to the same value. Setting the Mod at the individual Logical Node level gives more flexibility. For example, the overcurrent LN PTOC can be set in test mode while the distance LN PDIS can remain normal. How to implement the LN test mode on an actual IED is the manufacturer's decision, which has to balance flexibility and ease of use.

Similar to isolating IED output contacts with test switches, the GOOSE isolation operation should be able to be performed and the isolation indication to be visible regardless whether the IED is powered on or off. This is particularly important in IED replacement, where there is a need to ensure that the IED GOOSE has been isolated before being powered up so that no GOOSE messages can be sent out to cause possible tripping once the IED boots up.

5.2.2 Simulation

Simulation remains a powerful tool in IED testing. Transitional secondary voltage and current injecting testing is a kind of simulation in principle. The IEC 61850 simple measured values (SMV) simulation, though currently not mature, can be an alternative testing method to the secondary injection. On the other hand, GOOSE and IED client simulation has been used widely in testing IEC 61850 communications.

There are two scenarios where the IEC 61850 simulations can be particularly useful. One scenario is to test a subsystem of an IEC 61850 substation, where not all the IEC 61850 devices are available, either due to project schedule or ownership of project scope. A simulation tool needs to be able to simulate the unavailable devices by reading the substation configuration SCD file, establishing communication with the devices under test. The simulated devices can be IEDs, communication gateways, or a HMI.

Another scenario is that all the physical devices are present in an IEC 61850 substation, but there is a need to inject simulated IEC 61850 signals that overtake the actual signals from actual devices. IEC 61850 Edition 2 defined a simulation quality bit for this purpose. The following figure from IEC 61850-7-1 depicts how the IED processes the simulation signal.

The IED in the figure subscribes to three GOOSE messages. The IED physical device Sim.stVal is set FALSE during normal operation. When this changes to TRUE and there is a Goose 1 message with its simulation bit set to TRUE, the IED processes the simulated Goose 1 and ignores the actual message. The IED processes other normal GOOSE messages, Goose 2 and Goose 3, as usual. Note that unlike the test bit, the simulation bit exists in each of the GOOSE messages. Using this feature, the simulation tool can simulate any desired GOOSE messages with the simulation bit set to TRUE. The IEDs that subscribe to the GOOSE message will be set in simulation mode, then start to process the simulated GOOSE. The IED that publishes the actual GOOSE can be operating in normal mode, publishing the actual GOOSE message, as the subscribing IED in simulation mode will accept only the simulated GOOSE messages.

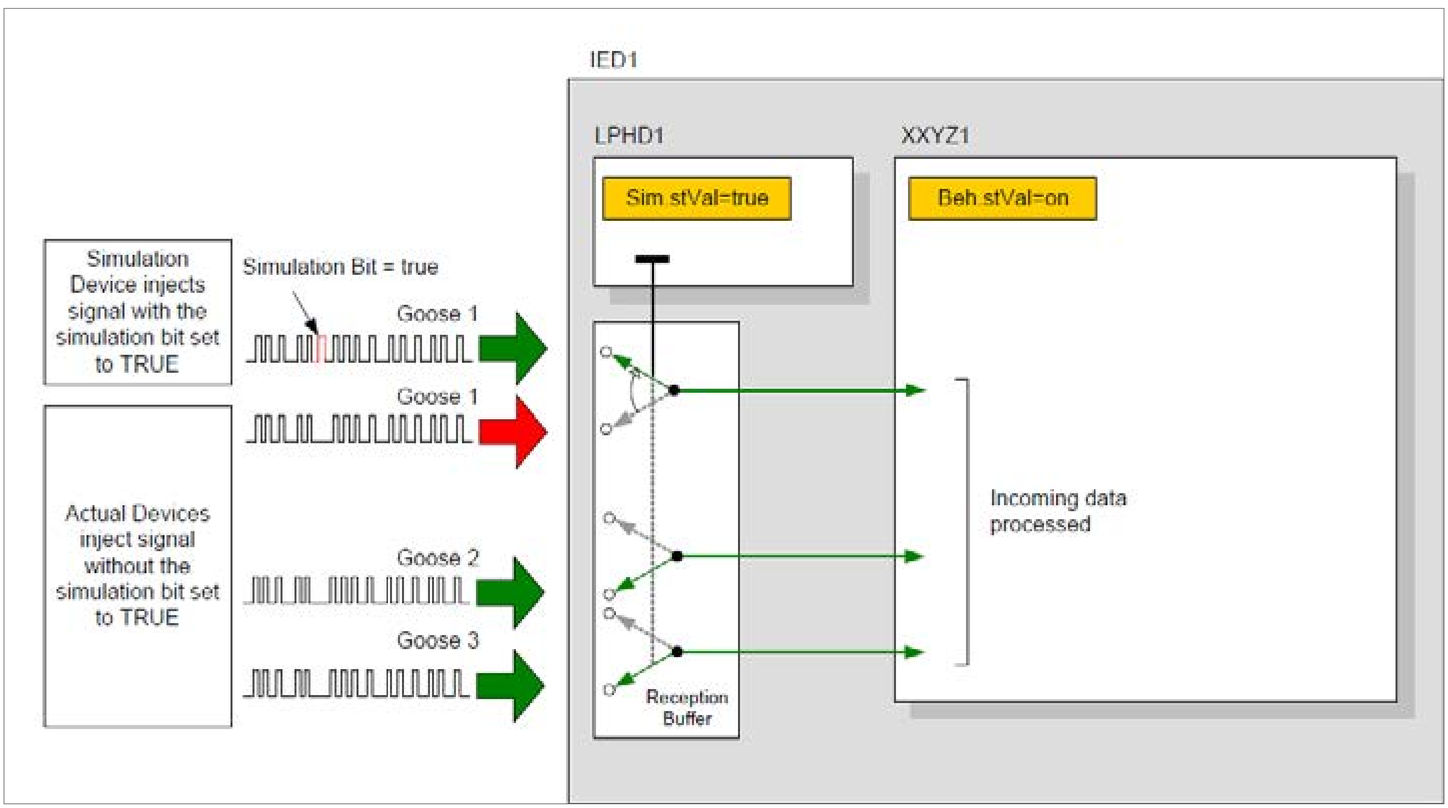


Figure 19: IED signal simulation (from IEC 61850-7-1 Sec 7.8.2)

5.2.3 GOOSE and reporting monitoring

In the early years of GOOSE adoption, network traffic analysis tools were widely used to monitor GOOSE messages. Nowadays most IEDs have built-in functions to monitor the GOOSE subscription. These functions, with varying degree of sophistication, are much easier to use than the network traffic analyzers for a field P&C technician. Nonetheless, the analyzers still remain powerful tools for a communications engineer to troubleshoot network-level issues.

IEC 61850 Edition 2 introduced a new Logical Node called LGOS for GOOSE subscription monitoring. There is one instance of LGOS per GOOSE subscription for a given GOOSE source, which reports the status of the GOOSE subscription as either active or inactive. While being useful in operational-level GOOSE monitoring, it falls short in the GOOSE testing, since it does not support monitoring the individual data item status.

An alternative approach is to implement a centralized GOOSE monitoring system. An IEC 61850 client software can create a substation-wide GOOSE messages table by extracting the GOOSE publishing/subscription, as well as the data set configuration data from the SCD file. Instead of capturing the network GOOSE messages like a network traffic analyzer, the client software reads the GOOSE data value from both the originating and subscribing IED logical node using MMS services. The advantage is that not only the GOOSE message itself is monitored, but also the logical nodes that supply and receive the GOOSE data. A conceptual centralized GOOSE monitoring function is shown in the following figures.

Subscribing IED

Publishing IED

	T1 A	T1 B	52-LV1	52-BT	BUS1 A	BUS1 B
T1 A		●	●			
T1 B			●			
52-LV1	●	●			●	●
52-BT			●		●	●
BUS1 A			●	●		
BUS1 B			●	●		

Clicking the GOOSE status button, the detailed data of the GOOSE message displays.

Publishing IED - T1 A				Subscribing IED - T1 B	
Message Items		Description	Value	Bit Label	Value
1	GGIO.ST.Ind1.stVal		True	CCIN001	False
2	GGIO.ST.Ind2.stVal		False	CCIN005	False
3	GGIO.ST.Ind3.stVal		True	-	-
4	GGIO.ST.Ind4.stVal		False	-	-
5	GGIO.ST.Ind5.stVal		True	-	-

All the GOOSE message statuses of both subscriber and publisher are displayed conveniently on one screen, eliminating the need for proprietary GOOSE monitoring tools from individual IEDs. This centralized universal tool can be used regardless the IED type.

6. Conclusion & Recommendations

IEC 61850 promises repeatable, reusable engineering design for substations. The top-down process of Figure 5 shows how the design process for a 61850-based substation comes together: the system specification and individual device capabilities are inputs into the SCT tool. The SCT tool is used to configure communications in the substation, and produces one file, the SCD file, as the complete communications configuration for the substation. This SCD file is not only the master file for this specific substation: it can be used again as the master file for any similar substation, with only minor modifications, such as updating device and equipment names, and disabling unneeded devices in the next substation. In short, IEC 61850 allows the use of a standard substation configuration.

This "top-down" approach using the concept of a System Configuration Tool is the right approach for adopting IEC 61850 in a substation. Configure all the devices and relationships between devices once, and reuse this configuration. However, the work performed in this interoperability lab shows there are currently some impediments to using top-down design in practice. Different vendors interpret and implement the Standard differently, leading to some incompatibility between devices and configuration tools. Many of these issues will be resolved over time as both vendors and end users develop a common understanding of how the Standard is implemented. But using the top-down process for configuring IEC 61850-based substations is the best method. This process can be used today, even with the limitations inherent in tools and devices, to speed up and simplify configuration over that of a traditional substation.

6.1 Use the IEC 61850 engineering process to create reusable files

What can be done today, even with the limitations of today's tools and devices, is to use the concept of configuration templates, based on the top-down IEC 61850 engineering process. This is made easier because many utilities have standardized the basic elements of their substation P&C and SAS design. The IED type and order code have been pre-selected according to the required protection functions, and the gateway/HMI have been pre-selected according to the needs of SCADA. The applications and interactions are also typically standardized, and need only be translated to an IEC 61850 implementation. After the first project, then the IEC 61850 configuration is also standardized. Therefore, other than device naming differences, the IEC 61850 configuration is almost identical across substations. In general, this permits reuse of the same engineering design and same configuration of devices for all substations.

The IEC 61850 engineering process can be greatly simplified with configuration templates. For a first pass, a set of IEC 61850 template files can be created using the SCT from the system specification file and device ICD files. Once the SCD file is created, this is used in conjunction with the individual device ICT tools to create CID files (or proprietary settings files as needed). At this point in time, since the SCD file may not be compatible with every ICT tool, some manual manipulation of the configuration file may be necessary to create valid files for the end device. Once the engineering process is complete, and all device configurations have been tested, all device files can be used as the basis for template files. The templates files can include the SCD, IID/CID files, as well as proprietary IED setting files. All the necessary communication links, such as client/server and GOOSE have been defined in the template files, where the IED name and other key communication IDs are place holders. When applying the templates to an IEC 61850 substation project, the place holders can be replaced with the actual names following a naming rule to ensure the uniqueness required by the Standard. The name replacing can be easily done with a text editor if the IED setting template is an IID or CID file. If the setting template is in IED proprietary format, then the IED Configuration Tool needs to be able to replace the names. Finally, each IED will export the project-specific IID files, which will be used to generate the substation SCD file. The SCD file can be used for documentation and to verify the IEC 61850 system engineering. Errors in the IED template name replacing process, such as stranded or duplicated IED names, can be detected in the SCD file.

6.2 Edition 1 and Edition 2

A special subset of the engineering process is that of working with devices and tools that only support the requirements of the original ("Edition 1") version of the Standard, only support the revised ("Edition 2") version of the Standard, or may support either version. It is recommended to use only devices supporting the same version in one project. However, this is not always practical, as substations may have existing devices that support only Edition 1. New devices may only support Edition 2, or only support Edition 1 in certain firmware versions. It is possible for devices that support only Edition 1 to interoperate successfully with devices supporting only Edition 2, but this will take more manual manipulation of configuration files. Note that while an SCT tool can produce an SCD file that works with both Edition 1 and Edition 2 devices, this SCD file is not standard, and may be rejected by device configuration tools. In a mixed project, then the recommendation is to work with an Edition 1 configuration file to start the process.

6.3 Understanding of the Standard

The results from the interoperability lab show that IEC 61850 capable devices and configuration tools from different vendors are not completely interoperable and compatible. Using the IEC 61850 engineering process can still greatly speed up substation configuration over conventional substations. However, understanding the capabilities of the devices and tools used is necessary to perform this work. Protective relays, especially, are often chosen on requirements other than how the device implements IEC 61850. For a successful project, it is necessary to understand how all devices implement various requirements of the Standard. To deal with the interoperability in multiple vendor environments with the IED Configuration Tool and System Configuration Tool, it is highly recommended to consider how the IED Configuration Tool and System Configuration Tool support the following items:

- Structured DataSet in GOOSE and Reporting
- Supported data formats
- Preconfigured Report /GOOSE Control Blocks versus dynamically configured Control Blocks
- Supported semantics, such as Unit (for example, V or kV for voltage)
- Report configuration

6.4 Private section

Every vendor has specific definitions for their protective setting and logic setting within a SCL file. Usually the information is stored in a private section in the SCL file, some in binary format, some in XML, and others in ASCII without tags. The System Configuration Tool needs to recognize this information and never make any change to the private section. Adding a private section to the IED section of SCL through a System Configuration Tool can inadvertently affect the importing of SCL back to the IED Configuration Tool.

6.5 Device interface to the System Configuration Tool

The major challenge to a System Configuration Tool is that this tool must interoperate with multiple devices from multiple different vendors. Each different device, and each vendor, will have a different interpretation of how best to implement the Standard. The SCT must know all of these devices, in the sense that the SCT tool can understand the SCL files coming from specific vendors, and translate the SCD configuration file into the format a specific vendor can understand. This requires a form of translation between the SCL files from devices and the SCL file created by the System Configuration Tool. To make this possible, the SCT vendors must define the requirements for a "vendor package", or a description of how this translation between files must work. This allows IED vendors to quickly develop a vendor package for any device, or new version of a device, without requiring significant effort on the part of the SCT vendor or the IED vendor.

6.6 What GE is doing

GE is actively working to address device configuration and interoperability for IEC 61850 devices, as well as continuing proactive participation on IEC standards committees, working with customers and other vendors to identify and define the benefits needed with regard to configuration tools. GE is also taking concrete steps in all products to improve configuration. One of these steps is implementing Edition 2 support across all product families, including support for IID/ICD/CID/SCD files in individual configuration tools. Another step is that GE IED configuration tools are designed to simply and easily support the "bottoms up" approach, ensuring there is always an effective way to perform system configuration, even when including third party devices. We're also actively developing "vendor packages" to allow simple integration of GE devices into third party SCT tools. As a final step, our ICT tools store all proprietary device configuration in the IID and CID files in a private section using XML.

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