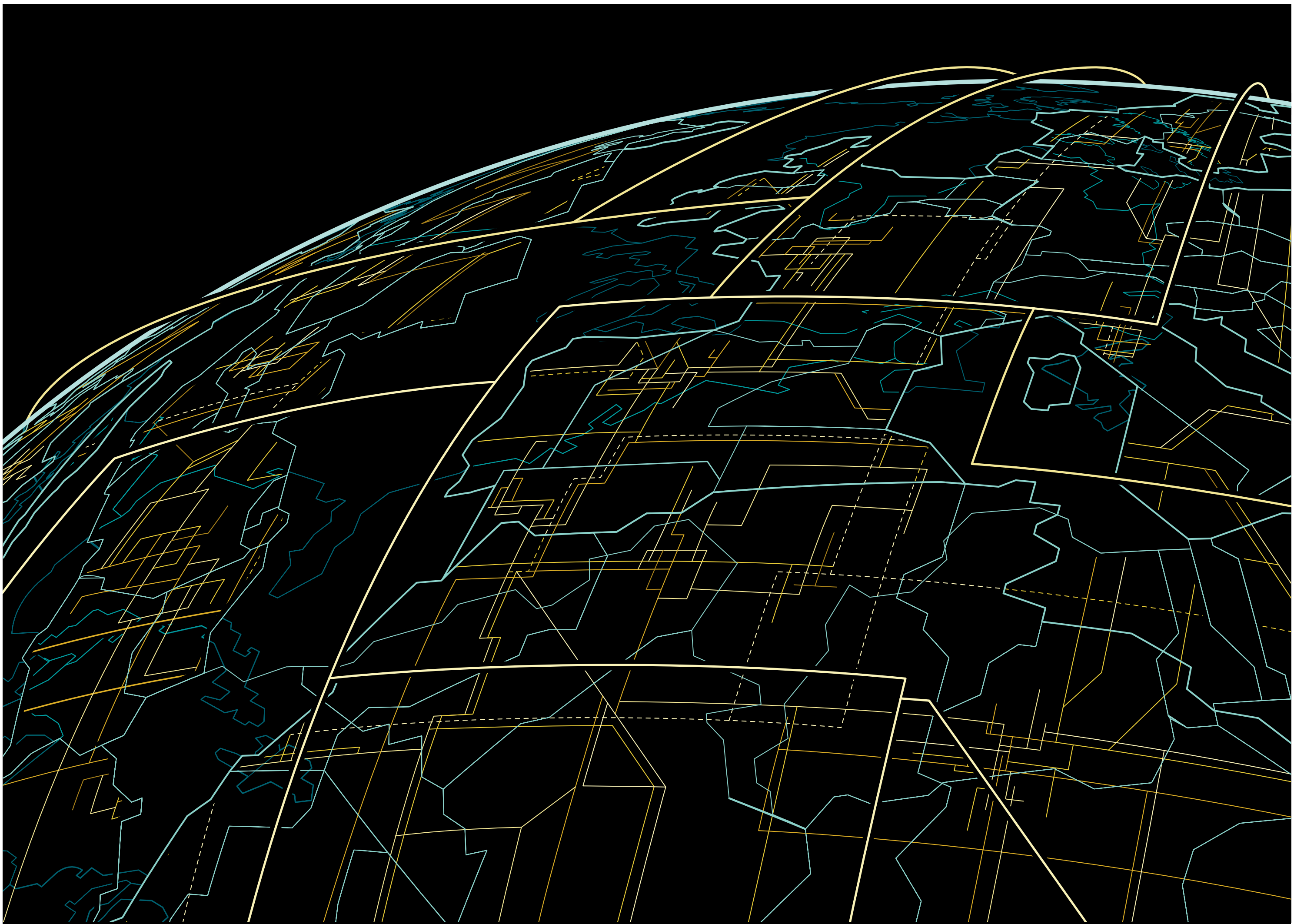


Medium voltage products

Technical Application Papers No. 19
Smart grids
3. Standard IEC 61850

ABB

Index

1. Introduction

In the technical area, communication can be much more than an exchange of data based on one of the various protocols available in the market. It can actually involve syntax and semantics to the extent that information becomes universally understandable.

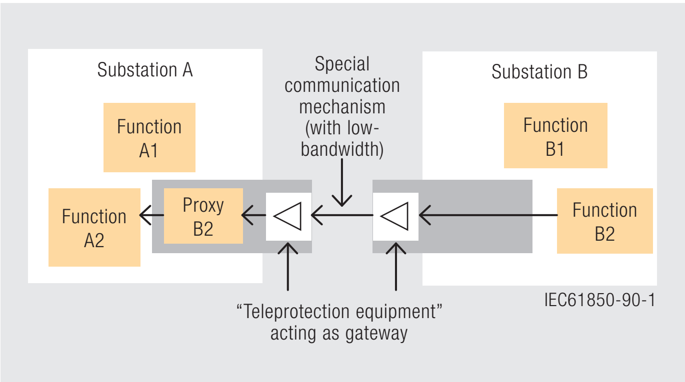
This was the goal pursued by IEC (International Electrotechnical Commission) when it addressed the issue that led to publication, in 2004, of a new standard for the purpose of:
– providing a single protocol for a complete substation;
– developing a common format able to describe the substation and facilitate object-oriented modelling of the data required in the substation itself;
– defining the basic services required so that data can be transferred using different communication protocols;
– allowing interoperability between products from different manufacturers.

ANSI (American National Standards Institute) supported the new standard right from the start in an effort that required more than 60 experts and almost ten years of work.
IEC 61850 provides a standardized structure for integrating substation components, functional characteristics, the structure of the data in the devices, data designation conventions, establishing how the applications must interact and monitor the devices and lastly, conformance testing.
IEC 61850 was very quickly accepted and only two years after having been issued was already being requested by the major part of the market as communication standard
The reasons for its success stem from the fact that designing, installing, configuring and servicing a traditional communication infrastructure is a costly business while the benefits introduced by IEC 61850 reduce these costs to a considerable extent while safeguarding, thanks to standardization, the investment.

2. IEC 61850: concept and structure

In the past, all distribution automation systems were based on proprietary solutions and protocols or on use of communication standards from other application fields, such as DNP3 or IEC 60870-5-104.
The problem with these solutions was that they made interoperability between different suppliers or even between different versions of switchgear produced by the same manufacturer, particularly arduous. It took more than twenty years before the need for a standard for communication in substations able to resolve the interoperability issues was formalized. A further aim was to create a standard able to support the continuous and rapid technological developments in this field. This explains the evolution sustained by IEC 61850, which passed from edition 1 to edition 2 with the addition of certain characteristics such as:

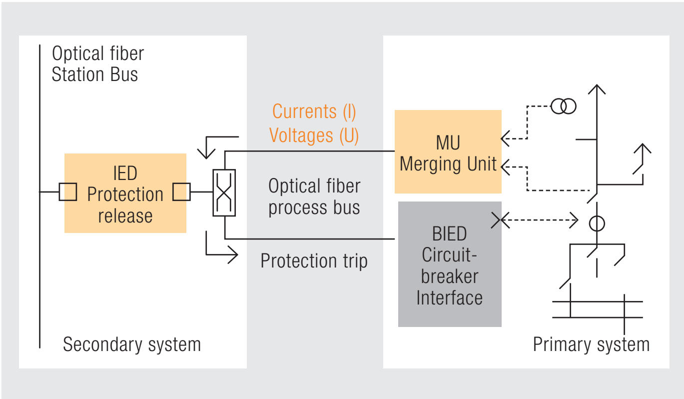
- clarification of certain parts like buffered reporting, the mode switch (in test mode) and hierarchical control of accesses (local/remote);
- communication between substations (part 90-1) and between substations and control centres (part 90-2). As can be seen in the diagram below, the standard also deals with use of proxy gateways in low-bandwidth connections;



Communication principles based on Standard IEC 61850, between substations

- the synchronization required for communicating voltage and current samples with speeds in the field of microseconds. An application recommendation was drawn up for that purpose, i.e. part 9-2. The recommendation introduced the merging unit (MU), which will be discussed in section 2.7 and whose task is to provide the samples with the synchronization required. Besides the measuring samples, the Ethernet-based connection also transmits the position of the switching devices, the commands and protection trips. This led to the definition of a true process bus between primary and secondary switchgear and controlgear.

The advantage is less wiring, galvanic separation thanks to use of optical fiber and a standard serial interface regardless of the type of measuring instrument used.



Process bus with "merging" unit (MU), circuit-breaker interface (BIED) and external Ethernet switch

- Support for the redundant interfaces of the IED.
- Data model extension for new application functions, such as supervision of non-electric quantities (new LN, mainly for hydroelectric power plants).
- Statistical assessment of the measurements in logical nodes MMXU and MMXN: mainly required for Power Quality and other applications, such as wind-powered generators.
- Support for tracking and recording services and relative responses: this function is useful for putting into service and security, since it shows the parameters and management of the services required without the need for protocol analyzers.
- Management of logical device hierarchy: useful in the case of complex IED protection systems requiring several functional levels in order to manage common parameters correctly.
- New objects and concepts for testing functional parts in operating systems: useful, since it allows standard applications to be used for the tests while supporting test texts in parallel to real texts.
- Extension of SCL so as to describe new IED properties and support the engineering and retrofitting phase in a better way.
- SCL Implementation Conformance Statements (SICS): defines the mandatory and optional characteristics of the tools for the IEDs and system. This allows the degree of tool interoperability to be assessed.
- The 7-5xx information parts with examples illustrating how to model the application functions of the system.

2. IEC 61850: concept and structure

The structure of Edition 2 of IEC 61850 is outlined below:

Parts of Standard IEC 61850 Edition 2: Communication networks and systems for power utility automation

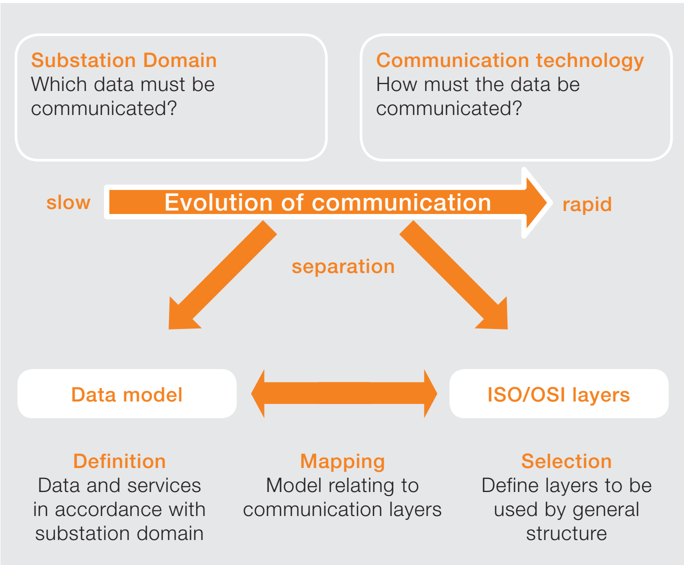
Part 1:	Introduction and overview
Part 2:	Glossary
Part 3:	General requirements
Part 4:	System and project management
Part 5:	Communication requirements for functions and device models
Part 6:	Configuration description language for communication in electrical substations related to IEDs
Part 7-1:	Basic communication structure – Principles and models
Part 7-2:	Basic communication structure – Abstract communication service interface (ACSI)
Part 7-3:	Basic communication structure – Common data classes
Part 7-4:	Basic communication structure – Compatible logical node classes and data classes
Part 7-410:	Hydroelectric power plants – Communication for monitoring and control
Part 7-420:	Basic communication structure – Distributed energy resources logical nodes
Part 7-5:	IEC 61850 – Modelling concepts
Part 7-500:	Use of logical nodes to model functions of a substation automation system
Part 7-510:	Use of logical nodes to model functions of a hydro power plant
Part 7-520:	Use of logical nodes to model functions of distributed energy resources
Part 8-1:	Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3
Part 80-1:	Guideline to exchange information from a CDC based data model using IEC 60870-5-101/104
Part 9-2:	Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3
Part 90-1:	Use of IEC 61850 for the communication between substations
Part 90-2:	Using IEC 61850 for the communication between substations and control centres
Part 90-3:	Using IEC 61850 for condition monitoring
Part 90-4:	Network Engineering Guidelines - Technical report
Part 90-5:	Using IEC 61850 to transmit synchrophasor information according to IEEE C37.118
Part 10:	Conformance testing

Note: IEC TC 88 published IEC 61400-25 Wind turbines - Part 25: Communications for monitoring and control of wind power plants.

How to handle the conversion and automatic mapping between data model IEC 61850 and the Common Information Model (CIM) described in IEC 61970 is still being defined. The breakthrough introduced by the Standard is the innovative and expandable language based on XML known as SCL (Substation Configuration Language) used to describe the substation. SCL allows the configuration of the IED to be formally described in functional terms (e.g. control of the circuit-breaker measurements and statuses), communication address and service terms (e.g. reporting procedures). The language can also describe the position of the apparatus and compare it with the functions implemented in the IED.

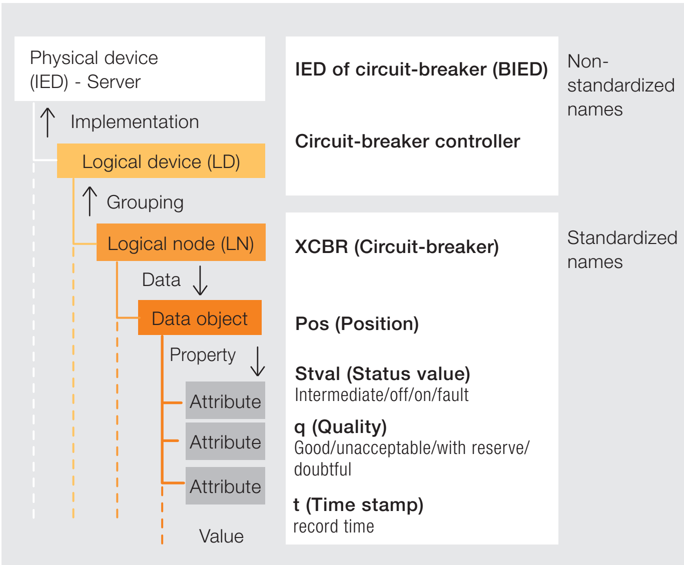
2.1 The basic approach of IEC 61850

To ensure long-term interoperability, considering that the substation functions have different development time-frames and the need to keep pace with the changes in communication technology, the approach followed by IEC 61850 is to separate the data and communication service models from the protocols, i.e. the seven ISO/OSI layers used for encoding and decoding information in strings of bits used to transmit that information to a communication medium. This approach is not only capable of meeting communication technology's state-of-the-art but also of safeguarding investments made in engineering and developing the applications. Either way, the data models have been standardized by IEC 61850 at various communication layers so as to assure interoperability.



2.2 The object-oriented data model

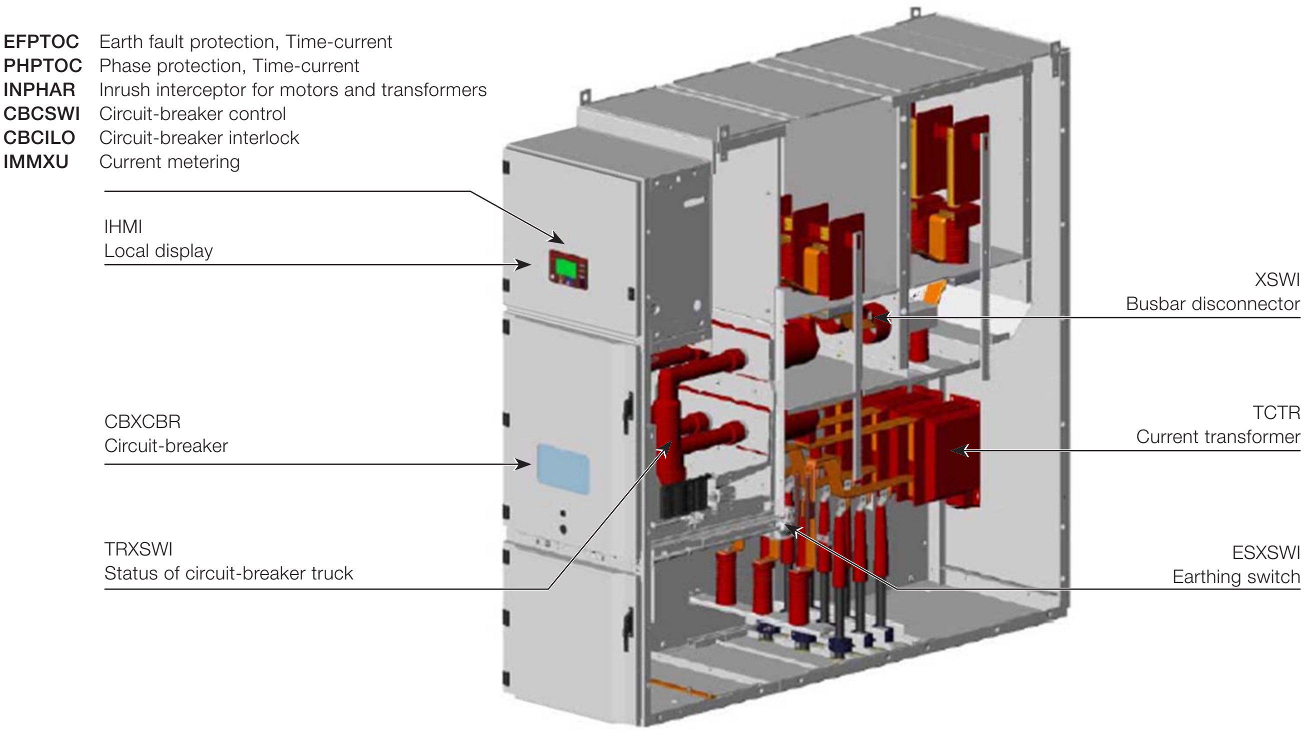
The basic structure of the data model is application-agnostic. However, the model classes are substantially related to one substation. Wind farm, hydroelectric power plant and distributed energy source object-oriented models were added later.
All the application functions, which include data interfaces towards primary apparatuses, are divided into the smallest possible parts that can communicate with each other and, more importantly, can be inplemented separately in the various IED. Standard IEC 61850 calls these basic objects Logical Nodes (or LN). The name of a class to which an LN belongs refers to the function to which the data object belongs. The data objects in an LN can be mandatory, optional or conditional. In addition, the data objects contain attributes which can be considered as detailed properties or values of the data object. This hierarchical model is illustrated in the figure below.



The IEC 61850 object-oriented data model of a physical device

2. IEC 61850: concept and structure

Since the names of the LN classes and the full names of the data objects and attributes have been standardized they provide, in a formal way, the semantics of all the transmitted objects in Standard IEC 61850.
In turn, the LN can be grouped into Logical Devices (LD) with non-standardized names that can be implemented in servers residing in the IED.
The common properties of the physical devices are connected with an LN class called LPHD.
A generic class with limited semantic meaning can be used if an LN class for a certain function is missing.
The extension of LN and data strictly in accordance with the extension rules provided by the Standard (which include the size of the name and unique references to the semantic meaning) is certainly a more challenging activity, since interoperability is guaranteed and maintained by these rules.
A hierarchical system for the designation of objects and functions will have to be used for the functional identification of each data item within the scope of a substation, preferably in accordance with IEC 81346: Industrial systems, installations and equipment and industrial products - Structuring principles and reference designations.
An example of a data model for a medium voltage switchgear unit is illustrated in the figure below.

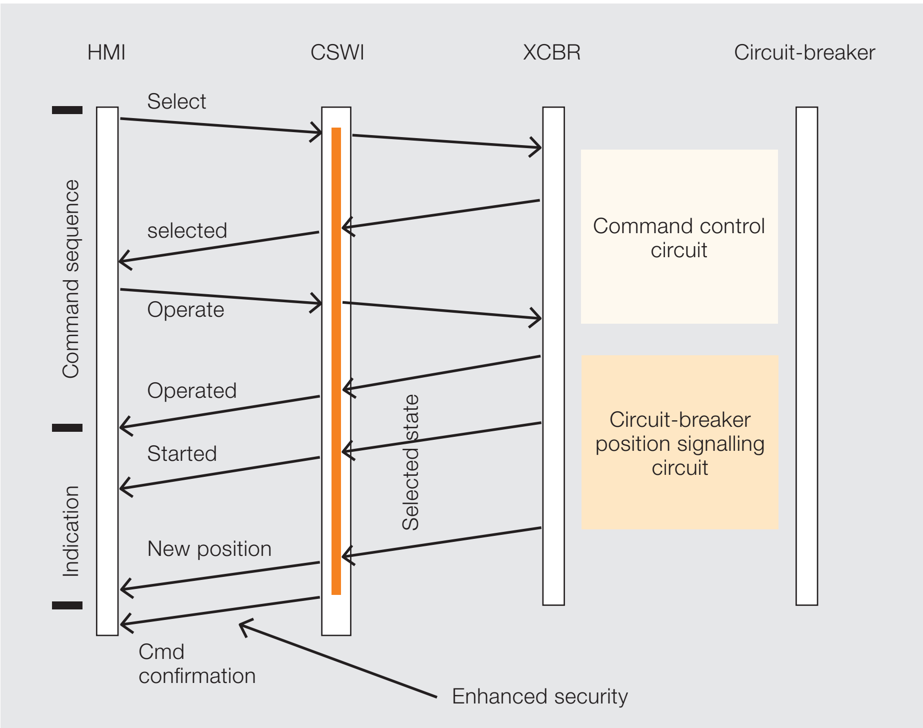


The data model for a medium voltage switchgear unit

2.3 The services envisaged for the data model

To ensure interoperability, not only must the data objects be standardized but also the mode by which they are accessed. IEC 61850 also deals with this issue.
The most common services are:
- Read: reading data such as the value of an attribute
- Write: writing a value, such as a configuration attribute
- Control: controlling operating mechanisms and other controllable objects using standard methods like “select-before-operate” or “direct operate”
- Reporting: for example, “event driven” signalling after a value has been changed
- Logging: local storage of events along with the relative time or other log data
- Get directory: i.e. display the data model
- File transfer: for configuring, recording interferences or log data
- GOOSE: this is the acronym for Generic Object Oriented System Event and is the service used for rapid transmissions of information that is critical in terms of time, such as changes of status, interlocks, opening commands between IED
- Sampled value (SV): the SV service rapidly transmits a flow of current or voltage samples

The following diagram illustrates the service known as Control, which implements the “select-before-operate with enhanced security” mode. The SELECT command is imparted by the operator to his work station (HMI) and is communicated to the bay controller (LN CSWI).



Control service with select-before-operate mode

The SELECT command is confirmed both by the bay control unit and by the IED of the circuit-breaker (LN XCBR), depending on the architecture of the System. The operator can issue an OPERATE command when he obtains a positive receipt (Selected) from CSWI. The operation request is transmitted to the circuit-breaker (XCBR) via the bay controller. Once the command has been executed, a positive receipt (“Operated”) is sent to the operator. Additional confirmation is provided by the reporting service, which is activated by the movement of the circuit-breaker (“Started”), and when the new position (“New position”) has been reached. If the service with “enhanced security” is used, the final result is confirmed by a command concluded message (“Cmd confirmation”), which definitively concludes the service.

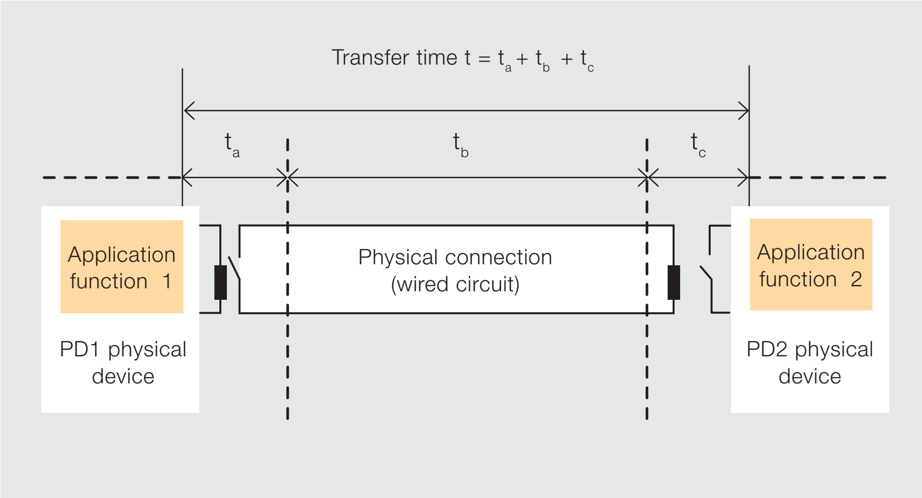
2. IEC 61850: concept and structure

2.4 Performance requirements

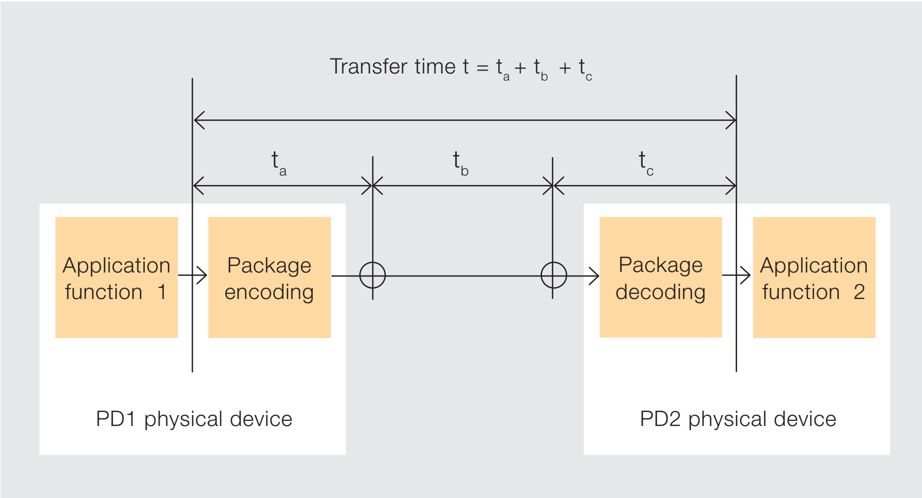
The time required to transfer messages between the transmitting application (e.g.: protection function that sends a release command) and the receiving application (circuit-breaker function that implements the operation) is determined by the requirements of the function that depends on this message being transferred.
Since circuit-breaker release is critical, it can be associated with the class possessing the most stringent transfer time requirements, i.e. 3 ms. Transfer of samples using the SV service is also assigned to this class so as to avoid delays in detecting fault conditions by the protections. In the diagram alongside, the transfer time of a GOOSE message on a serial line is compared to the transfer time in a wired circuit.

Speaking of GOOSE, it is important to underscore the security criteria adopted for these messages:
– the communication connection between IED is continuously monitored via cyclic data transmission;
– an event relating to modification of a data item is sent immediately and several times to ensure that it has been received;
– both the application and the user are informed in the case of timeout.

To analyze the sequence of events in the appropriate way and analyze a fault in retrospect, the events must have a time with 1 ms accuracy, which is better than any change of status a contact may undergo. This accuracy can be obtained by using the Simple Network Time Protocol (SNTP) on a serial communication line. Higher accuracy levels in the region of 1 μs can be achieved with one pulse per second (pps) using separate optical fiber or wire.



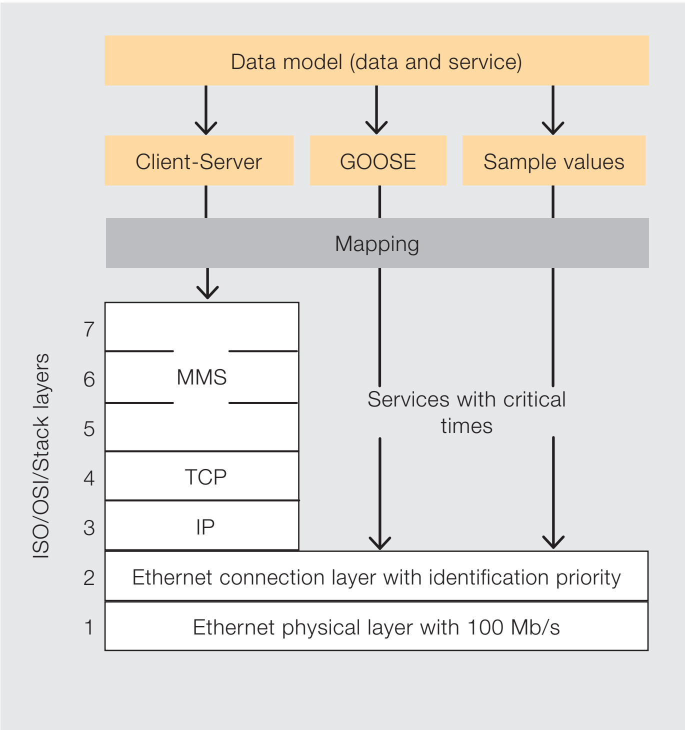
Definition of transfer time with wired circuit (input/output relay)



Definition of transfer time with communication packages

2.5 Mapping and communication stacks

IEC 61850 selects the basic technologies for communication stacks: a stack structure in accordance with ISO/OSI layers, which include Ethernet (layers 1 and 2), TCP/IP (layers 3 and 4) and the Manufacturing Messaging Specification or MMS (layers 5 to 7). The object-oriented model and relative services are mapped at MMS application layer (layer 7). Only critical services over time, such as SV and GOOSE, are mapped directly at Ethernet layer (layer 2).



Mapping in ISO/OSI layers in IEC 61850

2.6 Ethernet and the station and processes buses

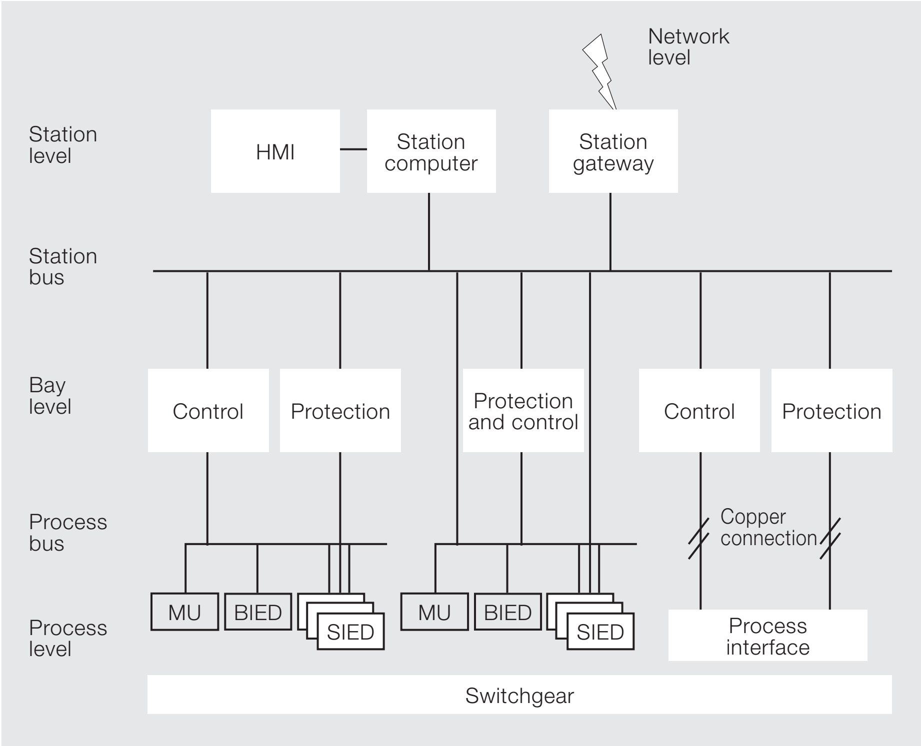
Ethernet, currently at a speed of 100 Mb/s, is the basic technology adopted by IEC 61850. The Standard envisages two buses based on Ethernet switch technology. The station bus connects the protection, control and monitoring IED of the bay units to the devices at station level, i.e. the central computers with relative HMI and the gateways towards the communication center (NCC, Network Communication Center) using all the services required by the applications.

The information in transit typically concerns control, such as measurements, interlocks and select-before-operate.
The MMS protocol is used for transferring data between the station level and the bay IED, while GOOSE is the service used for transferring data from bay to bay.
The process bus connects the bay units to operating devices in the field using services such as SV for transmitting measurement samples for protection purposes. Other information concerning the communication status, commands and operating apparatus trips is identical to that of the station bus.

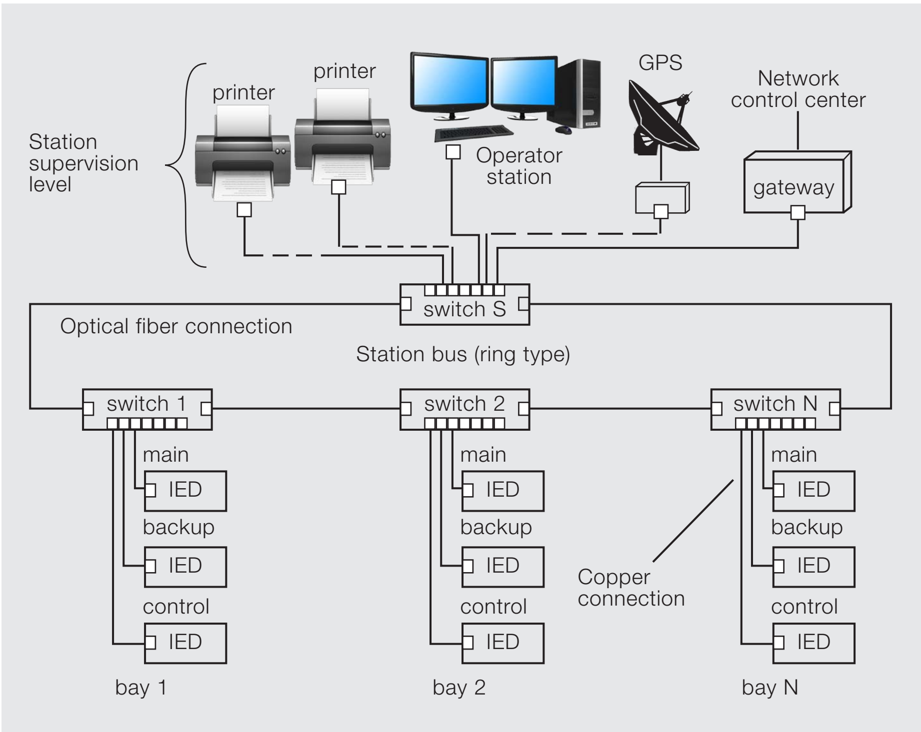
2. IEC 61850: concept and structure

Obtaining the synchronization of current and voltage samples and sending them to the protections using the SV service is a very challenging task.
Units called MU (merging unit) are used to convert the analog signals from conventional and non-conventional current- and voltage-measuring instrument transformers into IEC 61850 SV data frames. The format of a SV data frame containing voltages and currents for the three phases and the zero component has thus been defined. Two sampling speeds have been defined (80 and 256 samples per cycle) as well as a synchronization signal of one pulse per second (1 pps) with class T4 synchronizing accuracy (± 4 μs). At switchgear level, the process bus and relative functionalities consist of the IED of the circuit-breakers (BIED) and disconnectors (SIED), and the relative connections. Since the functions can be freely allocated, IED with BIED, SIED and MU functions can be created at the same time.
The Standard does not prescribe a specific topology since the physical Ethernet network supports clearly defined topologies.
For the station bus, the switch ring, with or without redundancy, is the most widely used topology for connecting the protection, backup and control IED.

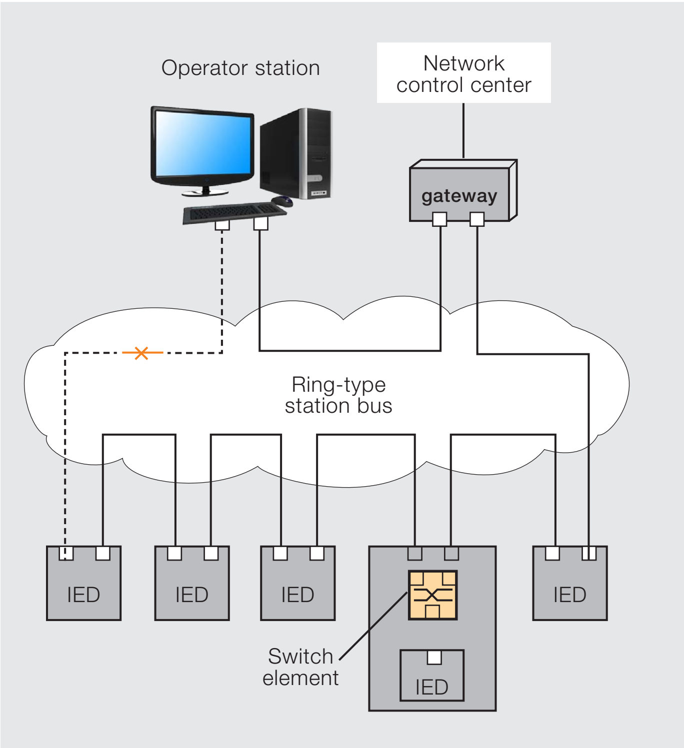
In small substations, the IED can be connected straight to the ring since they include a switch element able to support faults in a single connection.



Example of station and processes buses



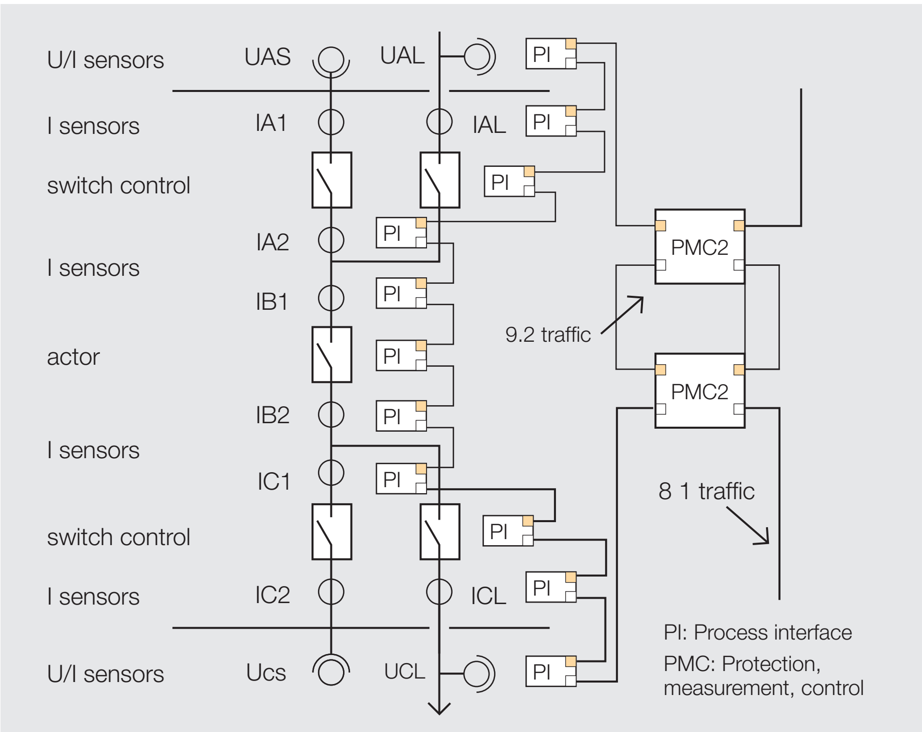
Example of non-redundant station bus



Ring with switches and nodes

Large substations can have several rings, one for each voltage level, connected to each other in a tree network, thus with mixed topology.
The process bus can also be configured with ring or star topology.

The downtime tolerated by the substation's automation system is called “grace period”. This means that the time the communication network takes to resume service after a fault must be less than the grace period. A 100 ms delay can be tolerated when the station bus transmits information about commands, for instance. Only 4 ms delay is tolerated when interlock or trip signals are transmitted. 4 ms is also the maximum delay tolerated in the case of the process bus that transmits critical data from the MU to the protections. The maximum recovery times suggested by IEC technical committee 57 are given in the figure below.



Process bus topology

Recovery time suggested by IEC TC57 WG10

Communication partner	Communication bus	Recovery time
From Scada to IED client - server	station bus	100 ms
Interlocks/locks between IED	station bus	4 ms
Busbar protection	station bus	0 ms
Sample values	process bus	0 ms

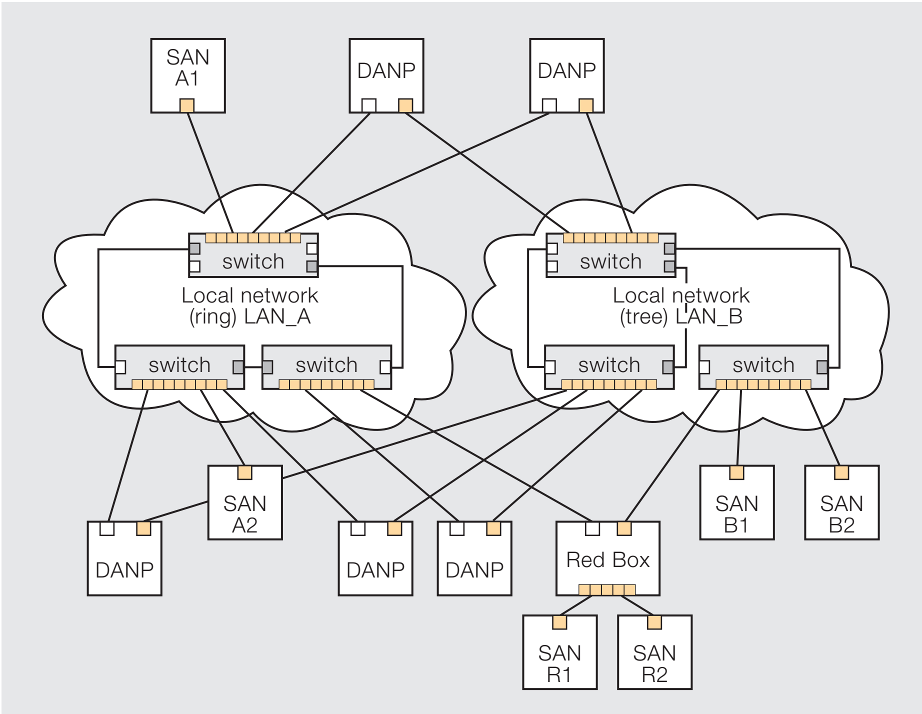
The values above affect the level of redundancy the system must provide.

2. IEC 61850: concept and structure

2.7 Redundancy

Standard IEC 62439, Industrial communication networks - High availability automation networks is applied to resolve the problem of redundancy. It is applicable to all industrial Ethernet networks since it proposes methods that are independent of the protocols used. The Standard einvisages two fundamental methods: network redundancy and node redundancy.

- Network redundancy requires redundant switches and connections. However, the individual nodes are connected to the switches by non-redundant connections. The level of availability is not very high since only part of the system is redundant. Redundancy is not normally active, thus activation involves a certain delay. An example of this solution is the method proposed by the RSTP protocol (IEEE 802.1D) which, however, guarantees less-than-a-second times solely in very restricted topologies. However, it can be an economical solution for substations where redundancy has not been planned.
- In node redundancy, the nodes must use two ports to connect to two different redundant networks. This method is applicable to any sort of network topology. It is a costly solution but extremely advantageous as to availability. In this case, the only non-redundant parts are the nodes themselves.

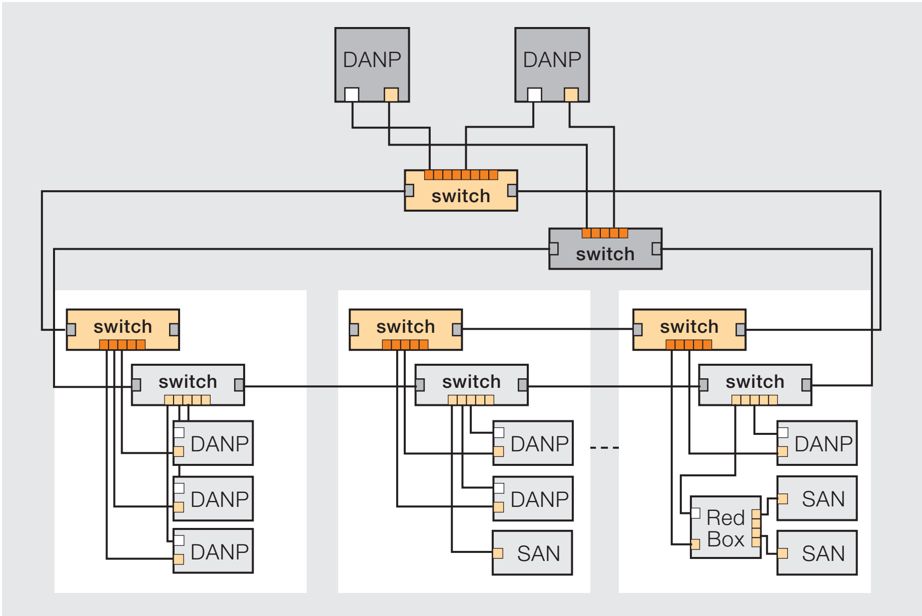


Node redundancy

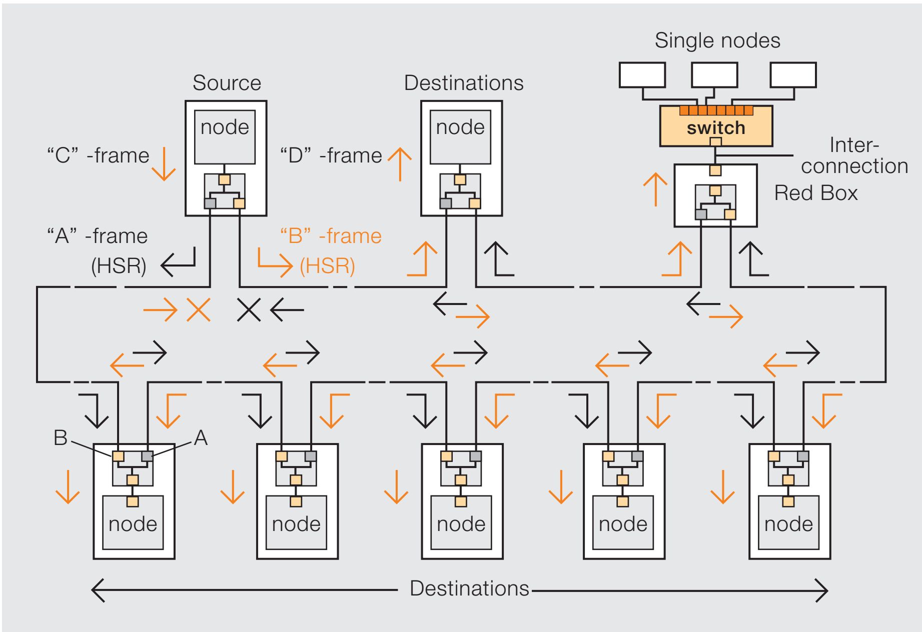
The second edition of Standard IEC 61850 includes two redundancy protocols that are defined in IEC 62439-3, Industrial communication networks - High availability automation networks - Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR).
These protocols are applicable to substations of any size and topology. In both cases, each node has two identical Ethernet ports for connection to the network. The protocols handle the duplication of all the information transmitted and provide zero-time transmission if the connection or switches are faulty.
The PRP protocol, which is defined in paragraph 4 of the Standard, specifies that each PRP node called DANP must be connected in parallel to two independent LAN with similar topology operating in parallel.

The recovery time is therefore nil, while the redundancy status is monitored so that it continues to be efficient. Non-PRP nodes (if any), which are called SAN, are connected to a single network and can therefore only communicate with other DANP and SAN nodes connected to the same network, or can be connected to a so-called redundancy box which acts like a DANP.

The PRP protocol does not cover faults in single nodes, but does accept the connection of duplicated nodes.
The HRS protocol applies the principles of PRP to a single ring topology. It considers the two directions as two independent virtual LAN, thereby creating a more economical solution. Switches are not used in this case since each device functionally or physically contains a switch.



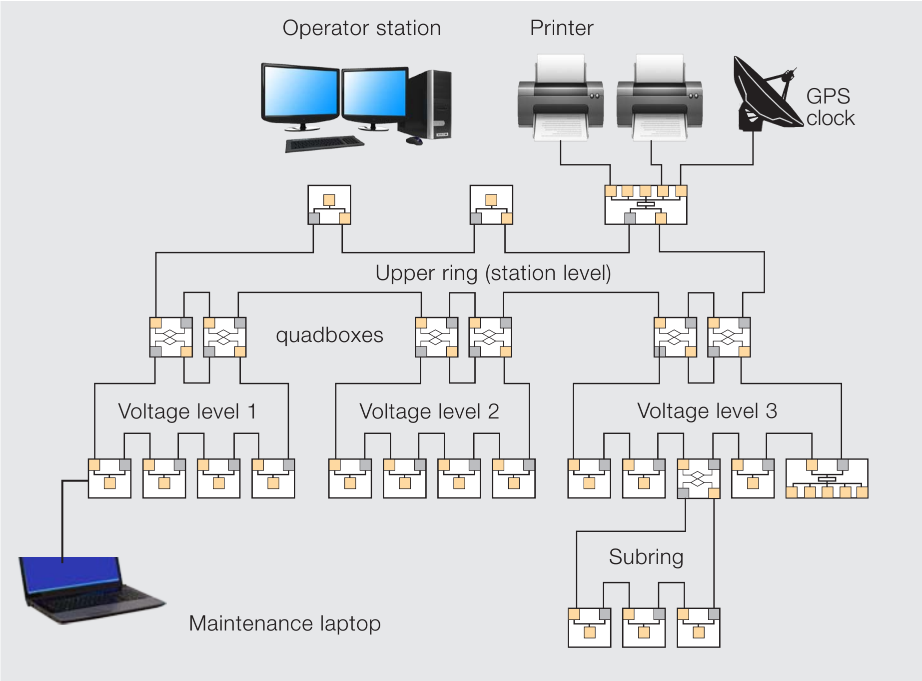
Station with duplicated buses and PRP protocol



High-availability ring with HSR protocol

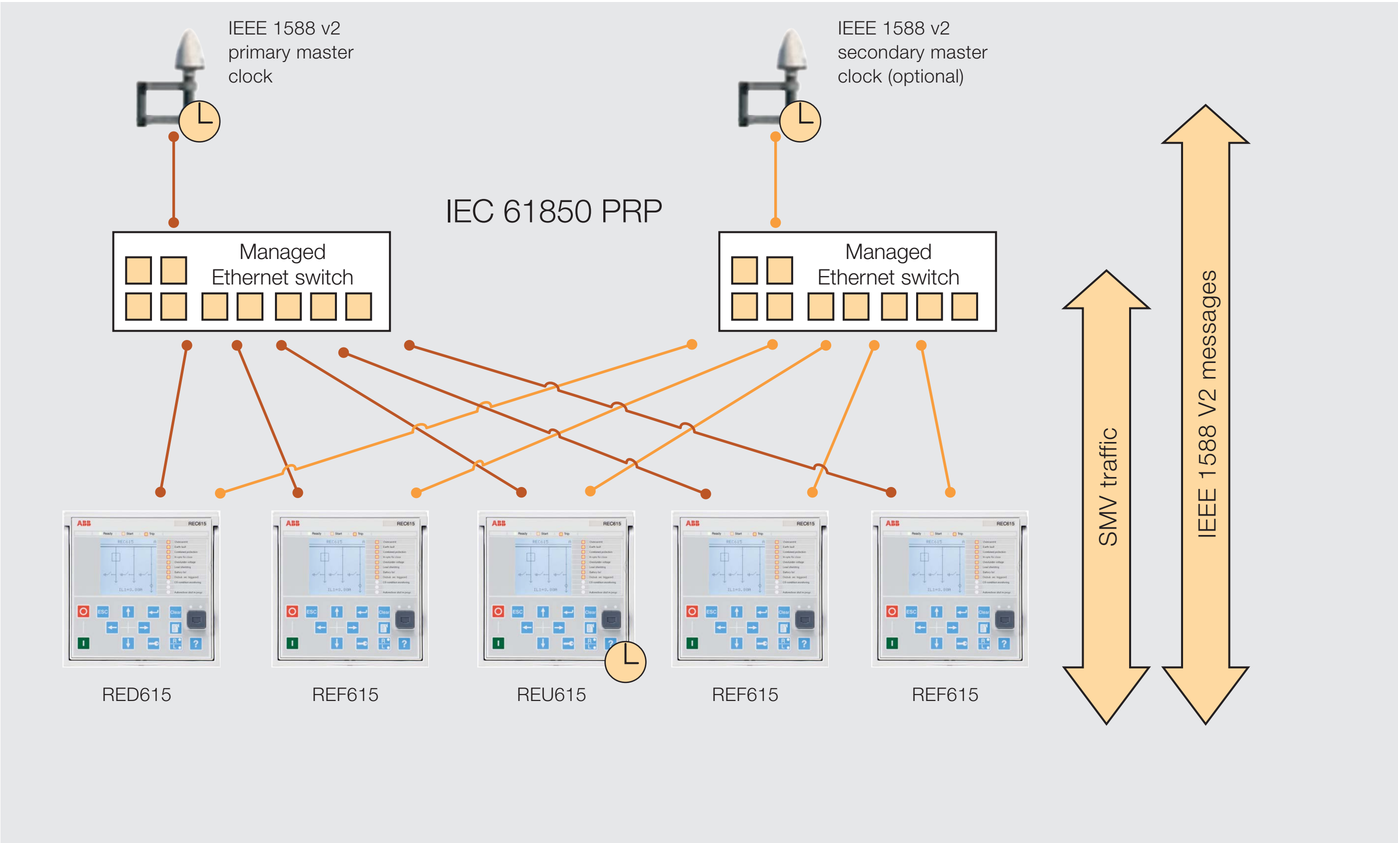
2. IEC 61850: concept and structure

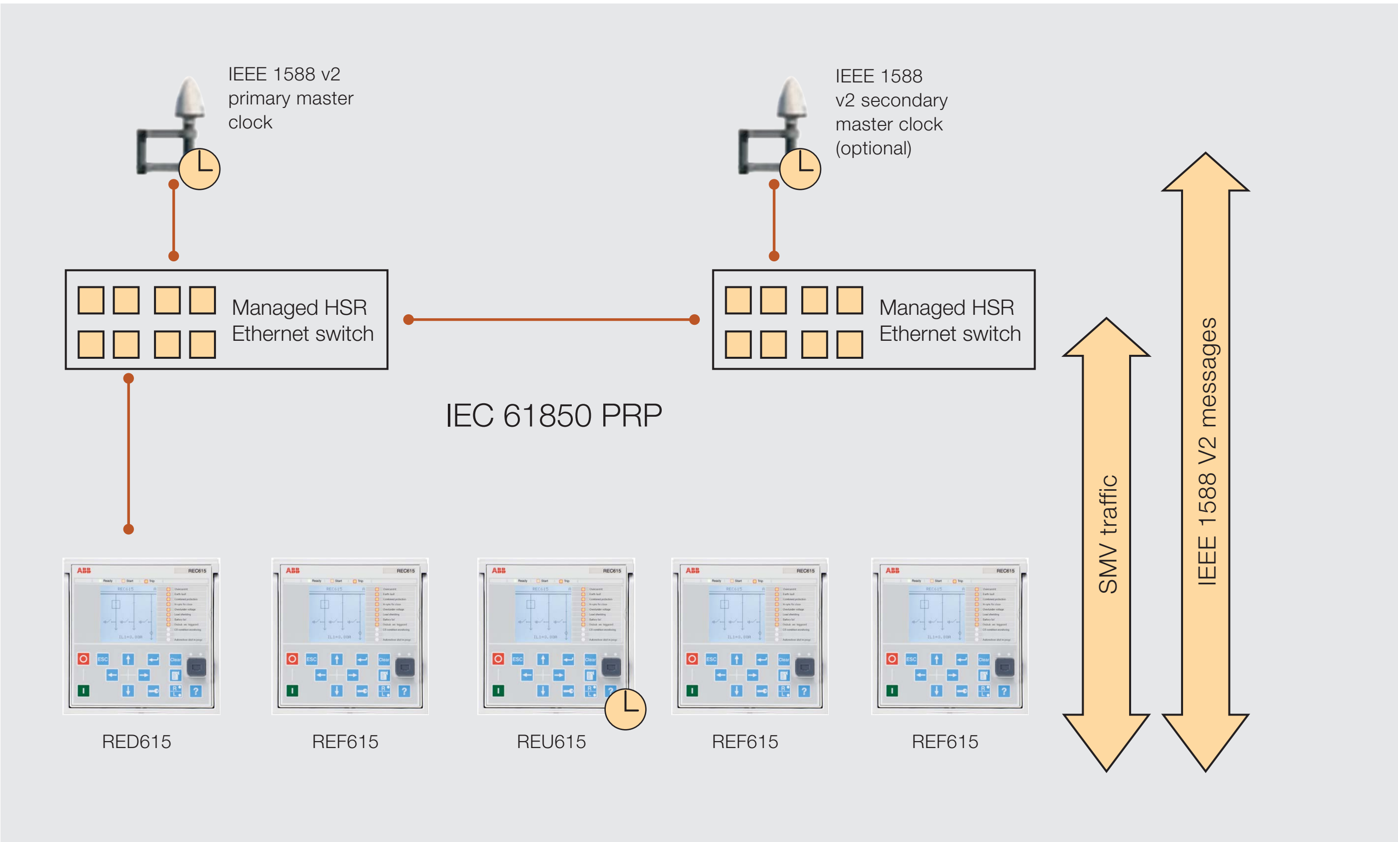
Whenever a data frame must be sent, the node actually transmits two, one for each port, which circulate in opposite directions. Each node re-transmits the data frames received from one port to the other. When the node that originated the data frame receives it again, it rejects it to prevent it from re-circulating. To identify duplicates, the source adds a sequence number to the frame header. This number is incremented by the source for each data frame sent. This allows the data frame to be rejected immediately prior to being read. The traffic is more or less double that of the single ring, but the average propagation time is less, thus the ring can support a similar number of devices.
Single nodes, e.g. printers and computers, can be connected to the network by means of the so-called redundancy boxes, which are considered as elements of the ring.
A pair of redundancy boxes can also be used to connected another isolated ring to a PRP redundant network. In this case, each redundancy box sends data frames in one direction only. This allows a series of networks structured in a hierarchical mode or of equal level to be created.



Series of HRS rings

Two concrete examples of redundant systems with ABB apparatus are illustrated on the next page. Full redundancy in the entire system can be achieved at station level with two computers (MicroSCADA1 and MicroSCADA2) and hot redundancy operation. At IED level, PRP and HRS redundancy is achieved with IED from the REx 615 family equipped with redundant double port.

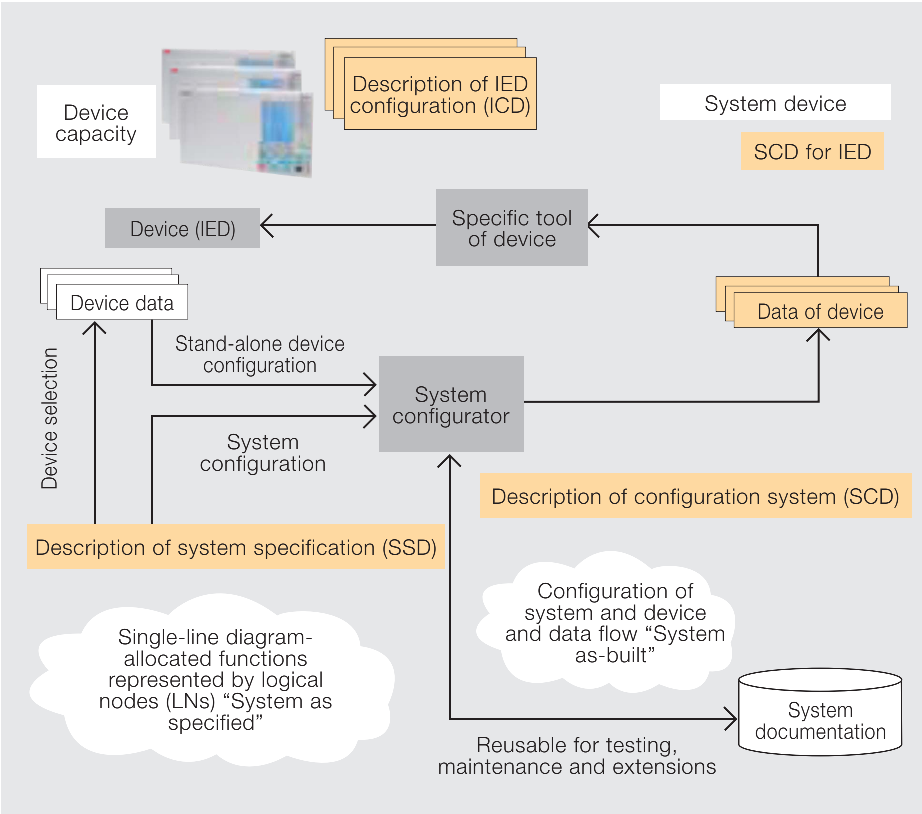

IEEE 1588 v2
primary master
clock
IEEE 1588 v2
secondary master
clock (optional)
IEC 61850 PRP
Managed
Ethernet switch
Managed
Ethernet switch
SMV traffic
IEEE 1588 V2 messages
RED615
REF615
REU615
REF615
REF615


IEEE 1588 v2
primary master
clock
IEEE 1588
v2 secondary
master clock
(optional)
Managed HSR
Ethernet switch
Managed HSR
Ethernet switch
IEC 61850 PRP
SMV traffic
IEEE 1588 V2 messages
RED615
REF615
REU615
REF615
REF615

2. IEC 61850: concept and structure

2.8 Engineering supported by SCL language

To process data from other IED, the receiving IED must know how these data have been sent, how they have been encoded, what they mean to the specific installation and the functions of the transmitting unit. This means that it is important to have a language allowing a standardized exchange of data from devices produced by different manufacturers that consequently use different configuration tools. To achieve this, IEC 61850 introduced an engineering process that uses SCL language based on XML (eXtensible Markup Language).
The installation specifications and description of the IED are first used for the purpose of selecting the types of devices. After this, their formal description, in the form of a file with file extension .ICD (IED Configuration Description), is loaded into the configuration tool of the system.
This tool defines the meaning of the functions of the IED within the installation and allocates the LN to the elements in the single-line diagram of the installation itself. The data that flow between all the IED are then defined and lastly, all the names of the IED and the relative communication parameters and addresses are configured.
The result is an SCD (System Configuration Description) file containing the full description of the entire system to IEC 61850 specifications. The file can then be imported by the configuration tools of the single IED devices so as to complete their individual configuration.
The engineering principle with SCL file is illustrated in the next diagram.



Example of engineering with SCL

Since the data model of the IED is visible via the communication system, including the possible configurations and setting parameter values, and since all this can be described in SCL, the SCD file is a medium that can be used by other applications throughout the entire life cycle of the system, such as archiving the configuration of the system in a standardized form and transferring the parameters of the protections to the configuration tool of the protection system.
It can also be used in test and simulation tools or for checking the real system configuration version with respect to the required configuration.

2.9 IEC 61850, a lasting concept

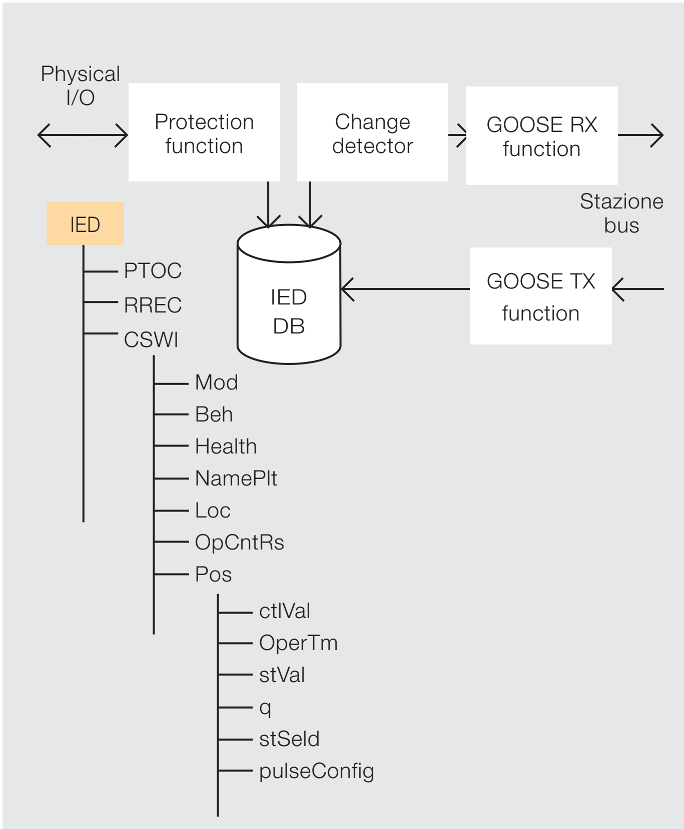
The long-term value of IEC 61850 for users lies in its object-oriented and hierarchical data model structure with high-level standardization of semantics and use of Ethernet, i.e. a widely established and prevalent communication technology. Thus IEC 61850 is more than a simple communication protocol. Its potential is such that in future, it could probably cover the entire spectrum of applications in power systems.

3. ABB products based on IEC 61850

3.1 Native development of IEC 61850 in ABB protection and monitoring devices

In an IED design where IEC 61850 is implemented in the native mode, the life-cycle of the device must be considered from its actual specifications, throughout the development of both device and system, their putting into service and finally their operation and maintenance.
In short, an IED based on IEC 61850 must:
- be able to provide the system and other IED and tools (even when produced by other manufacturers) with a complete set of protection and control data in accordance with the data model and in order to ensure the correct level of interoperability;
- provide rapid communication and a good performance level of the applications so that the GOOSE services can be used in the best possible way in critical situations, such as the creation of interlocks between bays and distributed protection algorithms;
- conform to data modelling and use SCL for engineering the system, configuring the devices, diagnostics and putting into service;
- be able to suppoprt further developments, e.g. for the transmission of current and voltage samples and synchronization accuracy.

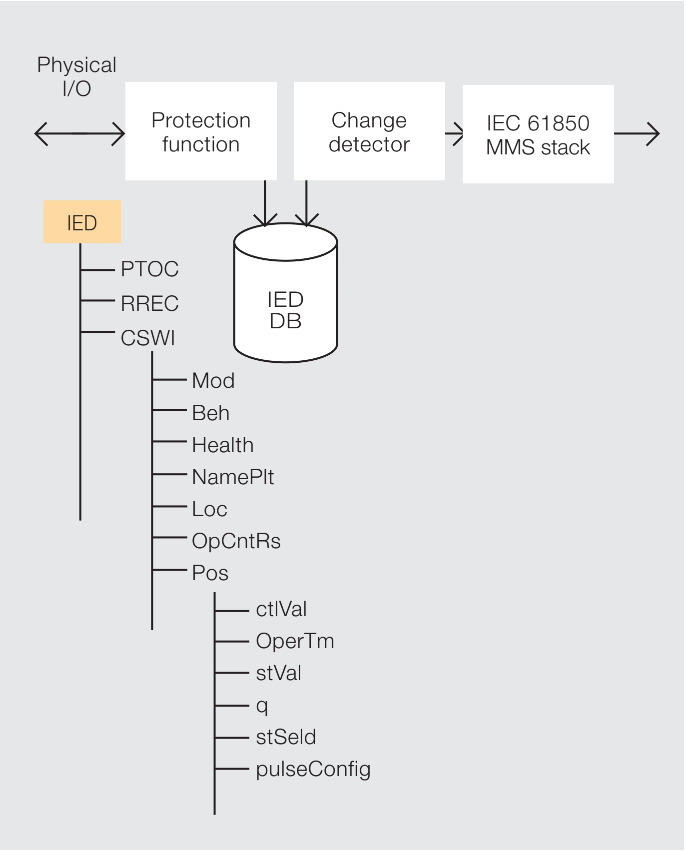
Development of ABB's Relion protection and control family has been based on these principles. Firstly, their functionality is based on the data model and LN defined by the Standard. The protection and control algorithms are modelled and development in full accordance with the rules established in IEC 61850. The data models in this architecture are directly implemented in the protection and control functions, thus the LN can be directly accessed by the communication services. This means that there is no need to either remap the data or convert their mapping: an essential feature if high performance is to be achieved. In short, the design of ABB IED focuses on reducing delays due to the interface to the minimum when received and transmitted analog and digital signals are processed, signals that in the past reached the IED via wiring.
During execution of the algorithm of an LN such as the time overcurrent protection function (PTOC), the value of a data item may change, e.g. an overcurrent may be detected.
At the end of the cycle, a process of the IED checks whether there have been changes in the sets of data relating to IEC 61850. Certain activities or services in the IEC 61850 data model are based on and activated by changes in the data sets, e.g. GOOSE and the events report. Thus, in an IED that uses GOOSE, the high-priority internal process that executes it is activated and the changed data item is sent as rapidly as possible to the station bus via the communication interface, using a GOOSE multicast message. Goose multicast messages are spontaneous and do not require cycle polling mechanisms. In addition, the data structure used in GOOSE allows direct access to the internal database of the IED and, since the data model conforms to standard IEC 61850, data conversion is not required.
This mechanism is illustrated in the figure below:



Management of GOOSE messages and data

3. ABB products based on IEC 61850

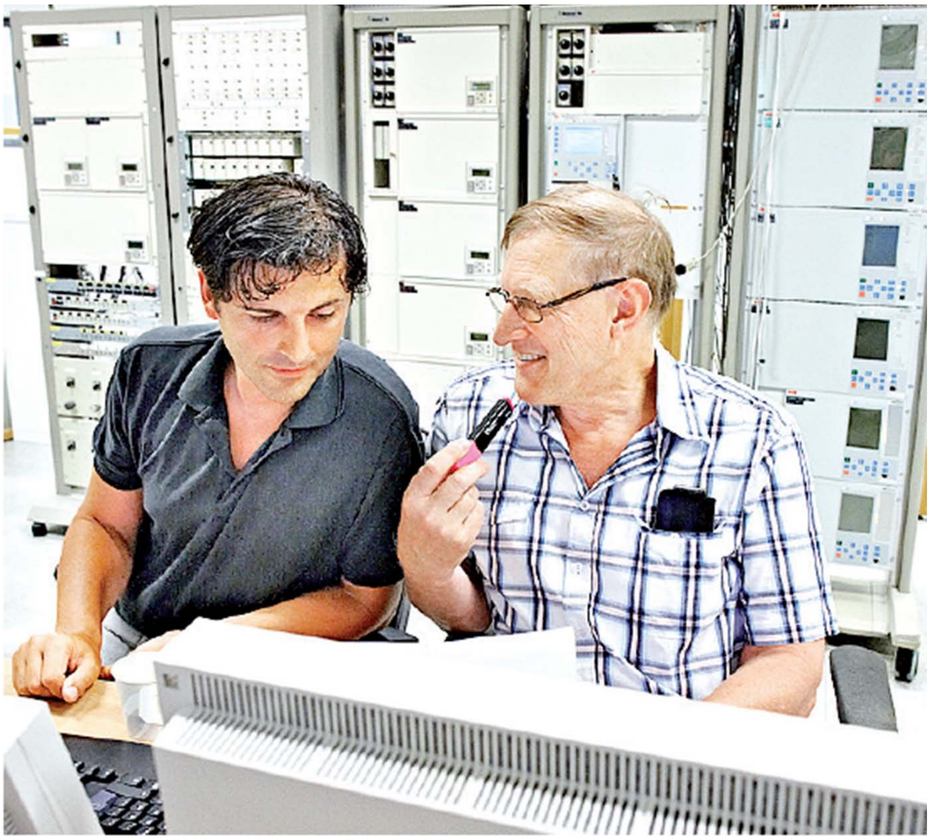
Similarly, and again thanks to native development of IEC 61850 in ABB devices, IED that receive GOOSE messages from other IED in the same LAN are extremely efficient and fast. This is because GOOSE messages are processed directly in the data link layer of Ethernet without additional processing via TCP and IP layers. This type of Ethernet communication is very fast, since the data are recovered directly by the hardware interface, allowing GOOSE to decode the message in less than 1 ms and enter solely the modified data item in the DB of the IED. This allows it to be immediately accessed by the protection and control algorithm for successive processing.
Reports of events to a SCADA system that uses the buffered/non-buffered reporting service is based on the mechanism previously described for GOOSE. When changes to a data item are activated by an application, e.g. the activation signal of a protection in PTOC, the new data item, the relative time and quality attribute are stored in an internal event queue by the change detector of the IED. Meanwhile, the communication interface of the IED is activated and begins to transmit the events to clients, such as a gateway or a computer. Here again, there is no need for any sort of data conversion because the internal data model and the structure of the data in the communication are based on standard IEC 61850.

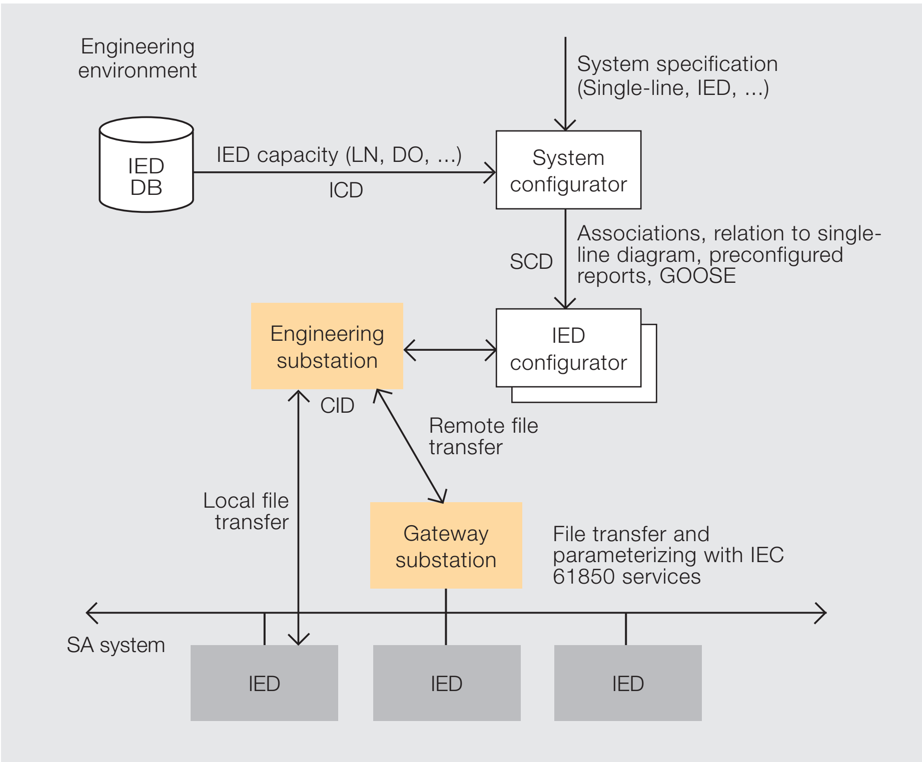


IEC 61850 events management

3.2 Installation and testing of ABB automation systems in substations

All the IED belonging to ABB's Relion family are configured in accordance with the rules defined in IEC 61850. The configuration is based on the library of ICD (Installable Client Driver) files available in the connectivity package of the IED. These files contain the data models of the IED. During the top-down engineering process, the system integrator selects the library of ICD files that represent the types of IED and creates the system configuration description (SCD) in accordance with the substation design. In this phase, the substation configuration already includes all the IED, the single-line diagram, the GOOSE connections between the devices and definition of the events. The SCD file is imported by the tools of the IED, thus the IED are parameterized and configured in accordance with the specifications of the grid and application.





System engineering flow

3. ABB products based on IEC 61850

In smaller substations, but still based on IEC 61850, engineering can be achieved using a bottom-up process. The process starts from the tools of the IED which, beginning from the IED themselves, create the SCD file (which includes the single-line diagram and data set for the events report) and export it to the system configuration tools. In many cases, this already meets the customer's specifications. The systems engineer can add the GOOSE connection (if required), define the details of the single-line diagram and the events to the system configuration tool. After this, the systems engineer re-exports the SCD file complete with the IED tools for their definitive configuration.

Whichever the case, the final result of the top-down and bottom-up processes is the SCD file, which is required for configuring the SCADA of the substation and gateways and which also provides useful information for creating the single-line diagram of the substation.

Taking advantage of active participation in the IEC 61850 standardization working group and having acquired in-depth knowledge of the design and supply of substation automation systems, ABB developed an ITT (Integrated Testing Toolkit) for use in the construction of numerous installations. ABB's approach has always been to supply a toolkit that would conceal the complexity of IEC 61850 technology while solely displaying the data required by the application. SCL language has led to the creation of files used for exchanging configuration data among the engineering tools. There are different types of files, the contents of which depend on the purpose of the tool in question. One of these files is the SCD, which is the main document of the substation automation system. The typical contents of the SCD file are as follows:

- description of the complete topology of the substation and of the primary devices;
- description of all the protection and control devices and of the automation system at station level, including the data models and their functionality;
- list of all the communication addresses;
- complete horizontal and vertical data flow in the system;
- relationship between functionality of the automation system and the primary apparatus.

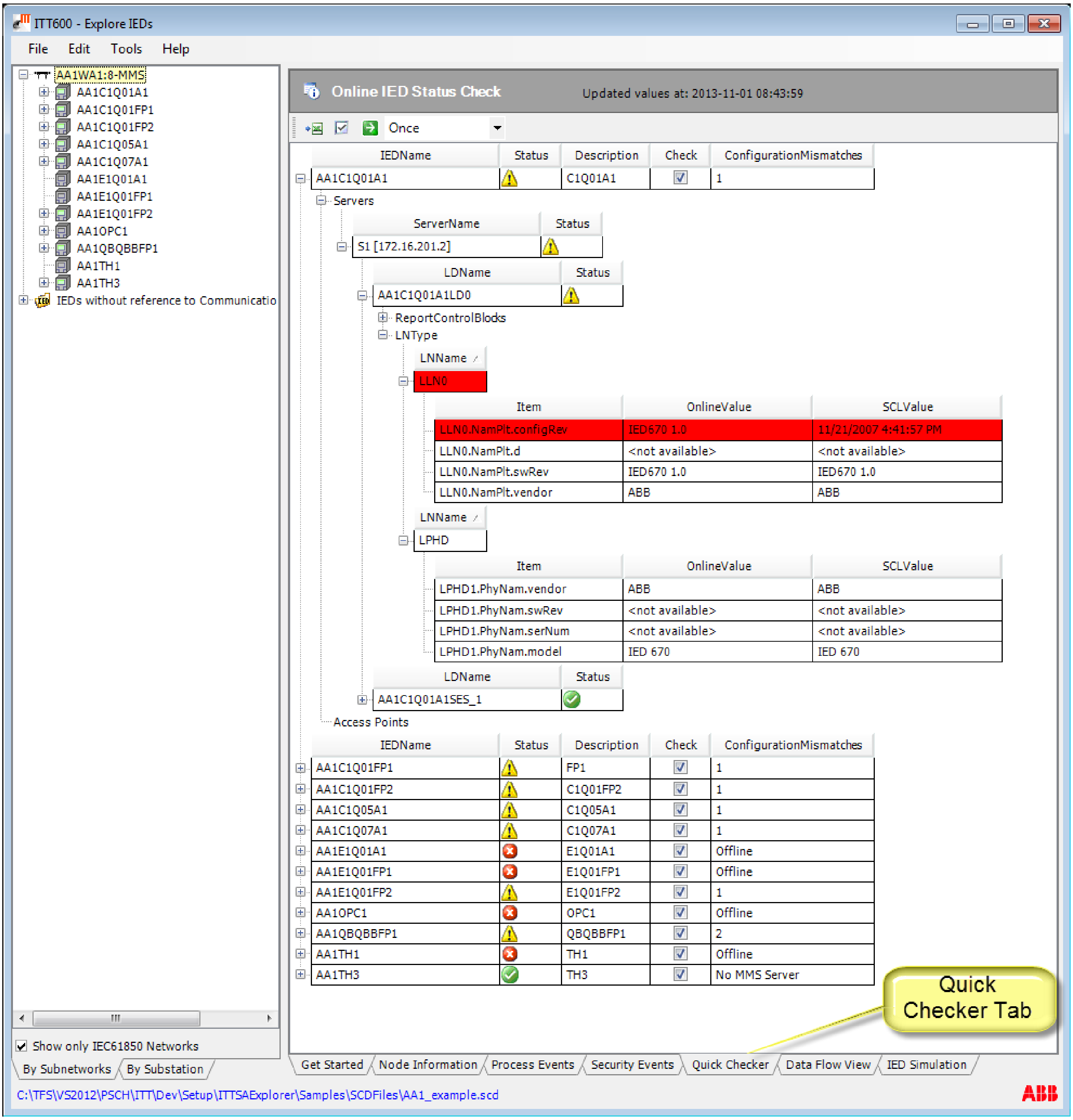
Thus the SCD file contains the interfaces between each device (client or server) and the system, so its use for successive activities like tests, maintenance and its possible extension are of interest. The systems engineer need no longer worry about committing errors in compiling the test configuration in the manual mode, since he simply needs to import the specific SCD file for that particular project into the test tool. The technician can then concentrate on analyzing the operation of the application.

Another situation that can be extremely onerous is when time inconsistencies, due to various causes, that prevent distributed functions from interoperating are detected when an IEC 61850-based system is tested and put into service. Finding errors can take a long time and require help from experts, something that is not always acceptable.

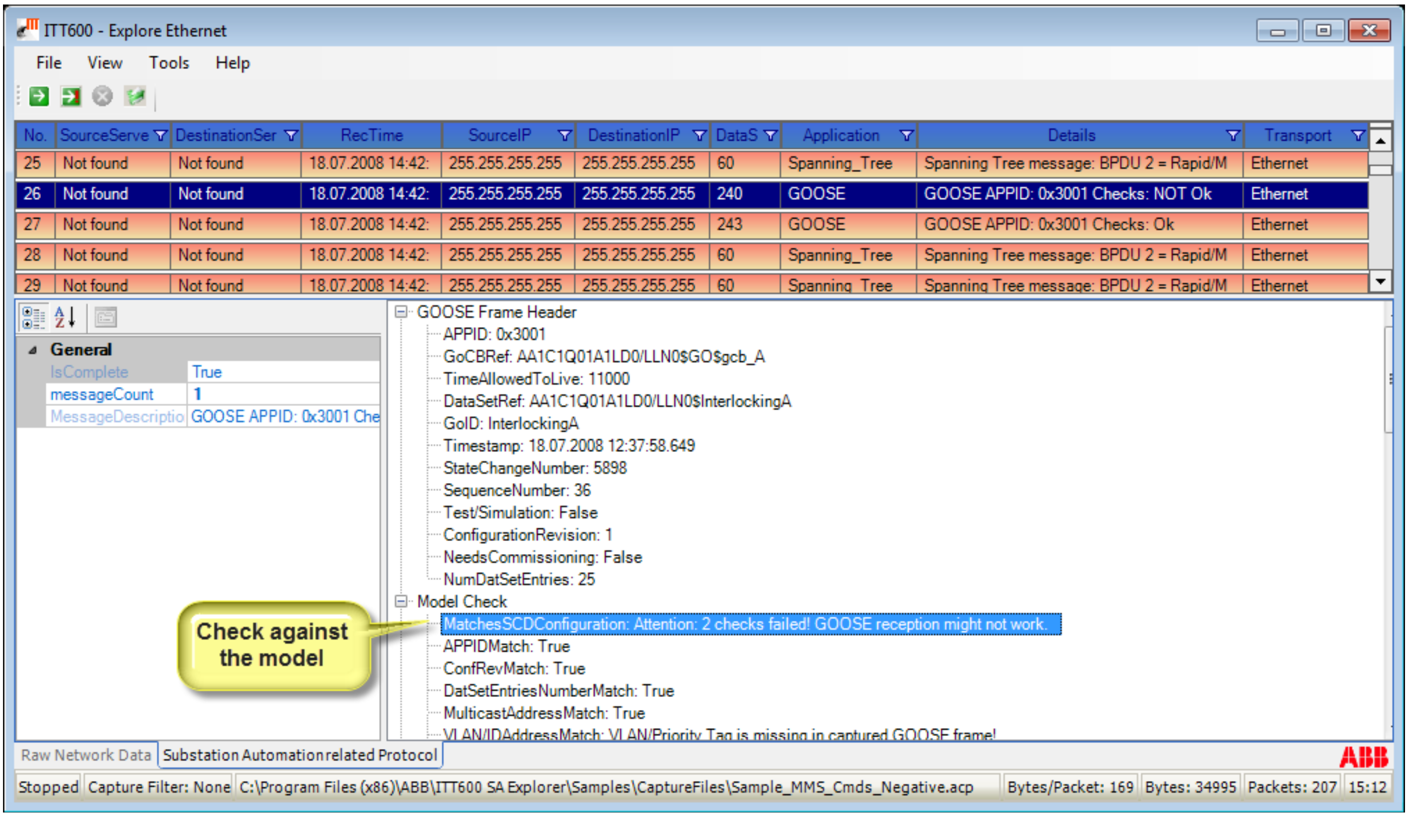
To overcome this problem, ABB has developed a tool called ITT600 SA Explorer, which simplifies problem diagnosis and remedying by combining a powerful online diagnostics tool with an intrinsic interpreter of IEC 61850 data. The typical characteristics of the diagnostics and analysis tool are listed below:

- use of the specific SCD file of the project;
- establishment of online communication with the IED using both the set of static and dynamic configuration data and the control blocks for the reports;
- display of the status of the system when operating;
- verification of data consistency and configuration review with reference to the SCD file;
- analysis and verification of operating applications;
- decoding of Ethernet traffic by converting it into the language of the automation system based on the SCD file;
- display of the addresses of recorded data pertaining to the system or products.

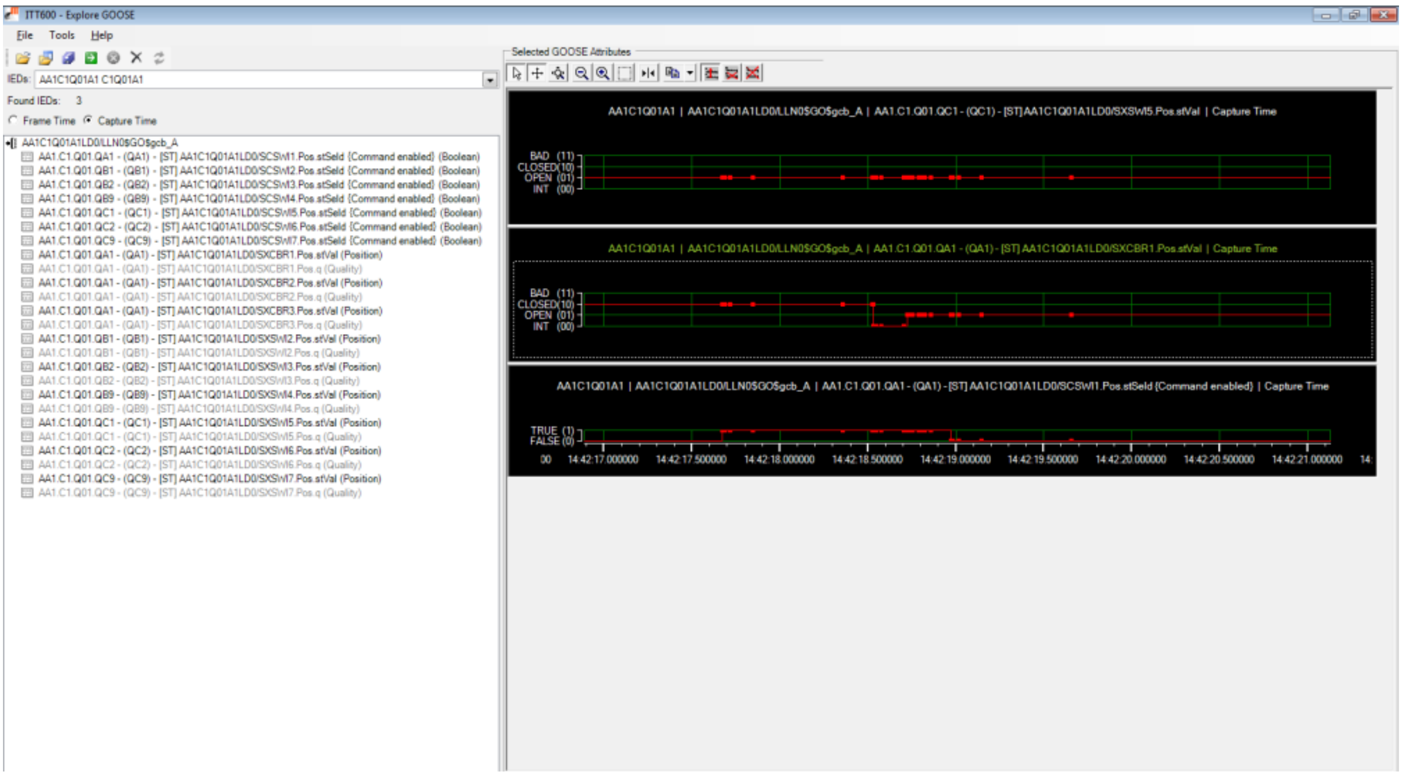
For example, comparison between the correct offline configuration and online communication can immediately detect possible inconsistencies.



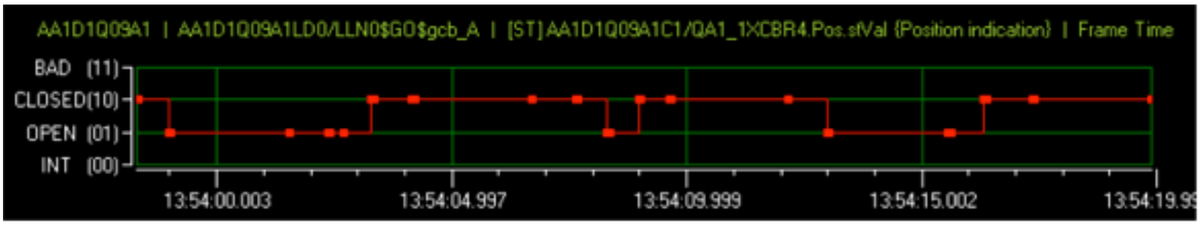
In a similar way, decoding of GOOSE messages by means of the ITT600 SA Explorer tool with clear texts, information about the application and relative mapping in the SCD file, provides an excellent view of Ethernet traffic.



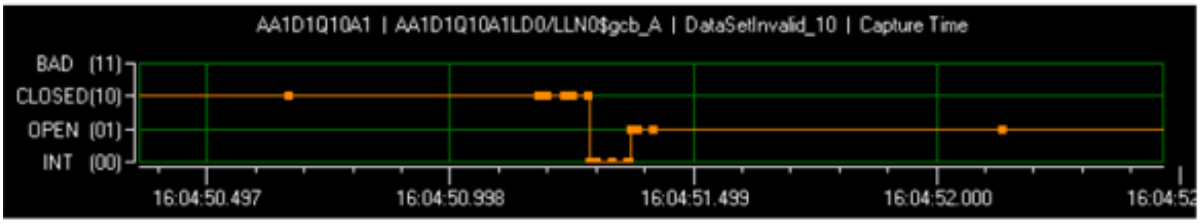
Another method for supporting the distributed function test is provided by a time trend of GOOSE messages between IED, which allows interaction between various applications such as interlocks to be easily monitored.



The different colours in the graph indicate different results of verification between the SCD file and online data.

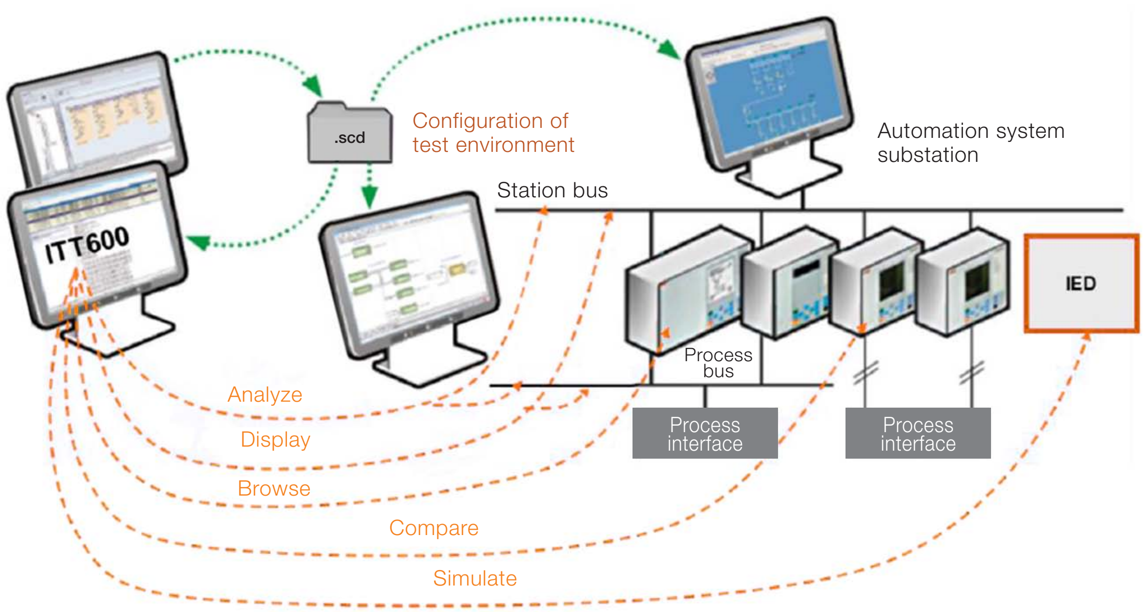


Red means that revision control is valid.



Orange means that revision control has failed.

The tool can be connnected to both the system bus and directly to an IED.



Case of principal use of ITT600 SA Explorer

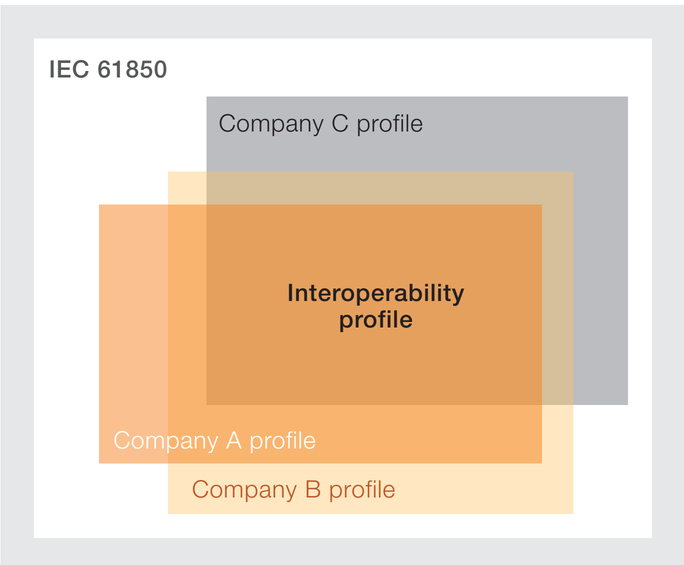
Created during the system engineering phase, the SCD file remains stored in the tool and is therefore available for simulations in real components of the system based on the description of the interface extracted from the file itself.

3. ABB products based on IEC 61850

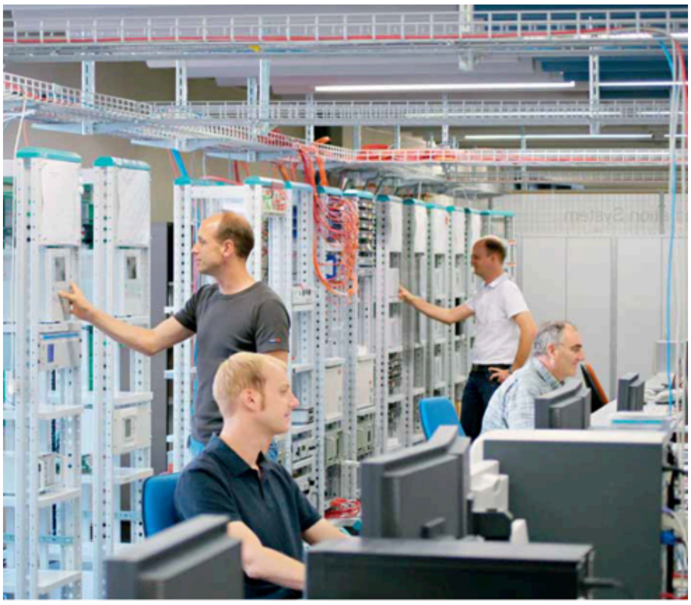
3.3 The ABB verification and validation site for IEC 61850

Native development of IEC 61850 in the design of ABB IED is tested at the ABB System Verification Center (SVC) as part of the validation process. Not only does the center test the devices individually, but also their integration into even large systems. It also provides support and explanations about the IEC 61850 standard, thereby facilitating its integration and development in the devices.

The SVC has been qualified by the UCA (Utility Communication Architecture) International User Group (called UCAlug) as a test laboratory and center of competence for IEC 61850. UCAlug is a no-profit consortium of electricity authorities and suppliers whose objective is to promote the integration and interoperability of the systems managed by electricity/gas/water supply and distribution authorities using technologies based on international standards. The group does not create standards but helps to compile and define product testing and certification schemes. SVC is therefore ufficially qualified to certify product conformance to IEC 61850.
The interoperability test is not defined in the Standard but is a fundamental step. The fact that products of different manufacturers conform to the Standard themselves does not guarantee interoperability since the communication profiles may not be the same. A communication profile defines the mandatory sub-assembly of the options developed in the device, chosen from among those defined by the Standard. The profiles of different products may therefore conform to the standard but may not be fully interoperable.



Products conforming to the standard do not guarantee interoperability

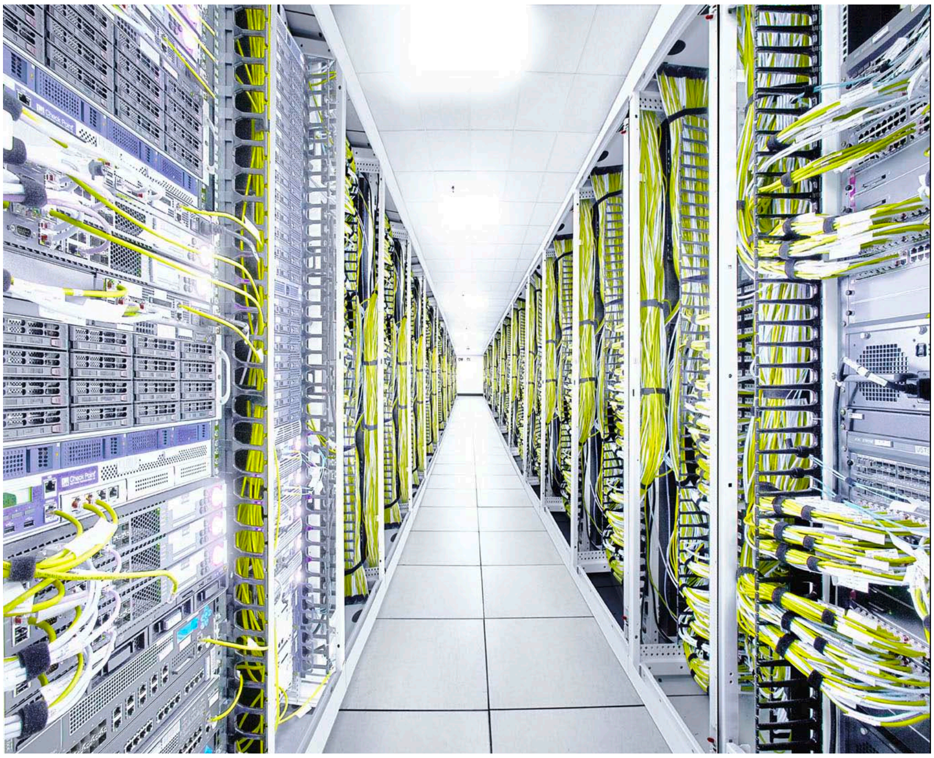


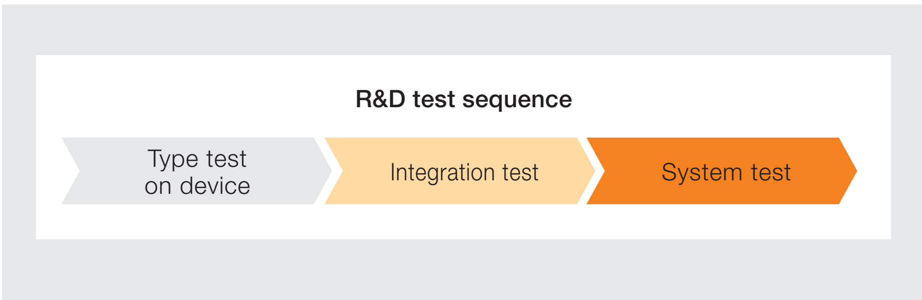
For instance, one manufacturer may have developed products that use only GOOSE, while another may have concentrated on products that use only GSSE (Generic Substation Status Event). As opposed to GOOSE, it only supports a fixed data structure). Both devices conform to the Standard even though they are not interoperable.
The system integrator is responsible for ascertaining that the products chosen for a substation design are interoperable. The interoperability test assesses the dynamic interaction between two or more IED of the system by covering all the different configurations, as far as possible. When it comes to distributed functions, this is especially important. The test also allows the performance of services supplied by communication devices (such as switches) to be assessed. The test must obviously be conducted for each specific substation design, just as though it were a type test for the system. From the interoperability aspect, it is important to also test the configuration tools and engineering (based on SCL) of different manufacturers.

SVC is representative of all the possible ABB automation system applications for 245 kV, 132 kV, 33 kV and 11 kV voltage ratings. All configurations are based on modular units, the purpose being to verify the most common and widely used solutions as far as possible.

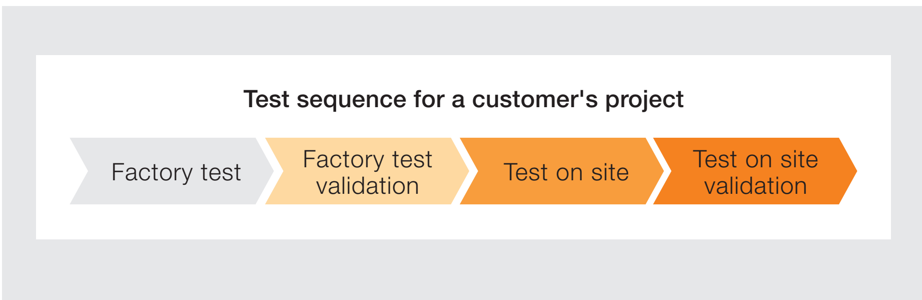
The primary part is fully simulated by means of simulation devices.
The test sequence for isolated products begins with type tests relating to IEC 61850 and terminates with the system test.

If the devices pass the type test, the sequence proceeds with integration tests that involve new products added to a small system. The sequence ends with the interoperability test, this being the objective of the Standard. However, as explained above, tests on single devices cannot guarantee interoperability in the specific real system.
Specific tests for a customer's design begin with routine tests.
This allows the specific factory acceptance test (FAT) to then be conducted. After this, dedicated tests on site prepare the system for the site acceptance test (SAT). All the tests are based on the specifications of the system ordered by the customer and are conducted by the integrator or supplier of the system under the customer's supervision.
ABB's SVC assures the high quality of ABB IED in relation to IEC 61850 thanks to its verification and validation capabilities, and provides a platform for the exchange of experience in ABB among communication experts.





Sequence of tests conducted by R&D, guarantee operation regardless of application design



Test sequence for a customer's project

4. Abbreviations and acronyms used in standard IEC 61850

The following is a list from chapter 3 of standard IEC 61850-2 describing the abbreviations used in various parts of the standard and, partially, in this document.

A	Current in Amperes (Amps)
a.c.	alternating current
ACD	ACtivation information of Directional protection
acs	Access
ACSE	Application Common Service Element
ACSI	Abstract Communication Service Interface
ACT	Protection ACTivation information
Acu	Acoustic
Age	Ageing
AIS	Air Insulated Switchgear
Alm	Alarm
ALPDU	Application Layer Protocol Data Unit
Amp	Current – non phase related
An	Analogue
Ang	Angle
A-Profile	Application Profile
APCI	Application Protocol Control Information
APDU	Application Protocol Data Unit
API	Application Program Interface
ASDU	Application Service Data Unit
ASG	Analogue SettinG
ASN.1	Abstract Syntax Notation One
AUI	Attachment Unit Interface, Transceiver, or connecting cable
Auth	Authorisation
Auto	Automatic
Aux	Auxiliary
Av	Average
B	Bushing
Bat	Battery
Beh	Behaviour
BER	Basic Encoding Rules ASN.1
Bin	Binary
Blk	Block, or Blocked
Bnd	Band
Bo	Bottom
BR	Buffered Report (Functional Constraint)
BRC	Buffered Report Control class
BRCB	Buffered Report Control Block
CAD	Computer Aided Design
Cap	Capability
Car	Carrier
CB	Circuit Breaker
CD	ROM Compact Disc Read Only Memory
CDC	Common Data Class
CDCAName	Common Data Class Attribute Name
cdcNs	common data class Name space
CDCNSpace	Common Data Class Name Space
CE	Cooling Equipment
Cf	Crest factor
CF	ConFiguration (Functional Constraint)
Cfg	Configuration
CFI	Canonical Format Identifier
CG	Core Ground
Ch	Channel
Cha	Charger
Chg	Change
Chk	Check
Chr	Characteristic
CIM	Common Information Model of IEC 61970-301
Cir	Circulating
CL	Connectionless
Clc	Calculate
Client-CR	Client Conformance Requirement
Clk	Clock or Clockwise
Cls	Close
Cnt	Counter
CO	ControI (Functional Constraint)
Col	Coil
ConNode	Connectivity Node
Cor	Correction
CRC	Cyclic Redundancy Check
Crd	Coordination
Crv	Curve
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
CT	Current Transformer/Transducer
Ctl	Control
Ctr	Centre
Cyc	Cycle
d.c.	direct current
DA	Data Attribute
DANP	Doubly Attached Node with PRP
DAT	Data Attribute Type
dataNs	Data Name Space
DataRef	Data Reference
DatAttrRef	Data Attribute Reference
DC	DesCription (functional constraint)
dchg	Trigger option for data-change
Dea	Dead
Den	Density
Det	Detected
DEX	De-EXcitation
DF	Data Frame
Diag	Diagnostics
Dif	Differential/Difference
Dir	Directional
Dl	Delay

Dlt	Delete
Dmd	Demand
Dn	Down
DO	Data Object
DORef	Data Object Reference
DPC	Double Point Control
DPS	Double Point Status information
DPSCO	Double Point Controllable Status Output
DQ0	Direct, Quadrature and Zero (0) axis quantities
Drag	Drag Hand
Drv	Drive
DS	Data Set
Dsch	Discharge
DSG	Data Set Group
DTD	Document Type Definition
dupd	trigger option for data update
Dur	Duration
DUT	Device Under Test
EC	Earth Coil
ECT	Electronic Current Transformer or transducer
EF	Earth Fault
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Interference
Ena	Enabled
EPRI	Electric Power Research Institute
Eq	Equalisation or Equal
Ev	Evaluation
EVT	Electronic Voltage Transformer or transducer
Ex	Excitation
EX	EXtended definition (Functional Constraint)
Exc	Exceeded
Excl	Exclusion
F/S	Functional Standard
FA	Fault Arc
Fact	Factor
FAT	Factory Acceptance Test
FC	Functional Constraint
FCD	Functionally Constrained Data
FCDA	Functionally Constrained Data Attribute
fchg	Trigger option for filtered-data change
FD	Fault Distance
Flt	Fault
Flw	Flow
FPF	Forward Power Flow
Fu	Fuse
Fwd	Forward
Gen	General
GI	General Interrogation
GIS	Gas Insulated Switchgear
Gn	Generator
Gnd	Ground

GO	GOose Control
GoCB	Goose Control Block
GOMSFE	Generic Object Models for Substation and Feeder Equipment
GOOSE	Generic Object Oriented Substation Events
GPS	Global Positioning System (time source)
Gr	Group
Grd	Guard
Gri	Grid
GS	GSSE Control (Functional Constraint)
GsCB	GSSE Control Block
GSE	Generic Substation Event
GSEM	Generic Substation Event Model
GSSE	Generic Substation Status Event
H	Harmonics (phase related)
H2	Hydrogen
Ha	Harmonics (non phase related)
Hi	High or Highest
HMI	Human Machine Interface
HP	Hot Point
HSR	High-availability Seamless Redundancy
Hz	Hertz – frequency cycles/second
I/O	Status Inputs/Output contacts, or channels
ICD	IED Configuration Description
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IF	Interface (serial)
Imb	Imbalance
Imp	Impedance (non phase related)
In	Input
Ina	Inactivity
INC	INteger status – Controllable
Incr	Increment
Ind	Indication
Inh	Inhibit
Ins	Insulation
Int	Integer
IntgPd	Integrity Period
IP	Internet Protocol
ISC	Integer Step Controlled position information
ISCSO	Integer Status Controllable Status Output
ISI	Integer Status Information
ISO	International Standards Organisation
IT	Current x Time product
L	Lower
LAN	Local Area Network
LC	LOG CONTROL Class
LCB	Log Control Block
LD	Logical Device

4. Abbreviations and acronyms used in standard IEC 61850

Ld	Lead
LD0	Logical Device Zero (0)
LDC	Line Drop Compensation
LDCR	Line Drop Compensation Resistance
LDCX	Line Drop Compensation Reactance (X)
LDCZ	Line Drop Compensation Impedance (Z)
ldNs	logical device Name space
LED	Light Emitting Diode
Len	Length
Lev	Level
Lg	Lag
LG	LoGging (Functional Constraint)
Lim	Limit
Lin	Line
Liv	Live
LLC	Logical Link Control
LLN0	Logical Node Zero (0)
LN	Logical Node IEC 61850-1
LN	Name Logical Node Name
LNC	Logical Node Class
LNData	Logical Node Data
LNG	Logical Node Group
lnNs	logical node Name space
Lo	Low
LO	LockOut
Loc	Local
Lod	Load or Loading
Lok	Locked
Los	Loss
LPHD	Logical Node PHysical Device
LSAP	Link Service Access Point
LSDU	Link layer Service Data Unit
Lst	List
LTC	Load Tap Changer
m	Minutes
M	Mandatory
M/O	Data Object is Mandatory or Optional
MAC	Media Access Control
MAU	Medium Attachment Unit (Transceiver)
Max	Maximum
MCAA	MultiCast Application Association
Mem	Memory
MICS	Model Implementation Conformance Statement
Min	Minimum
MMS	Manufacturing Message Specification (ISO 9506)
Mod	Mode
Mot	Motor
ms	Milliseconds
MS	Multicast Sampled value control (Functional Constraint)
Mst	Moisture
MSVC	Multicast Sampled Value Control
MSVCB	Multicast Sampled Value Control Block
MT	Main Tank
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
MU	Merging Unit
MX	Measurand analogue value X (Functional Constraint)
N	Neutral
Nam	Name
NCC	Network Control Centre
Net	Net sum
Ng	Negative
Nom	Nominal, Normalising
NPL	Name PLate
Num	Number
O	Optional
Ofs	Offset
Op	Operate/Operating
Opn	Open
OSI	Open Systems Interconnection
Out	Output
Ov	Over/Override/Overflow
Pa	Partial
Par	Parallel
PC	Physical Connection
Pct	Percent PD Physical Device
PDU	Protocol Data Unit
PE	Process Environment
Per	Periodic
PF	Power Factor
Ph	Phase
PHD	PHysical Device
PhPh	Phase to Phase
Phy	Physical
PICOM	Piece of Information for COMmunication
PICS	Protocol Implementation Conformance Statement (ISO/IEC 8823-2:1994)
PIXIT	Protocol Implementation eXtra Information for Testing
Pls	Pulse
Plt	Plate
Pmp	Pump
Po	Polar
Pol	Polarizing
pos	Position
POW	Point On Wave Switching
PP	Phase to Phase
PPV	Phase to Phase Voltage
Pres	Pressure
Prg	Progress
Pri	Primary
Pro	Protection
PRP	Parallel Redundancy Protocol

Ps	Positive
Pst	Post
Pwr	Power
qchg	Trigger option for quality-change
Qty	Quantity
R0	Zero Sequence Resistance
R1	Positive Sequence Resistance
Ra	Raise
Rat	Ratio
Rcd	Record or Recording
Rch	Reach
Rcl	Reclaim
Re	Retry
React	Reactance
Rec	Reclose
Red	Reduction
Rel	Release
Rem	Remote
Res	Residual
Rest	Resistance
RFC	Request For Comments
Ris	Resistance
Rl	Relation
Rms	Root mean square
Rot	Rotation
RP	Unbuffered RePort (functional constraint)
RPF	Reverse Power Flow
Rs	Reset, Resetable
Rsl	Result
Rst	Restraint
RSTP	Rapid Spanning Tree Protocol
Rsv	Reserve
Rte	Rate
Rtg	Rating
RTU	Remote Terminal Unit
Rv	Reverse
Rx	Receive/Received
S1	Step one
S2	Step two
SA	Substation Automation
SAN	Singly Attached Node
SAP	Service Access Point
SAS	Substation Automation System
SAT	Site Acceptance Test
SAV	Sampled Analogue Value
SBO	Select Before Operate
SC	Secondary Converter
SCADA	Supervisory Control And Data Acquisition
SCD	Substation Configuration Description
Sch	Scheme
SCL	Substation Configuration description Language

SCO	Supply Change Over
SCSM	Specific Communication Service Mapping
SE	Setting Group Editable (functional constraint)
Sec	Security
Seq	Sequence
Server-CR	Server-Conformance Requirement
Set	Setting
SF6	Sulphur HexaFluoride gas
SG	Setting Group (functional constraint)
SGC	Setting Group Control class
SGCB	Setting Group Control Block
Sh	Shunt
SIG	Status Indication Group
SMV	Sampled Measured Value
SMVC	Sampled Measured Value Control IEC
SNTP	Simple Network Time Protocol
SoE	Sequence of Events
Sp	Speed
SP	SetPoint (functional constraint)
SPC	Single Point Control
SPCSO	Single Point Controllable Status Output
SPS	Single Point Status information
Src	Source
ST	STatus information (functional constraint)
Stat	Statistics
Std	Standard
Str	Start
Sts	Stress
Sup	Supply
SUT	System Under Test
SV	Sampled Value (functional constraint – SV substitution)
Svc	Service
SVC	Sampled Value Control
Sw	Switch
Swg	Swing
Syn	Synchronisation
T	Transient data
TCI	TeleControl Interface
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol / Internet Protocol
Td	Total distortion
Tdf	Transformer derating factor
TE	Telecommunication Environment
Thd	Total harmonic distortion
Thm	Thermal
Tif	Telephone influence factor
Tm	Time
Tmh	Time in hours
TMI	TeleMonitoring Interface (for example to engineer's work-station)
Tmm	Time in minutes

4. Abbreviations and acronyms used in standard IEC 61850

Tmms	Time in milliseconds
Tmp	Temperature
Tms	Time in seconds
To	Top
Tot	Total
T-Profile	Transport Profile
TP	Three Pole
TPAA	Two Party Application Association
TPID	Tag Protocol Identifier
Tr	Trip
Trg	Trigger
TrgOp	Trigger Option
TrgOpEna	Trigger Option Enabled
Ts	Total signed
Tu	Total unsigned
Tx	Transmit/Transmitted
Typ	Type
UCA™	Utility Communications Architecture
UML	Unified Modelling Language
Un	Under
URC	Unbuffered Report Control
URCB	Unbuffered Report Control Block
URI	Universal Resource Identifier
US	Unicast Sampled value control (functional constraint)
USMVC	Unicast Sampled Measured Value Control
USVC	Unicast Sampled Value Control
USVCB	Unicast Sampled Value Control Block
UTC	Co-ordinated Universal Time
V	Voltage
VA	Volt Amperes
Vac	Vacuum
Val	Value
Var	Volt Amperes reactive
V-Get	Virtual Get function (ISO 9506-1)
VID	VLAN IDentifier
VLAN	Virtual Local Area Network
Vlv	Valve
VMD	Virtual Manufacturing Device
Vol	Voltage (non phase related)
V-Put	Virtual Put function (ISO 9506-1)
VT	Voltage Transformer/Transducer
W	Watts active power
Wac	Watchdog
Watt	active power (non phase related)
Wei	Week infeed
Wh	Watt hours
Wid	Width
Win	Window
Wrm	Warm
X0	Zero sequence reactance
X1	Positive sequence reactance
XML	eXtensible Mark-up Language
XX	Wildcard characters for example all functional constraints apply
Z	impedance
Z0	Zero sequence impedance
Z1	Positive sequence impedance
Zer	Zero
Zn	Zone
Zro	Zero sequence method

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