The concept of IEC 61850

A new approach for communication in substation automation and beyond

KLAUS-PETER BRAND, WOLFGANG WIMMER – The ability to cope with the natural migration of technology combined with the need for interoperability are just some of the reasons the IEC 61850, an international standard that defines communication in and between electrical substation automation systems was developed. Using it's object-oriented hierarchical data model approach with high-level standardized semantics, IEC 61850 enables the abstract definition of data items and services to not only specify what data or information needs to be exchanged but also the mechanics of how it is to be exchanged using mainstream communication and networking (mainly Ethernet) technologies. In addition, the cost benefits of implementing IEC 61850 can already be seen in the system design phase and experienced right through to the commissioning and operating phases. All of these factors help to explain the eagerness and speed with which the first edition of the standard has been accepted around the globe.

Substation automation (SA) is commonly used to control, protect and monitor a substation [1]. However, over the years advances in electronics, information and communications technology have brought about sweeping changes in the way substations are operated. The advent of software-based substation automation systems (hereafter referred to as SA systems) connected by serial links rather then rigid parallel copper wiring gradually became the norm rather than the exception. Though successful and widely accepted, these systems were based on either the manufacturers' own proprietary communication solutions or the defined use of communication standards from other application domains, such as DNP3 or IEC 60870-5-104. These solutions made interoperability between devices from different suppliers, and sometimes even between different versions of devices from the same supplier, an engineering nightmare which could only be mitigated by expensive protocol conversion or re-engineering. The connection of the SA system with the switchgear and instrument transformers was still left to analog standards such as 1 A and 3 A for current transformers, and 110 V and 220 V for voltage transformers and contact circuits for switchgear operations.

It took over 20 years before global forces, such as international suppliers and transnational utilities raised their voices to request a solution, in the form of a substation communication standard, to overcome the interoperability problem → 1. While interoperability was a major concern, it wasn't the only one. Only too aware of the dizzying pace at which technologies change, the authors of this new standard, known as IEC 61850, also set about finding a way to create a "future-proof" standard that would be immune

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to any future technological developments.

As the IEC 61850 standard evolved, other features, such as the definition of two time-critical services – the fast transmission of trip-type signals and sampled analog current and voltage values – were added. These time-critical services enable the extension of the serial links to be used between any intelligent electronic device (IED) and the electronic interfaces near the switchyard equipment. Demanding market requirements, such as the shortening of transfer times down to 3 ms and time synchronization in the order of 1 µs had also to be considered.

Perhaps the cornerstone of the standard is the innovative extensible markup language or XML-based substation configuration description language (SCL). SCL formally describes the configuration of IEDs in terms of functionality (eg, circuit breaker control, measurements and status values) communication addresses and services (eg, reporting). It also describes the switchyard layout and its relation to the functions implemented in the IEDs.

The emergence of a new standard

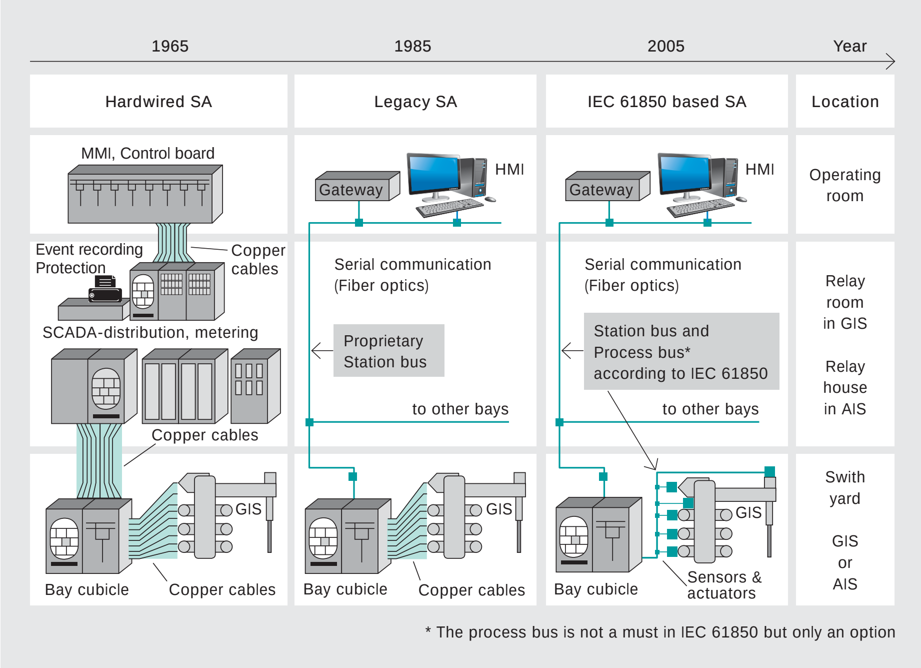
When the authors of the IEC 61850 standard first sat together, they identified a list of market requirements that would influence the form the new standard would take. The most important ones were interoperability, free architecture and long-term stability.

Interoperability

To begin with, the standard must be able to support all functions in its application domain substation. Therefore, in addition to protection, automation, control and monitoring functions, many service functions, such as time synchronization, self supervision and version handling have also to be supported. These functions are executed by software implemented in the IEDs. Interoperability in the SA system means that IEDs from different suppliers or different versions from the same supplier must be able to exchange and use information in real time without any protocol converters and without the need for human interpretation.

It is important to distinguish interoperability from interchangeability. If IEDs were also to be interchangeable, the functions

1 Substation automation (SA) architecture from hardwires over proprietary protocols to IEC 61850



and devices would need to be standardized, thus blocking any technical evolution and functional competition. Nevertheless it must be possible to exchange faulty IEDs within the lifetime of the SA system. Using IEDs that are compliant with the same standard in terms of interoperability will facilitate easy exchangeability.

Free architecture

For a standard to be termed “global,” it must support the operation philosophy of utilities around the world. It has to support an arbitrary allocation of functions to devices and should therefore be capable of supporting centralized and decentralized system architectures.

Long-term stability

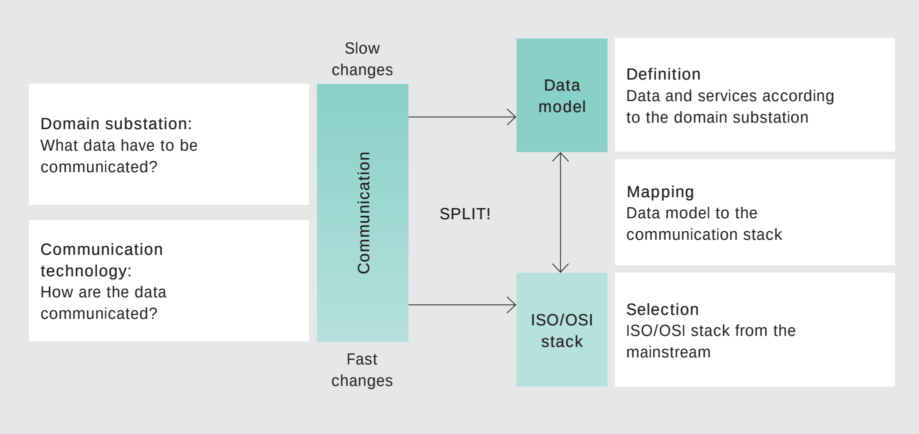
Given that the lifetime of a substation (primary equipment) is between 40 and 60 years, it is anticipated that components of the SA system have to be exchanged, on average, around two to three times during this period; some components may need replacements on a more regular basis. Naturally over time the substation will have to cope with the integration of new components from the same or new suppliers, or it may need to be extended. The point is that irrespective of the changes, interoperability must be maintained indefinitely, or to be more specific, the standard has to be future-proof. This requirement not only applies to substation devices, but also to the various technologies employed in a typical substation. For example, fast-changing mainstream communication technology will always need to serve the slower-changing requirements of protection and substation automation.

To facilitate the use of the standard for users, the identification of all transmitted data should not be based on a limited number scheme derived from contact terminal rows, but rather on the object-oriented grouping of data and a naming structure that uses standardized acronyms understandable to any substation engineer. In addition, configuration and engineering tools should be used to create systems with minimum effort and with a minimum risk of failure.

The basic approach of IEC 61850

To reach long-term interoperability, ie, to cope with the different time scales of function evolution in the domain substation and with changing communication technology, the approach taken in the IEC 61850 standard separates the domain related model for both data and communication services from the protocols, ie, the ISO/OSI seven-layer stack used to code and decode information into bit strings for communication over a serial link. This approach not only accommodates state-of-the-art communication technology, but it also safeguards investments in applications and engineering (based on the object and com-

2 The split between data model and communication stack



munication service model). Therefore, the standard is future-proof. The mapping of the data model to the communication stack is also standardized in IEC 61850 to ensure interoperable communication ➔ 2.

The object-oriented data model

The basic data model structure defined in the IEC 61850 standard is application independent. However, depending on the scope of the standard, the object model classes, as issued in edition 1 of the standard ➔ 3 [2], are related to the domain substation. Object models for wind power [3], hydro power [4] and distributed energy resources [5] were added at a later date. All application functions, including the data interfaces to the primary equipment, are broken down into the smallest feasible pieces, which may communicate with each other and, more importantly, may be implemented separately in dedicated IEDs. In IEC 61850, these basic objects are called logical nodes (LNs). The class name of the LN refers to the function the data objects belong to. The data objects contained in a LN may be mandatory, optional or conditional. The data objects themselves contain attributes [1], which may be seen as values or detailed properties of the data objects. This hierarchical data model is illustrated in ➔ 4.

Since the class names of LNs and the full names of data objects and attributes are standardized, they formally provide the semantics of all exchanged values within the scope of IEC 61850. LNs may be grouped into logical devices (LDs) with non-standardized names, and these LDs are implemented in servers residing in IEDs. The common properties of the physical device itself are dealt with by an LN class named LPHD.

Only if a LN class for some function is missing it may be substituted by generic LN classes that have restricted semantic meaning. More demanding, however, is the extension of LNs and data according to the strict and restrictive extension rules of the standard, including name spaces as unambiguous references to semantic meaning. These rules preserve interoperability, even in cases where extensions are required.

For the functional identification of each data in the context of the switchyard, a hierarchical plant designation system shall be used for the designation of substation objects and functions preferably according to IEC 61346 [6].

The services of the data model

Interoperability requires the standardization of not only the data objects but also the access to them. Therefore, standardized abstract services also belong to IEC 61850. The most common ones include:

- Read: reading data such as the value of an attribute
- Write: for example writing the value of a configuration attribute
- Control: controlling switching devices and other controllable objects using standardized methods such as “select before operate” or “direct operate”
- Reporting: for example, event driven reporting after value changes
- Logging: the local storage of time-stamped events or other historical data
- Get directory: in other words, to read out the data model (important part of self-description)

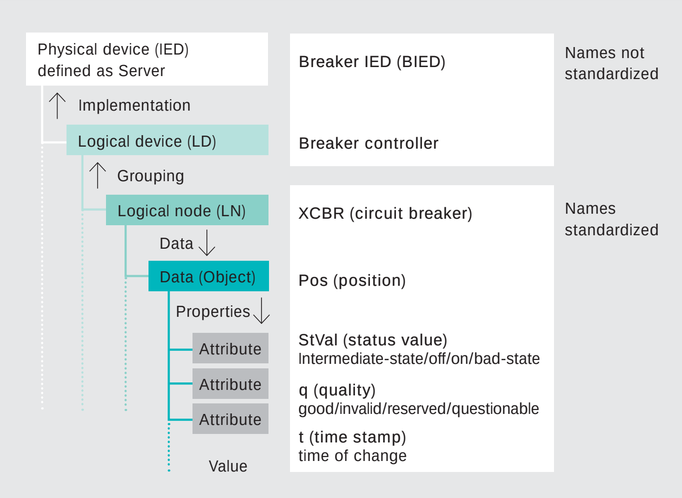
3 The parts of the standard IEC 61850 Edition 1

Communication networks and systems in substations

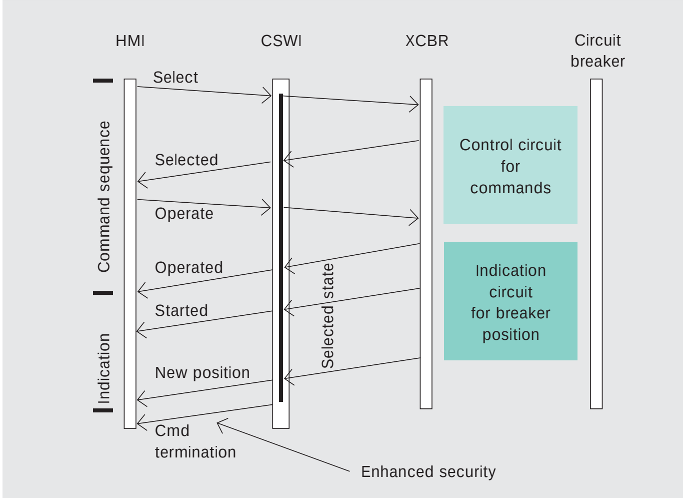
Part 1:	Introduction and overview
Part 2:	Glossary
Part 3:	General requirements
Part 4:	System and project management
Part 5:	Communication requirements for functions and device models
Part 6:	Configuration description language for communication in electrical substations related IEDs
Part 7-1:	Principles and models
Part 7-2:	Abstract communication service interface
Part 7-3:	Common data classes
Part 7-4:	Compatible logical node (LN) classes and data classes
Part 8-1:	Mapping to MMS and to ISO/IEC 8802-3
Part 9-1:	Sampled values over serial unidirectional multidrop point-to-point link
Part 9-2:	Sampled values over ISO 8802-3
Part 10:	Conformance testing

All application functions, including the data interfaces to the primary equipment, are broken down into the smallest feasible pieces, which may communicate with each other and be implemented separately in dedicated IEDs.

4 Hierarchical data model



5 An illustration of the control service



GOOSE is the acronym for generic object oriented system event and is a service used for the speedy transmission of time critical information like status changes, blockings, releases or trips between IEDs.

– File transfer: for configuration, disturbance recording or historical data
– GOOSE: GOOSE is the acronym for generic object oriented system event and is a service used for the speedy transmission of time critical information like status changes, blockings, releases or trips between IEDs
– Sampled value (SV): the SV service quickly transmits a synchronized stream of current and voltage samples for voltages and currents

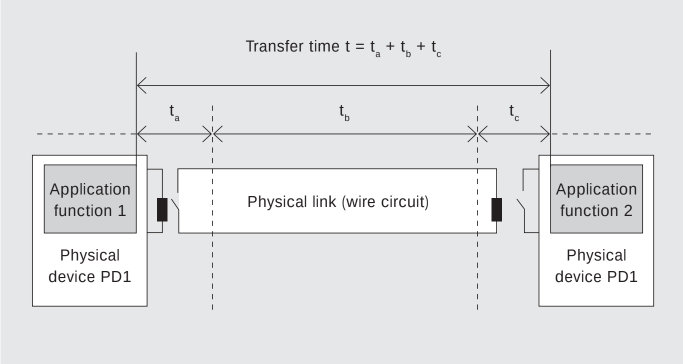
The control service implementing the "select before operate with enhanced security" mode is illustrated in ➔ 5 in the context of a switch operation: The SELECT command is issued at the operator's HMI and communicated to the bay control unit represented by the LN CSWI. Depending on the system architecture the SELECT command is confirmed either by the bay controller or the circuit-breaker IED, which is represented by the LN XCBR. When the operator receives a positive acknowledgement (ie, "Selected") from the CSWI, he then issues an OPERATE command. Once permission has been granted, an operation request is sent via the bay controller to the circuit breaker (XCBR). The execution of the command request is positively acknowledged using the message "Operated." Additional feedback is provided using the reporting service, which is initiated by the start of the circuit-breaker contact movement ("Started") and when the end position is reached ("New position"). In cases where a command service with enhanced security is chosen, the end result is confirmed by the command termination message ("Cmd confirmation"), which terminates the control service.

Performance requirements

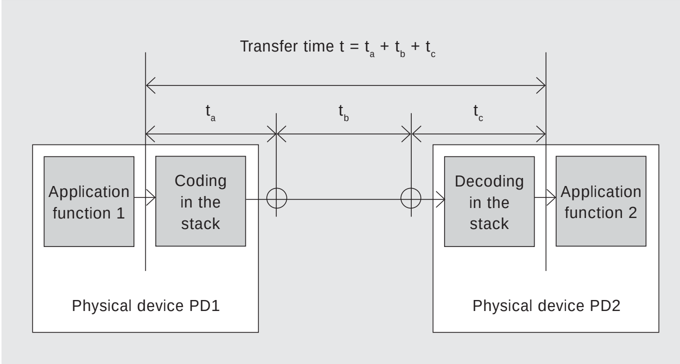
The transfer time of messages between the sending application (eg, protection function issuing the trip) and the receiving application (breaker function performing the breaker operation) is determined by the requirements of functions that depend on this message transfer. As a protection trip is time critical, with a worst case taking around 20 ms, it is allocated to the most demanding transfer requirement class, which means 3 ms. The transfer of samples using the SV service is also assigned to this requirement class to avoid, for example, delays in fault detection by protection. The requirements have to be fulfilled not only by the IEDs but also by the SA system design. The transfer time of a GOOSE message over a serial link is compared in ➔ 6 and ➔ 7 with the response time of a hardwired contact circuit.

To properly analyze the sequence of events in the system and for post-event fault analysis, the events need a time stamp with an accuracy against real time of 1 ms; this incidentally is better than any contact change. However, time synchronization for current and voltage samples, which are needed for differential or distance protection or global phasor comparison, requires an accuracy of the order of 1 µs! The 1 ms accuracy level is achieved using the simple network time protocol (SNTP) directly over a serial communication link, while one pulse per second (pps) over a separate wire or fiber achieves the 1 µs time synchronization. In the future, the IEEE 1588 stan-

6 Transfer time definition with hardwired contacts



7 Transfer time definition with communication stacks



dard [7] will allow high-precision time synchronization also directly over Ethernet.

The communication stack and mapping

IEC 61850 has selected mainstream technology for the communication stack, ie, a stack structure according to the ISO/OSI layers consisting of Ethernet (layers 1 and 2), TCP/IP (layers 3 and 4) and manufacturing messaging specification, MMS, (layers 5 to 7). The object model and its services are mapped to the MMS application layer (layer 7). Only time-critical services, such as SV and GOOSE are mapped directly to the Ethernet [2] link layer (layer 2) → 8.

Ethernet bus architectures and dual port redundancy

IEC 61850 uses Ethernet as the basic communication technology, currently with a speed of 100 MBit/s at the IEDs. Support of message priorities by managed switches allows time critical requirements, such as the 3 ms application to application transfer time, to be met. Tree and ring topologies are possible with switches. However, according to the first edition of the standard, the Ethernet ring topology with automatic reconfiguration in case of link or switch failures is the most common architecture for systems. Tree topologies are not used very often because the switch representing the root is a potential single point of failure. It should be noted that in the ring, one switch connection has to be always open – creating in effect a kind of tree topology – to avoid endlessly circulating telegrams. The open switch connection is automatically closed if a failure in any of the ring links or in another switch creates an unwanted second opening (ie, a tree recovery algorithm).

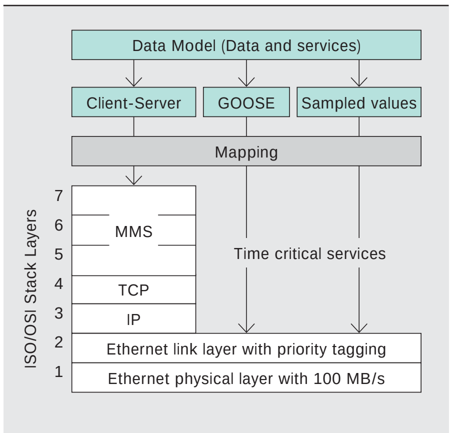
Edition 2 [8] of the standard scheduled for publication in 2010 will define protocols for the connection of IEDs with two ports to two redundant communication systems or the formation of a ring with redundant traffic in both ring directions [3].

The station and process buses

The station bus connects the IEDs for protection, control and monitoring (ie, bay units) with station level devices (ie, the station computer with HMI and the gateway to the network communication center (NCC)) using whatever services are required by the applications. The process bus connects the bay units with the switchyard devices, and the communication of status information, commands and trips is the same as for the station bus → 9. However, getting synchronized samples of current and voltage to the relevant protection IEDs using the SV service is quite challenging.

The conversion of proprietary signals from nonconventional instrument transformers for current and voltage or of the analog values from conventional instrument transformers to IEC 61850 telegrams is done using an IED called a merging unit (MU). An MU merges the 3-phase currents and voltages, including the zero-components of one bay high-precision time-synchronized by definition. The process bus functionality for the switchgear is provided by the so-called breaker or switch IEDs (BIED, SIED). The free allocation of functions allows the creation of IEDs with both BIED and SIED, and MU functionalities.

8 Mapping to the stack

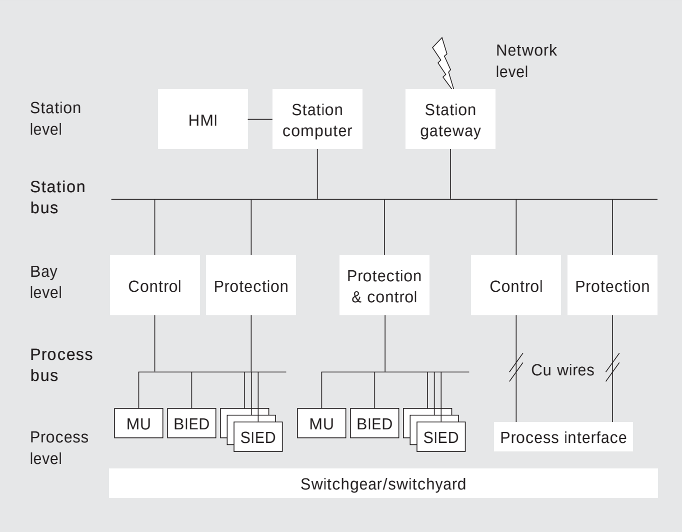


The station bus may be configured in a ring topology with ring redundancy, a redundant star for IEDs with dual port redundancy or any solutions which fulfill the requested performance and reliability requirements. The process bus may also adopt a ring or even a star topology, but at the very least one or more point-to-point connections.

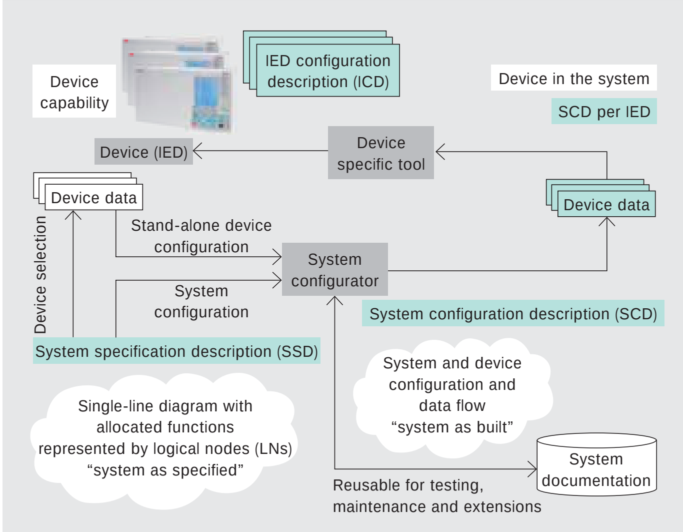
Such is the potential of IEC 61850 that in the future it is hoped it can be applied right across the power system spectrum.

SCL supported engineering

In order to process data received from IEDs, the receiving IED needs to know how this data has been sent; how it has been coded; what it means in the context of the switchyard; and the functionality of the sender. To be able to transfer this information from one tool to another in a standardized way, the XML-based SCL language has been defined.



9 Station and process bus examples



10 Example of engineering with SCL

To allow the exchange of data between tools from different manufacturers, IEC 61850 introduces a basic engineering process: Based on the system specification and the description of the IEDs, the required device types are selected and their formal description, in the form of an ICD file, is loaded into the system configuration tool. The system configuration tool then defines the meaning of IED functions in the context of the switchyard by allocating LNs to elements of the switchyard single-line diagram. The data flow between all IEDs is then defined, and all IED names and communication related addresses and parameters are configured. The resulting SCD file is a comprehensive description of the entire system in the context of IEC 61850. This file is then imported into the device tools of the different IEDs to complete their individual configuration in the context of the system. The principles of engineering with SCL files are shown in ➔ 10.

> The station bus connects the IEDs for protection, control and monitoring with station-level devices while the process bus connects the bay units with the switchyard devices.

As the entire IED data model is visible via the communication system, including possible configuration and setting parameter values, and all this can be described in SCL, the SCD file is also a medium usable by other applications in the life-cycle of the system [9], such as the archiving of the system configuration in a standardized form and the transfer of protection parameters to protection system configuration tools. It may be used in simulation and testing tools or to check the configuration (version) state of the running system against the intended state. While these applications are outside the scope of IEC 61850 as a communication standard, they are of additional benefit for the user of the standard.

A future-proof outlook

The long-term value of IEC 61850 for users lies in its object-oriented hierarchical data model approach with its high-level standardized semantics and the use of mainstream communication technology, which is dominated by Ethernet. However, IEC 61850 is much more than just a normal communication protocol. Such is its potential that in the future it is hoped IEC 61850 can be applied right across the power system spectrum.

A second edition of the standard is scheduled for publication in 2010. It will contain many additional features, such as the support of dual port redundancy for IEDs.

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Footnotes

1 The attributes carry the data values.
2 Nowadays in communication technology, most efforts and money are invested in Ethernet technology. In fact Ethernet is now successfully competing with the traditional field busses.
3 Please refer to "Seamless redundancy " on page 57 of this issue of *ABB Review*.

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