Pushing the limits

ABB product development based on the IEC 61850 standard

JANNE STARCK, STEVEN A. KUNSMAN – Since the publication of the first edition in 2004, the IEC 61850 communication standard has practically become the de-facto standard in the context of substation automation. Almost from the moment of its publication, intelligent electronic devices (IEDs) supporting IEC 61850 started to appear on the market. However, for many of these IEDs, it soon became clear that performance and flexibility were sacrificed in the race to get to the market first. ABB took a somewhat different approach. Experts from within the company participated in the standardization work from day one, and as it was being developed it was decided to upgrade ABB's Relion® protection and control product family to support the IEC 61850 standard. By the time the standard came into existence, ABB had already adopted a philosophy of "native IEC 61850 implementation" in that the standard is implemented from the start in new product developments. Today, ABB's IEC 61850-based protection and control products are recognized as the number one choice for both utility and industrial power systems.

1 Phase time overcurrent (PTOC) overcurrent function design

	PTOC Logical Node Class		
Data Object Name	Explanation	Mandatory/ Optional	IED Design
Mod	Mode	M	X
Beh	Behavior	M	X
Health	Health	M	X
NamePlt	Name Plate	M	X
OpCnt	Operation Counter	O	
OpCntRs	Operation Counter Reset	O	
Str	Start	M	X
Op	Operate	M	X
TmASt	Active Curve Characteristic	O	
TmACrv	Operating Curve Type	O	X
StrVal	Start Value	O	X
TmMult	Time Dial Multiplier	O	
MinOpTmms	Minimum Operate Time	O	X
MaxOpTmms	Maximum Operate Time	O	
OpDlTmms	Operate Delay Time	O	X
TypRsCrv	Type of Reset Curve	O	X
RsDlTmms	Reset Time Delay	O	X
DirMod	Directional mode	O	

With the introduction of the IEC 61850 standard, the world of substation automation has taken its biggest technology leap since the introduction of microprocessor-based protection and control devices in the early 1980s.

As soon as the standard was published, intelligent electronic devices (IEDs) supporting IEC 61850 started to appear on the market. The speed at which this happened was achieved by upgrading existing IED platforms with an internal or external gateway serving as a proxy to the IEC 61850 Ethernet-based protocol. Because this approach left the IED architecture, internal software and tools unchanged, protocol conversion was required to enable communication between existing IEDs and a modern IEC 61850-based substation. At the time, the IEC 61850 standard was just one of a number of protocols to expose the IED's internal information, which was mapped to the IEC 61850 data models and logical nodes (LNs). The internal architecture did not differ from other point or register-based communication protocols (eg, DNP V3.00 and MODBUS). While these early implementations resulted in a fast time-to-market, performance and flexibility were sacrificed as a result.

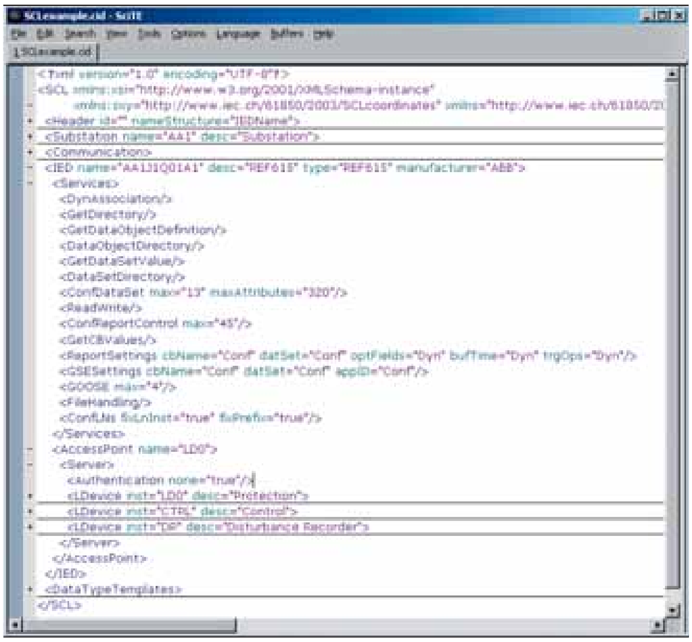
As the standard became better known, however, engineers realized the benefits it provided presented them with an opportunity to rethink IED platform and architecture development and introduce new conceptual ideas for substation automation. ABB was taking this approach even before the standard's publication by fully and genuinely implementing the standard in many of its devices, engineering and commissioning tools, and substation automation (SA) systems. In fact, ABB had already adopted a "native IEC 61850 implementation" philosophy, which stated that from then on the standard would be implemented in new product developments.

Even before its publication in 2004, ABB was extending the limits of IEC 61850 with its full implementation of the standard in many of its devices, tools and substation automation (SA) systems.

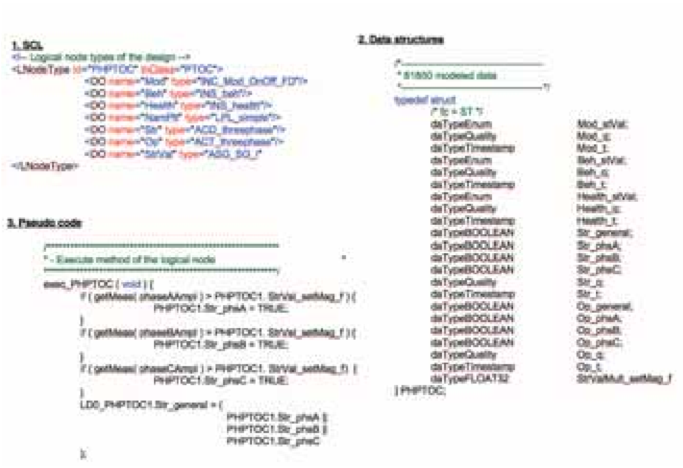
Native IEC 61850 implementation

In a typical IEC 61850 native design, the functionality of the IED must consider the entire process, including specification and evaluation, system and device engineering, system commissioning, and operations and maintenance. An IEC 61850 native IED should provide:
– A full set of protection and control data to SA systems, and to other IEDs and third-party tools in compliance with the defined data models and LNs to achieve a high level of interoperability
– Fast communication and application performance, which is critical when using generic object oriented substation events (GOOSE) peer-to-peer communication for distributed protection algorithms, and complex station and bay control interlocking schemes over Ethernet in the substation station bus
– Adherence to data modeling and substation configuration language (SCL) information available for system engineering, device configuration, diagnostics and commissioning tools

2 Visualization of the substation configuration language (SCL)



3 Data structure in a PTOC function



– Ease of adaptation and be future proof to evolving technologies enabled by Ethernet and IEC 61850, for example, utilizing IEC 61850-9-2 sampled values and microsecond-level time synchronization accuracy via IEEE 1588

ABB's Relion® protection and control product family was one of the first to undergo the IEC 61850 transformation. The products required a completely new platform architecture that would integrate communication services and data representation into the core protection and control applications. This development was carried out in parallel with the development of the IEC 61850 standard (pre-2004) to ensure that the future ABB Relion family was designed from the beginning to support IEC 61850.

Transforming the Relion IEDs

One of the key factors that led to successful product transformations was to fully base the IED's functionality on the data model and LNs as defined in the standard. As it now stands, protection and control algorithms, which provide the core IED functionality, are modeled and implemented fully according to the IEC 61850 standard rules. In the new architecture, the data models are supported directly in the protection and control functions, making the LN data directly accessible from the communications services. With this approach the data mapping and conversion process is not required, something that is a key factor in IED performance. IED data are therefore directly available without time-consuming additional processing.

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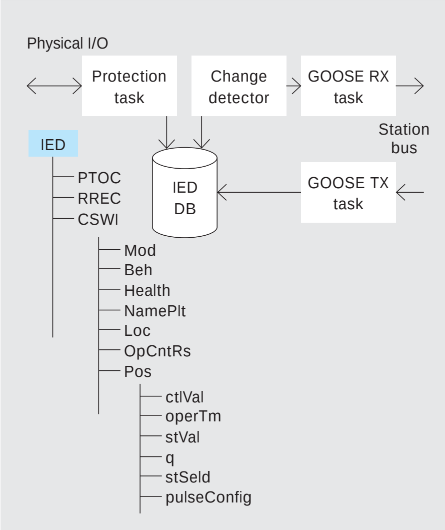
When a new protection function, such as overcurrent protection, is implemented, the standard phase time overcurrent (PTOC) LN-class definition is the foundation for modeling the protection algorithm. Depending on product and application requirements, all mandatory and selected optional attributes of the LN-class are used in the function design. The IEC 61850 standard requires that the mandatory data objects must exist in the data model of the device. The optional parts are only used when applicable, and this is dependent on the product and intended application → 1. The supported standard data objects are documented in the mandatory model implementation conformance statement (MICS) document.

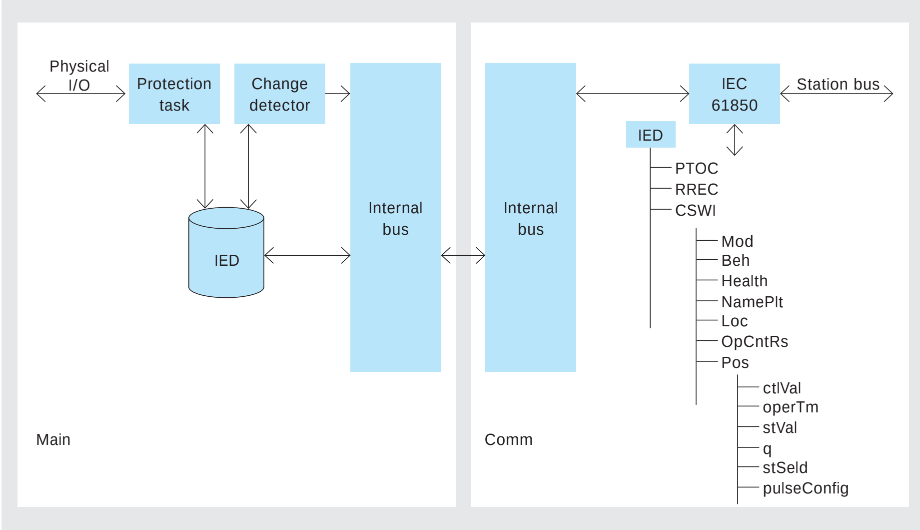
In the next stage, the standard LN and its selected functionality are modeled using the SCL, which describes the function structures, data objects and data types of an LN → 2. With the defined function structures according to the SCL, it is possible to automatically generate the skeleton of the application data access functions (read, write) for the IED system software. These functions are inherited and directly linked to the protection algorithm (eg, PTOC) data in the IED architecture's core protection and control subsystem. This direct mapping provides a high-performance interface to the IED's IEC 61850 communication stack, which in turn makes the data accessible to the station bus → 3. No additional conversion of protection and control data is required to support the communication's architecture and protocol. Structures based on LNs can also have a function for settings, which are directly visible to the SA system via the communication stack.

In general, the IEC 61850 standard provides a solid foundation for the design of native IEC 61850 protection and control IEDs due to the fact that data models have been defined by an international working group composed of experts in

4 GOOSE data and message handling



5 IEC 61850 handling in case of a separate communications module



the field. With standard-based data modeling, faster development of IED application functions and communication interfaces can be obtained. The improvements are due to the LN structures, which are inherent in the protection application. This therefore makes data access from the IEC 61850 based SA system to the IED's internal protection and control algorithms very computationally efficient and eliminates the need for time-consuming protocol conversion processing.

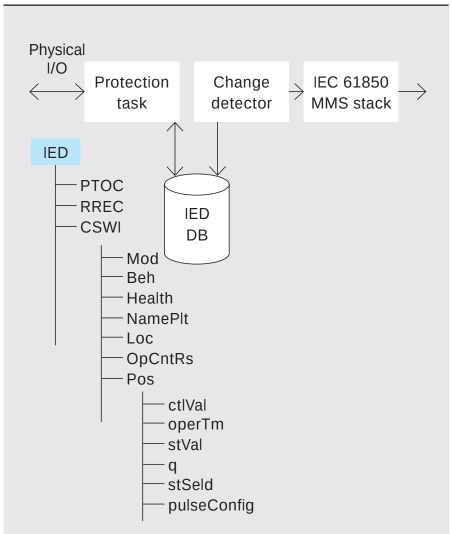
The performance of a native Relion IED

IED architectures designed to support IEC 61850 from the start need to ensure that the delay in communicating control signals, analog values and other time critical data between the process and the IEDs is as small as possible. In traditional IEDs, the binary and analog signals were processed by the IED hardware I/O subsystem. In IEC 61850-based architectures, conventional wiring has been eliminated and these signals are transmitted and received via the communications interface. Thus, the communication interface in the new IEC 61850-based IEDs must be very efficient at processing the communication data.

The fast GOOSE performance of a Relion IED is critical in a native IEC 61850 implementation to allow control signal processing as if it were a traditional hardwired IED. During IED algorithm execution or task cycle, the data values of a protection function (eg, the protection start in PTOC) can change if an overcurrent is detected on a feeder, and this in turn updates the database supporting the particular LN structure. After a protection task cycle completes, the IED processing subsystem performs a signal comparison to identify new data in the IEC 61850 connected datasets. In the IEC 61850 data model, most data-change driven activities are based on the datasets, for example, event reporting and GOOSE data publishing. The IED change detector identifies changes in the datasets and if a new value is detected, the dataset and its connected functionality are triggered. In an IED using GOOSE, the internal high-priority subsystem executing the GOOSE function is triggered. Subsequently, the modified data is sent as quickly as possible through the IED communication interface to the SA system station bus using a GOOSE multicast message. GOOSE multicast messages are unsolicited broadcasts which do not require any cyclical data polling mechanism. Data structures used in GOOSE include direct access to the IED internal database, and because the internal data model exactly matches the IEC 61850 standard, no data conversions are required → 4.

In the same way, the IED's IEC 61850 native design yields high-performance subscribing GOOSE datasets from other IEDs in the local sub-network. As GOOSE messages are processed in the data link layer in the Ethernet stack, this does not require additional processing through the TCP and IP layers. This type of Ethernet communication is very fast since the data is retrieved directly from the IED communications hardware interface. The IED's GOOSE processing capabilities can decode the message in less than 1 ms and

6 IEC 61850 event handling



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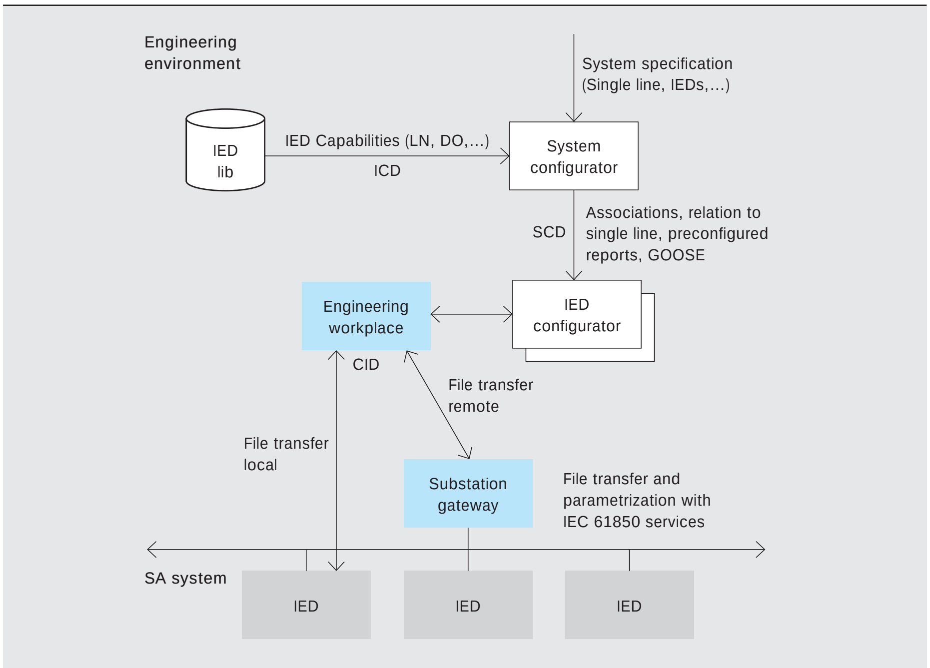
7 System engineering workflow



deliver only the modified subscribed GOOSE data to the IED's internal database, which makes it immediately accessible to the next execution of the protection and control algorithms. A "put" operation is a single data value copy from a GOOSE frame to the internal LN structure database → 4. No conversion is required as the data in both the IED database and incoming GOOSE message comply with IEC 61850 data types. The next application execution checks for new input values and processes them accordingly.

If GOOSE was based on a non-native IEC 61850 implementation, a conversion from an internal data model to an IEC 61850 data model would be needed. It would therefore be difficult to achieve the performance classes for protection communication as stated in the IEC 61850 standard. In some architectures, the processing of horizontal communication utilizes a different processor on a separate IED communication card or an external gateway, which would make the performance and configuration even more challenging → 5.

Reporting events to SCADA systems using standard buffered or unbuffered reporting services is based on the same mechanism that is implemented to detect GOOSE data changes. When a change of data is activated by an application, for example, a protection start signal in PTOC, the new data value and its associated timestamp and quality attributes are stored in an internal event queue by the IED's change detector. At the same time, the IED's communication interface is triggered and starts sending queued events to clients (eg, the gateway or station HMI) on the station bus → 6. As internal data models and stack data structures are based on the same IEC 61850 data model, there is no need to carry out any additional data processing.

ABB has created an internal IEC 61850 application guideline that defines the appropriate default dataset names and uses; for example, StatNrml for protection events and StatUrg for primary equipment value changes. In this way, different IEDs in the Relion family have similar properties and are easier to configure in the SA system. Default values are defined and used in the IED tool and connectivity packages, and are available for the user when an IEC 61850 configuration (SCL) is exported using the IED tool.

> The configuration of IEDs belonging to the Relion product family is based on ICD files available in the IED connectivity packages.

In the new IED architecture, traditional communication protocols, such as Modbus, IEC 60870-5-103 and DNP 3.0 are mapped from the IEC 61850-based data model and event datasets. The convenience of protocol mapping stems from the fact that IEC 61850 includes most of the different data and service types required for legacy protocols. A comparison of legacy protocols and IEC 61850 typically shows that legacy protocols have a subset of services and data types available. Many customers prefer to use legacy protocols and the internal architecture of an IED must be ready to support multiple protocols. IEC 61850, however, is the preferred superset in terms of functionality and services.

System engineering

IEDs belonging to the Relion product family are configured according to the rules defined in the IEC 61850 standard. The configuration is based on library installable client driver (ICD) files available in the IED connectivity packages where these library files include the IED's data model. In the top-down engineering process, the system integrator selects the appropriate library ICD files representing the Relion IED types and builds the system configuration description (SCD) according to the substation design. In this phase, the substation configuration already includes all IEDs, the single-line diagram, the GOOSE links between the devices and the event definitions. The SCD file is imported to the IED tool where the IEDs are parameterized and configured according to the application/power system specifications → 7.

In small and simple IEC 61850 based substations, the system engineering of the substation automation system can be done using a bottom-up process. The workflow starts from the IED tool, which creates the set of IEDs and exports the initial SCD file to the system configuration tool. Using connectivity packages, the IED tool exports the SCD file, including a default single-line diagram and datasets for event reporting. In many cases, these values, as such, fit customer specifications. In the system configu-

8 A KEMA certificate

IEC 61850 Certificate Level A[1]

ABB Oy
Distribution Automation

KEMA

The product has not shown to be non-conforming to:

IEC 61850-6, 7-1, 7-2, 7-3, 7-4 and 8-1

Communication networks and systems in substations

9 IED members of the Relion family and their installation in ABB's UniGear MV switchgear

ration tool, the system engineer can add GOOSE links and if required, customize the details of the single-line diagram and event datasets. The system engineer exports the completed SCD file back to the relay setting tool where the IED's application configuration is finalized.

In both top-down and bottom-up system engineering processes, the final result is an SCD file which is needed for the configuration of substation SCADA systems and gateways. The substation section of the SCD file can be used as an information source to create the substation single-line diagram, which in turn minimizes any additional work needed for the design of the substation's graphical diagram. In this way, the SA system greatly benefits from the self-descriptive feature of the IEC 61850 defined SCL.

Testing and using Relion IEDs

The capability of the native IEC 61850 implementation and the IED design have been thoroughly tested as part of the development validation – as have products already on the market – at the ABB UCA level B certified System Verification test Center (SVC)[1]. The most important test is the basic IEC 61850 conformance test. All Relion IEDs have been tested and certified according to the procedures defined in part 10 of the IEC 61850 standard. For end users and manufacturers, the certificate states that no nonconformities to the standard have been found in the behavior of the IEDs. The IEDs are therefore capable of interoperating with other systems offering IED protocol services and which have SCL files exported from the IED tool. A typical IEC 61850 certificate from KEMA is shown in → 8.

To date the IEC 61850 standard conformance test does not test IED performance. However, part 5 of the standard defines, for example, a performance class P1, type 1A "Trip" for protection purposes using horizontal GOOSE communication. According to this definition, data exchange times between IEDs must not exceed 10 ms in distribution automation applications.

Two IEDs, the REF630 and REF615, both members of the Relion family, were installed in ABB's UniGear medium-voltage switchgear cubicles and tested according to the procedures stated in the IEC 62271-3 standard[2] → 9. This standard, applicable to switchgear and control gear, specifies equipment for digital communication with other parts of the substation and its impact on testing. Specifically, the standard defines performance test procedures with reference to the IEC 61850 performance classes and the requirements which the IED must fulfill for these applications.

The test results more than proved the concept. In fact the functional and performance test results have been nothing short of impressive. The Relion IEDs fulfilled the performance class defined by

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10 IEC 62271-3 performance test results

Protection blocking data exchange time between Relion® IEDs using hard wired signals (max) including protection activation time	32 ms
Protection blocking data exchange time between Relion® IEDs using IEC 61850 GOOSE (max) including protection activation time	16 ms
Signal transfer time between Relion® IEDs using hard wired signals (max)	24 ms
Signal transfer time between Relion® IEDs using IEC 61850 GOOSE (max)	8 ms

IEC 61850-5 for protection applications using GOOSE. In addition, they showed that the signaling between devices using GOOSE was faster than with traditional hardwired signals → 10.

The performance capability of the Relion product family allows the customer to fully exploit the benefits of the IEC 61850 standard in SA systems and smart grid solutions. Based on a native implementation, the Relion product technology is well prepared for tomorrow's challenges. This surely puts ABB's solution in a pre-eminent position among competitors worldwide.

SA application perspectives for IEC 61850 transmission applications

The benefits of IEC 61850 over traditional communication protocols are not strictly limited to IEDs, open infrastructures and device interoperability in multi-vendor systems.

ABB continues to explore advanced applications and engineering improvements and the goal is to continue to push the benefits of IEC 61850 well beyond what is now possible.

To explain further, major features of the standard that are used include the self-describing IEDs and the standardized SCL. The complete topology of both the primary and secondary network of a substation is described in the SCD file. This information source can be used to automatically generate graphical diagrams on the station HMI, such as the communication network overview including supervision data and the station single-line diagram. While this reduces the engineering work needed, it also improves quality with respect to consistency because of the single information source being used. Furthermore, maintenance and extension work becomes more efficient and the efforts needed for testing can be automated or reduced. Moreover, based on the static information available in the SCD file together with the online status information from the substation IEDs, new types of applications can be developed.

One example of a new application already implemented in today's products, and which is very beneficial to operators, is dynamic busbar coloring. The primary network layout (ie, conducting equipment, objects) is known from the SCD file. Together with the actual positions and measurements reported from the IEDs, all information is available to perform this task.

A more complex function or application is station interlocking. Algorithms can be implemented to dynamically adapt the interlocking rules based on the current substation network topology. Again, the required information to perform this topology-based interlocking can be retrieved from the SCD file and the online data provided by the IEDs.

And last but not least, the IEC 61850 LNs allow the implementation of distributed functions, which will no doubt lead to new applications in the not too distant future.

Keep pushing the limits

The introduction of the IEC 61850 standard and its achievement in enabling device level interoperability is considered a major advancement over legacy and proprietary protocols. ABB's native IEC 61850 Relion product family implementation demonstrates that interoperability is only one goal that can be realized by this standard. The product architectures provide increased value and high performance, and are capable of meeting the most demanding application requirements. Another main goal of IEC 61850 is that it future proof's a company's investment. This can only be done when the products meet tomorrow's anticipated performance requirement and engineering tools, and processes can be easily extended in future station expansion. ABB continues to explore advanced applications and engineering improvements. Its GOOSE performance is best in its class and the goal is to continue to push the benefits of IEC 61850 well beyond what is now possible.

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[1] IEC 61850 (2003). Communication networks and systems in substations, International Standard.
[2] IEC 62271 (2006). High-voltage switchgear and controlgear.
[3] Hakala-Ranta, A., Rintamaki, O., Starck, J. (2009). Utilizing Possibilities of IEC 61850 and GOOSE. CIRED, Prague.

Footnotes

1 The UCA users group maintains the IEC 61850 standard and defines different levels of certified IEC 61850 test centers. Independent labs are generally classed as level A test centers while manufacturer test labs, like ABB SVC, are certified as level B test centers. For more information on SVC, please also read "Verified and validated" on pages 23–28 of this *ABB Review* Special Report

2 The tests were witnessed and reported by KEMA.