



zenon
by COPA-DATA

Successful digitalization in energy projects with IEC 61850

An executive overview

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1. Executive summary

A growing number of tenders in the energy sector and, in particular, for substation projects include the requirement for IEC 61850. This standard is becoming increasingly widespread and forms a reference system that now goes far beyond the communication function of individual equipment components. Instead, IEC 61850 focuses on the integrity of the equipment as a whole and decisively increases the modularity and maintainability of a solution through consistent functional orientation.

Initially, IEC 61850 was often wrongly reduced to its communication mechanisms and interpreted merely as a new technological rehash of known tasks in automation. When properly understood and applied, however, IEC 61850 unleashes several benefits for the energy industry that go far beyond the capabilities of conventional communication protocols. IEC 61850 helps companies sustainably use digitalization to make their processes simpler and their equipment more flexible. The benefits include:

- Elimination of physical cabling and associated building requirements using secure, digital communication.
- Independent equipment design, free from manufacturer constraints, through universally accepted functional models.
- Functional adaptation and enhancement through software (re)configuration rather than changing the physical cabling.
- Less work involved in testing and replacing components thanks to modular in-process test procedures and simulation functions.
- Increased equipment availability thanks to information acquisition based on extensive data acquisition and long-term monitoring (advanced analytics).
- Open system configuration and interoperability of components made by different manufacturers.

However, working toward the IEC 61850 standard can be a considerable challenge, not least because of its large scope. It presents energy service providers and system integrators with a choice they must weigh up – should they take the step toward a fully digitalized substation, or should they stick with the techniques and processes that have been established for decades?

This white paper outlines useful points to consider when assessing readiness to adopt IEC 61850 in energy solutions. It provides tips on how energy companies can prepare for its systematic adoption.

2. Successful digitalization in energy projects with IEC 61850

2.1. Why the energy world needed a new standard

The 1990s saw the start of signals being bundled together in substations. In particular, this involved signals running from the high-voltage switchgear and measuring transformers to the local control center. Originally, the signal information was carried by copper wire from the equipment to the protection device or to the display instrument in a display panel. The amount of material involved was considerable and hundreds of kilometers of copper wire had to be laid. The first products were based on RS422 and RS485 connections. They used protocols that considered the functionalities of a substation. In addition to the quality information of a signal, the protocols provided for the transmission of commands to switchgear. With these first systems, attention was focused on electromagnetic compatibility and a shift to optical fibers was initiated. These first attempts resulted in standardization by IEC Technical Committee 57. Its working group 3 produced the standards IEC 60870-5-101, 102, and 103 – a series of protocols for different tasks within a substation. However, the IEC's work was behind that of the Anglo-American region, which adopted the lower layers from IEC 60870-5 and defined the upper layers itself. The resulting protocol was called DNP3. The two protocols were used in remote control and locally in the substation. During the 1990s, Ethernet networks finally became commercially viable, and the industry recognized the potential of this technology and prepared for its deployment. The IEC 60870 and DNP3 application protocols were also transferred to the corresponding Ethernet transport protocols and TCP/IP-based variants for IEC 60870 and DNP3 were available by the end of the 1990s. The IEC protocol was given the suffix -104.

Both the IEC and DNP3 standards focused purely on defining communication protocols and addressed signals numerically. This made it possible to assign the data type (command, message, with/without timestamp) via addressing, but there was no way of recognizing the actual purpose of the signal in the context of the application. Operators and organizations therefore started to develop individual addressing schemes to assign a meaning to the addressing numbers, of which there were up to five. This approach highlights the need for self-explanatory addresses, something that is also of importance in the context of IEC 61850.

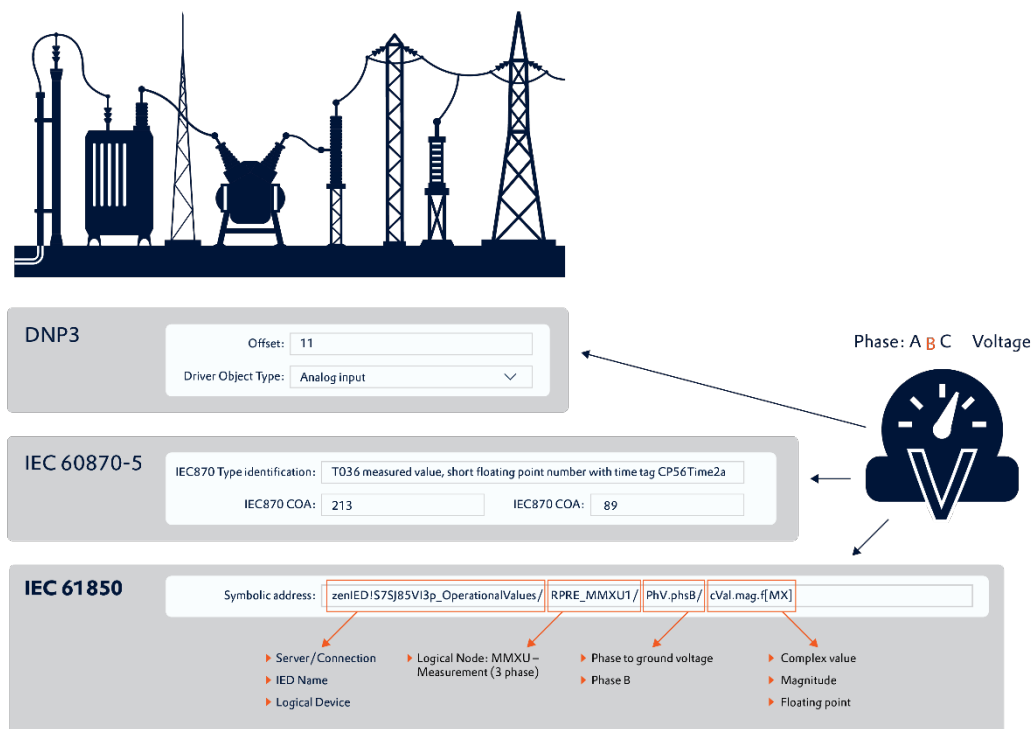


Figure: Numerical addressing as a mental exercise in conventional protocol standards such as IEC 60870 or DNP3. IEC 61850 significantly improves the ability to manage this thanks to self-explanatory designations.

Both IEC 60870 and DNP3 were able to transmit their information spontaneously, without it being requested. The value was only sent to the receiver automatically (together with the timestamp) if there was a change to the value at the signal source. This reduced the data traffic, taking strain off the receiver as it was not busy with cyclical demand (polling). In addition, in the event of a line

interruption, the data would not be lost, but instead buffered locally in the devices. IEC 60870 and DNP3 contained no provision for cyclical polling except in the case of a general poll (integrity poll).

Both machine-to-machine (M2M) communication standards, IEC 60870 and DNP3, provided general data objects and services to transmit signals and values using a digital protocol in soft real time. Time-critical signal transmission – used for rapid notification of a protection trip, for example – was not provided for in this case. This still had to be done either via direct, rigid wiring or using proprietary communication solutions from protection device manufacturers.

The new IEC 61850 standard was intended to provide the basis for integrating substation equipment and protection devices, using an open-vendor approach. Based on a well-defined, generally accepted design language and a comprehensive function and data model, the goal was to enable the free design of the best possible set of functions and signal connections for each specific application. It would then also be possible to transfer the solution, created in this way, to the appropriate hardware and device architecture. Using dedicated protocols and services, systems would be able to interact with each other at both control room level and at real-time, critical-process level.

This new approach would require considerable willingness to change on the part of application engineers. Up until this point, they were used to placing what were essentially pre-assembled protection devices next to each other and connecting them according to the application at hand or parameterizing and testing them one after the other. Now, they would have to create a detailed plan of the PAC (protection, automation, and control) functionality for the equipment as a whole, so that they could then apply it to the device infrastructure (using a top-down approach) and systematically validate the PAC functions it contained. At the same time, manufacturers were also required to adapt their solutions to provide standard-compliant interoperability at the communication protocol level and provide compliant interfaces for configuring their systems.

The vision and concepts behind IEC 61850 would eventually prove to be an acceptable way forward and became a global success story from the 2000s onward.

2.2. Key IEC 61850 concepts at a glance

For the automation of electrical networks – in substations, for example – IEC 61850 first provides a comprehensive data model specification that enables detailed mapping of every characteristic value, every function, and interface parameters for operation or monitoring. Components, such as circuit breakers or differential protection, can then be clearly described using a corresponding data model. Thanks to standardized structures, these functional units — or “logical nodes” as they are also called — can be distributed to the relevant devices and put into operation there. In this way, even extensive facilities for controlling, protecting, and monitoring network components can be designed and managed in a modular way. The open format of the data models allows flexible interaction with engineering tools for the purpose of creating, reading, or editing configurations.

An essential component of the technology is, of course, the communication between the individual systems and functions of a PAC solution. Immediate actions/reactions are required in the area near the process — that is, wherever sensors and actuators must be directly connected to the associated control units or protection devices. For example, if a protection device signals a ground fault, a control device must instruct the circuit breaker there to immediately disconnect the affected connection. When faced with these situations, conventional systems prior to this operated in a way that was rigidly predetermined by electrical wiring. Although this approach works perfectly when properly installed and tested, the installation itself — involving dozens of kilometers of copper cable in the case of medium-sized air-insulated substations — and any subsequent adjustments would incur significant cost. By its very nature, this rigid arrangement considerably inhibits the ability to optimize and maintain an installation.

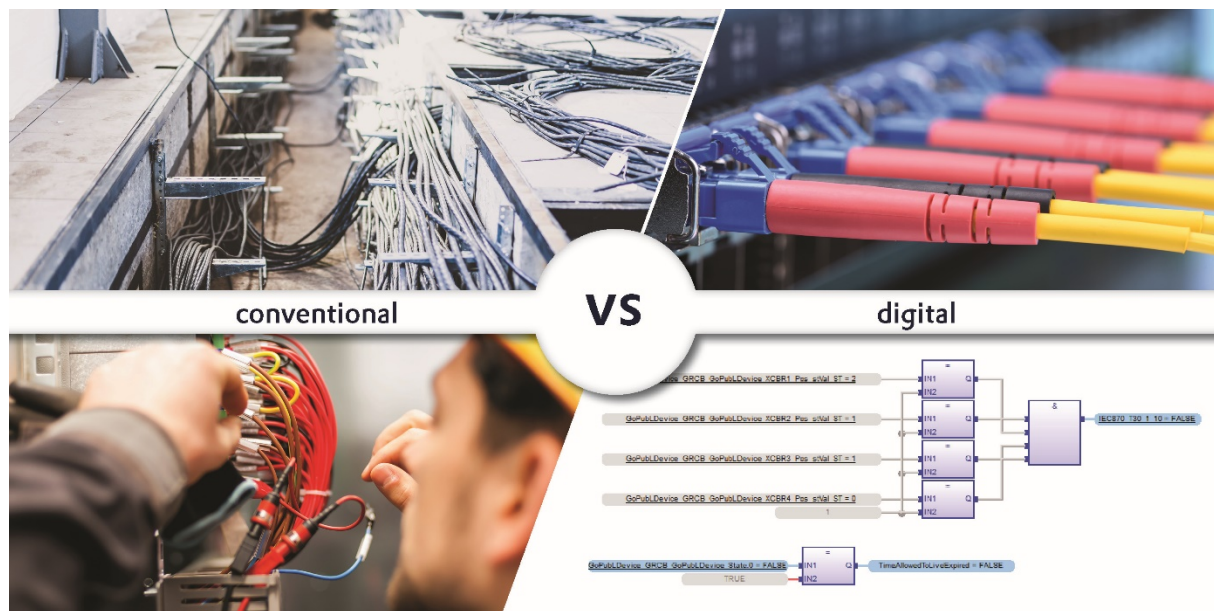


Figure: Complex cabling through the equipment is replaced by network or fiber-optic cables. Rigid wiring for signals running to protection devices is replaced by flexible, configuration-based signal transmission.

End-to-end digital networking as the key to highly flexible PAC systems

Digital substations use an IEC 61850 type of communication known as GOOSE (Generic Object Oriented Substation Events). Selected signals are sent and received within a common Ethernet network at a high temporal resolution. The protection device referred to earlier thus becomes a GOOSE publisher and sends out the trip signal to the Ethernet communication network in real time. The control device selectively takes this message — as a GOOSE subscriber — and executes the corresponding reaction. It goes without saying that the desired signal flows can now be achieved with complete flexibility and, above all, without dedicated physical wiring. Using industrial-grade Ethernet network components reduces the initial investment and increases synergy with additional Ethernet-based applications. Special monitoring measures ensure a high degree of robustness, and thick bundles of copper lines are replaced with a simple Ethernet or fiber-optic cable over which all connected components can reliably exchange signals.

While GOOSE is aimed more at the fast and spontaneous transmission of discrete events, such as protection tripping, another protocol variant takes care of the real-time transmission of measured

values. What is known as the Sampled Values protocol — described in Part 9 of the IEC 61850 standard — enables the transmission of measured values in the form of a continuous data stream in real time. This requires a sampling rate in the range of 4,000 to 19,600 samples per second. As a result, analog measured values, which were previously transported to specific protection or control devices via a fixed measuring line and a corresponding transducer, can now be transmitted via a digital real-time bus. Merging units, in other words devices that can translate a binary or analog measured value into sampled values, publish the corresponding data stream to the network. This stream can therefore be read out by any connected control or protection devices. The fast time sampling of process values using sampled values provides the receiver with a quasi-analog measurement that can be used to deliver electrical protection, automation, or control functions. This form of digitalized networking offers huge advantages in terms of flexibility for the transmission of measured values, since any required value can be made available to any number of receivers simply by configuring the software appropriately.

Connecting PAC devices at process level to higher-level software systems such as HMI/SCADA, RTUs, communication gateways, or service and diagnostic tools also requires a suitable communication method — albeit with lower demands on the real-time characteristics — so that specific process data and status values, configurations, or commands can be retrieved or addressed. For this purpose, IEC 61850 offers a type of communication known as MMS (Machine Messaging Specification, ISO 9506). Corresponding communication services are provided based on the MMS standard. This means that elements of the integrated IEC 61850 data model, such as data from switches, protective functions, or the various data points of the devices involved, can be specifically selected, and linked in the application in question. For this purpose, IEC 61850 MMS enables both the spontaneous communication of values (known in this case as reports) based on adjustable transmission events (referred to as triggers), and the continuous, cyclical polling of data points. The options for combining data points and their individual transmission format (spontaneous or cyclical) are flexible, making it possible to select the best possible combination for any given set of requirements.

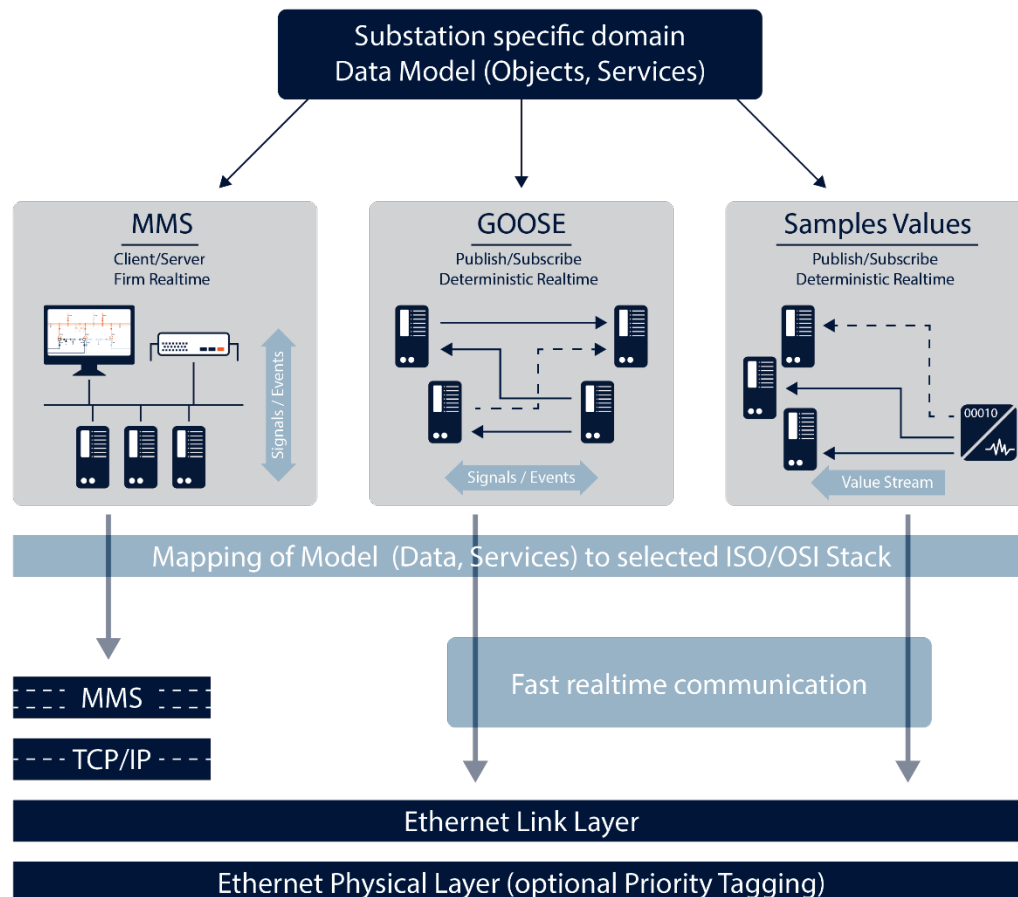


Figure: IEC 61850 communication protocols at a glance¹. These can be used to digitally network the equipment as a whole, both for time-critical signals and protective functions and for data exchange with higher-level systems such as HMIs or RTUs.

2.3. A systematic path to creation for complex equipment

IEC 61850 has provided specifications for more than just communication protocols, however. Conventional protocols like IEC 60870, DNP3, and MODBUS do not offer the option to name signals in a self-explanatory way. IEC 61850 is different, as the standard specifies detailed and readable naming of objects and attributes. This makes it possible to determine the purpose of a signal using

¹ Created on the basis of **Brand, K.P. and Janssen, M. (2005)** The specification of IEC 61850 based substation automation systems. Paper presented at DistribuTech 2005, San Diego, January 25–27, 2005, 8 p.

the address string alone. In this way, the data model of the equipment can be defined conclusively and is both machine-interpretable and easily comprehended by experienced application engineers. The IEC 61850 data model can be used in a variety of ways: it can describe all functions of a device (in an IED capabilities description or ICD); it can describe the scope of functions and signals used (as a configured IED description or CID); or it can collate all devices of the equipment and describe a holistic data model (in a substation configuration description or SCD). All of these possibilities and the structure of the different data models — ultimately stored in XML files — are standardized in Part 6 of IEC 61850.

The configuration process indicates that the preferred approach is to work from the system perspective (a top-down approach), but it can also be carried out from the device perspective (bottom-up approach). In the top-down approach, the equipment is initially described at a higher level, independently of the device. The device descriptions are then created step by step. The significant advantage of this is that there is always a complete overview of the equipment as a whole and that the equipment specification can be reused for other devices if required. With the bottom-up approach, on the other hand, it is often difficult to maintain a consistent overall view because the implementation of application components is usually distributed across several engineering tools. End-to-end documentation can be difficult to achieve as a result. In addition, different levels of compliance or different engineering processes and usability standards among different manufacturers can create unnecessary complexity. With the bottom-up approach, making configuration changes is often a complicated and, therefore, error-prone process because of existing dependencies between systems.

Another major advantage of the top-down approach is the ability to derive HMI-related information. Information for creating the single line diagram can be taken from certain sections of the model. Under ideal circumstances, this can reduce substation HMI engineering to a fraction of the time required when compared with purely manual creation.

2.4. A prime example of digitalization: virtual isolation and testing

Reliable methods for testing equipment and protective functions are a must-have. The activities involved in this must be possible without restriction, not only during initial commissioning, but also during plant operation — that is, while the substation is live. In conventional plants, tests for

protective functions or devices, for example, are comparatively complex because wiring has to be temporarily altered or device settings varied in order to isolate the test object in question. Digitalized equipment with IEC 61850, on the other hand, offers flexible options for targeted verification of maintenance, device replacement, or expansions, even during operation — without the need to change the physical configuration of the equipment.

An important feature of IEC 61850 in this respect is that tests can be organized primarily by functions (including protective functions) rather than by devices. An example of this is a case in which functions (logical nodes) that are distributed over several devices are involved in the complete chain of action of a busbar protective function, from monitoring, detection, and signaling all the way through to the tripping of the corresponding breakers. It is, therefore, essential that this chain of action is tested as a network. Separate testing of individual sub-functions on the physical devices on which they are executed would be costly and far from completely reliable.

First, a “blocked” operating mode can be used for individual IEC 61850 objects (logical nodes) to ensure that no test output signals are propagated during test processes. This prevents any impact on downstream functions or the underlying operation. Furthermore, individual messages, such as a GOOSE telegram regarding a protection trip, can be provided with a test flag by the sender. Only logical nodes for which a test operating mode has been activated evaluate this message. This means that, while all the devices are still on the same network and operational signals and values are exchanged between the logical nodes, individual (logical) functions can be virtually separated. Additionally, IEC 61850 test devices can be connected to the Ethernet network to inject test signals and log the resulting activity in the network. In this way, extensive tests can be performed without affecting operation and without the need to specifically change wiring configurations or device settings.

The simplified figure below illustrates the options for the virtual isolation of devices or their partial functions (logical nodes). Breaker failure protection is implemented by combining several functions that are placed on separate IEDs². By using the test mode, selected logical nodes can now be segregated to perform a functional test, this example shows a “PTOC” element (“AC time over

² **Apostolov, A. (2017)** Efficient maintenance testing in digital substations based on IEC 61850 edition 2. Prot Control Mod Power Syst 2, 37. <https://doi.org/10.1186/s41601-017-0054-0>

current protection"). This can monitor a measured current value and signal an excessively high value using a predefined characteristic. A test system connected to the network can now generate corresponding measured values on a test basis and log the reaction of the logical node. The operational function of the logical node can be operated continuously regardless of the test procedure, provided that the IED in question supports this. As a result, the integrity of the entire protection device can be continuously assured.

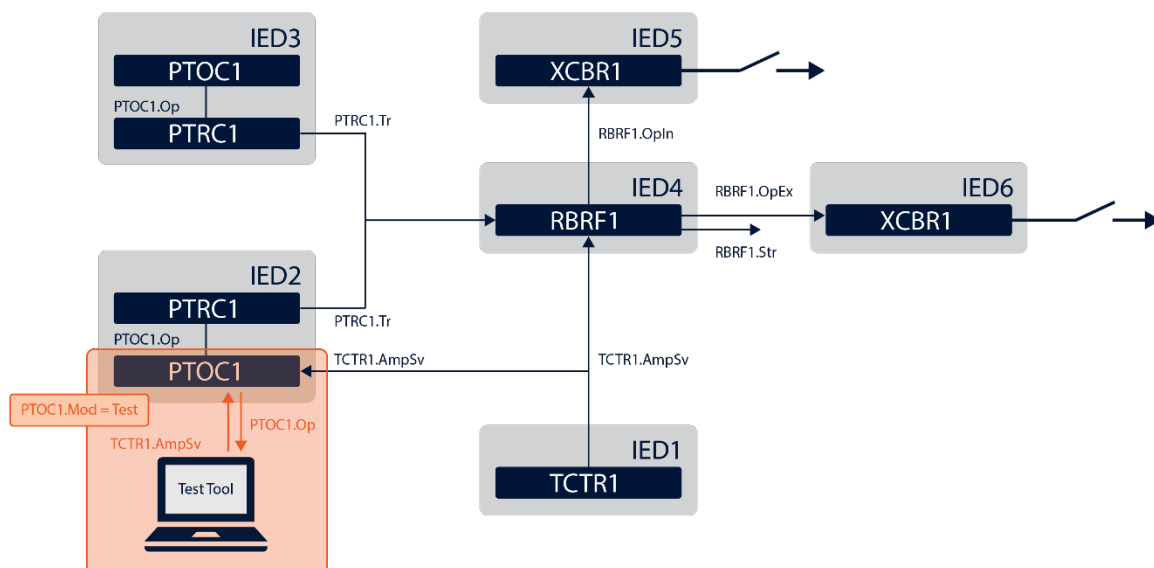


Figure: Integrated methods for virtual isolation and testing make it possible to execute in-process tests or virtual commissioning – preventing the need for time-consuming wiring changes or adjustments to protection parameters on a test basis.

Another IEC 61850 technique allows simulation values for GOOSE messages or sampled values (time series data) to be incorporated into the architecture. In this process, devices are configured to accept simulated values with appropriate labeling from the network in addition to regular messages. As soon as simulated values are available individually or as a data stream, they are given priority over the regular process value in question. In this way, simulated values can be specifically introduced into the network — by an IEC 61850 test device, for example — to verify the correct behavior of the corresponding functions.

Despite their significant benefits during commissioning and maintenance, many technicians are often hesitant to make use of virtual methods in practice. What was previously prepared by laying physical cabling or moving physical wire bridges can now be achieved by software configuration alone — and conventional methods such as visual inspection are being replaced. Considering this, skills in using new software tools and the relevant IEC 61850 technology need to be acquired. In most cases, the teams working in this context will see considerable changes to their everyday activities as a result, which means that they will need encouragement and support that addresses the specific issues involved.

2.5. Next-generation substations: what really matters?

IEC 61850 provides a comprehensive framework for digitalizing substations and switchyards. Significant cost benefits can be gained from using guidance on systematic equipment design and options for modular development of tool-supported testing and commissioning.

Consistently using digital communication technologies significantly increases flexibility, opening more options for creating the best possible design as well as for later expansion of protection and automation equipment. Functions are no longer provided by structural measures or physical interventions, but by virtual interconnection using modern software configuration techniques. This not only significantly reduces the number of changes required, but also enables experts at remote locations to perform changes. Furthermore, making equipment suitable for software-defined functions paves the way for adaptive solutions that can adjust dynamically and, if necessary, even autonomously to changing environmental conditions.

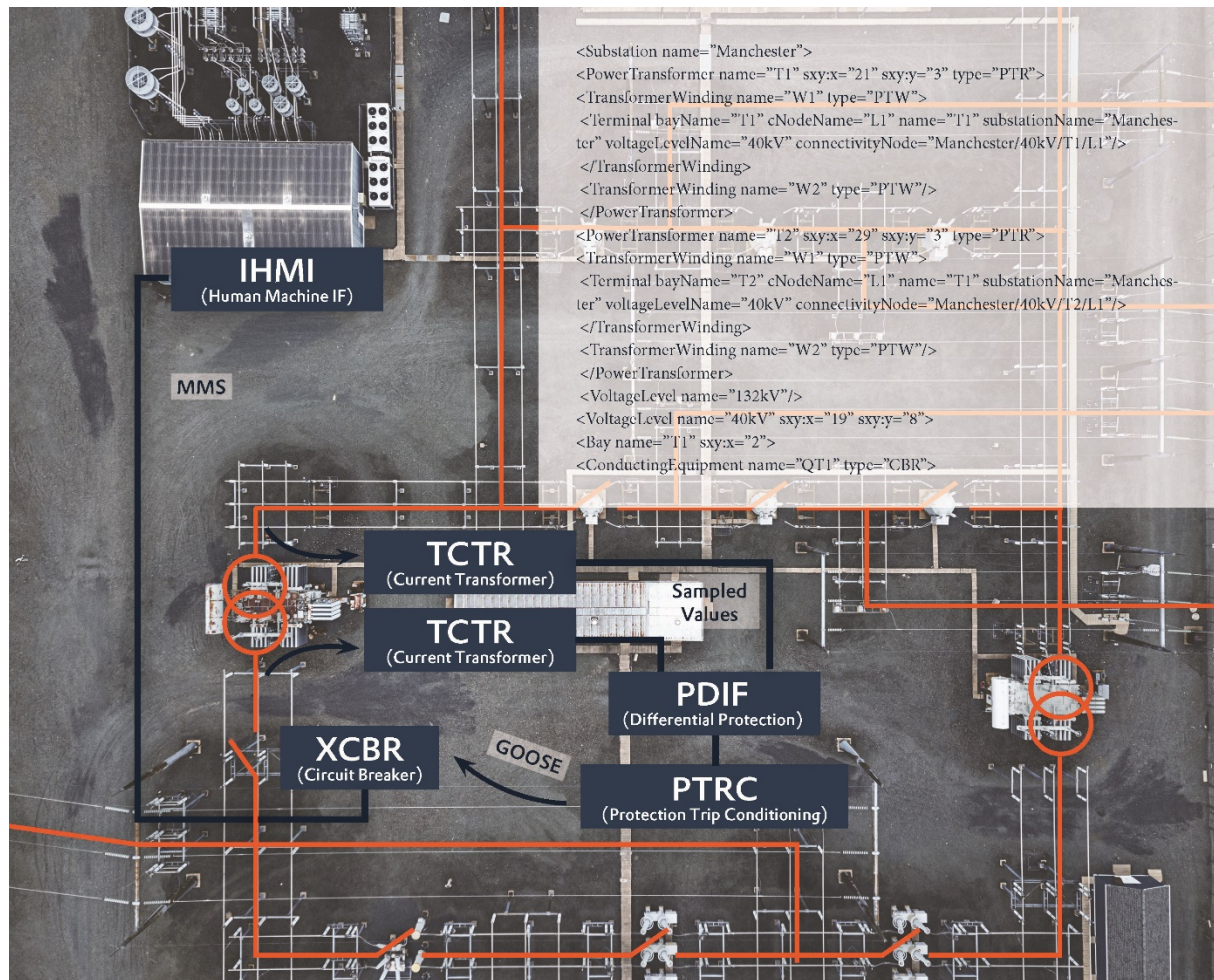


Figure: Virtual equipment model in IEC 61850 as the basis for software-guided adjustments, leading to adaptive functions.

Standardization within the framework of IEC 61850 provides a uniform specification for systems at all levels. This means that products from different manufacturers become compatible and can interact with each other. In turn, this allows companies to draw directly on the IEC 61850 expertise existing within them. The individual solution can therefore be assembled simply and cost-effectively using the appropriate components from the supplier landscape. This can provide cost benefits even at the level of individual items of equipment, viewed over their entire lifecycle. When implementing large-scale platform concepts — involving digital equipment for substation fleets, for example — the advantages of standardization, technical flexibility, experience, and component procurement without tie-in to manufacturers can be multiplied.

2.6. The huge potential of equipment data

The introduction of IEC 61850 has created the potential to collect operating data from equipment and use this for specific purposes, opening huge strategic potential as a result. IEC 61850 can form the foundation for long-term optimization of supply stability and power quality. Advanced analyses can be performed thanks to the high component-related resolution, reliable standardization, and descriptions of the available data. Digital twins can also be created to assess operating conditions in detail or to assess or simulate operating scenarios. The behavior of individual equipment components, such as a circuit breaker type or a transformer, can be recorded over long periods of time and over changing operating and environmental conditions. The resulting stock of data can be examined from specific perspectives to draw conclusions about optimized operation, the ideal maintenance strategy, or impending failures.

Newer IEC 61850 concepts enable distributed equipment to be merged so that operational management can be coordinated more effectively. Techniques known as “routable GOOSE” or “routable Sampled Values”, for example, can overcome existing equipment boundaries. This creates a continuous medium for exchanging process signals and process values from distributed equipment with stable real-time characteristics. In an age where we are seeing the energy environment become increasingly dynamic thanks to a growing share of renewable energies, this represents a further strategic advantage.

2.7. Putting all your eggs in one basket? The reliable route to IEC 61850

Introducing digital substation solutions based on IEC 61850 delivers huge potential for improving efficiency throughout the entire lifecycle of the equipment. As with any technical innovation, the introduction of IEC 61850 requires a high level of commitment to systematic preparation and implementation. Clearly defining goals for the medium and long term, establishing teams with the appropriate expertise, and laying the right organizational foundations are all essential components in creating a successful digitalization initiative involving IEC 61850.

Typically, IEC 61850 solutions are closely examined in laboratory setups or in pilot plants to develop architectures and processes and to gain insights into how components from different manufacturers

interact. For obvious reasons, current equipment already in use in the energy environment cannot usually be equipped with new technology in a single pass. Consequently, IEC 61850 systems are often implemented during partial renovations and successively expanded over time. The systems involved must therefore be able to operate with other devices or standards, such as DNP3, IEC 60870, or MODBUS, in addition to providing full coverage for the applicable IEC 61850 functions. This is an essential step in establishing a company's ability to gradually advance equipment digitalization, while continuing to operate established systems reliably until they are finally replaced.



The [zenon software platform](#) was developed as a manufacturer-independent system in order to provide a basis for scalable energy solutions based on IEC 61850. New equipment with IEC 61850 implemented end to end can be operated using zenon in the same way as hybrid systems, with various existing components considered. For energy companies, zenon creates important scope for constant, sustainable development within the framework of a digitalization agenda with manageable investment. This means that there is no need for companies to go all in when it comes to either the extent of the investment or the choice of protection component manufacturer.

2.8. Successfully implementing IEC 61850 projects with zenon

PAC solutions with certain properties must be chosen to achieve sustainable investment and innovation. First, it must be possible to deploy systems in the required expansion stages. Depending on the technical scope or available budget, digitalization initiatives can be comprehensive or may need to be implemented in smaller stages. The systems used must, therefore, support efficient implementation equally on every scale. In most cases, it can be assumed that existing systems will still play a role in new projects. They may be involved in existing protection technology or systems at network control technology level. In addition, data from existing systems can also be used to inform the deployment and management of equipment. These existing systems must be integrated effectively to achieve reliable implementation as quickly as possible. In the end, a stable overall system must be able to guarantee equipment operation without interruption and compensate for any component failures, as required.

When it comes to digitalizing substations and their subcomponents, the zenon software platform can play a unique role thanks to its features. zenon offers almost every option for connecting protection technology devices and systems at station level and network control level, regardless of the device type or manufacturer. In addition to standards such as DNP3, MODBUS, and IEC 60870, which are each available as master and outstation or master and slave, IEC 61850 is also comprehensively implemented in zenon and is easy to apply. As an HMI or as a communication gateway, zenon uses MMS communication to visualize process and control data or, if necessary, forward this data to higher-level network control rooms. Completely pre-built control models handle secure command processing and can be easily configured for any security requirement. Every event and status within the equipment is accurately captured and recorded. The ability to combine and forward data and commands via various protocols is also part of zenon's standard repertoire. The available drivers for IEC 61850 GOOSE (publisher/subscriber) and for routable Sampled Values (IEC 61850-90-5 client) allow direct interaction with the protection technology at IEC 61850 process bus level. In addition to communication process monitoring, this means that it is possible to execute advanced functions such as temporary device substitution (GOOSE substitution), complex interlocks, load balancing, and special automation functions. Thanks to the end-to-end design, the functional scope of IEC 61850 can be fully exploited — and zenon's simple scalability concept plays a significant role in protecting the company's investment. From local PAC solutions, substation HMIs, and gateways to network control room equipment, companies benefit from a complete solution with

end-to-end networking. zenon users, in turn, can take advantage of the comprehensive wealth of functions from the IEC 61850 standard in the form of sophisticated templates and configurable elements. This means that applications can be configured, tested, and put into operation quickly and easily.



Using zenon, established security concepts, such as central RBAC (role-based access control), segmentation into security zones, and monitoring of network activity using industry-standard firewalls or IDS (intrusion detection systems), central logging of system events (Syslog, SNMP) or TLS protocol encryption, and authentication according to IEC 62351 can be applied flexibly. zenon creates the very best design options for getting started and ensuring engineering productivity so that any investment that is made in IEC 61850 technology reveals visible, tangible progress in no time at all.

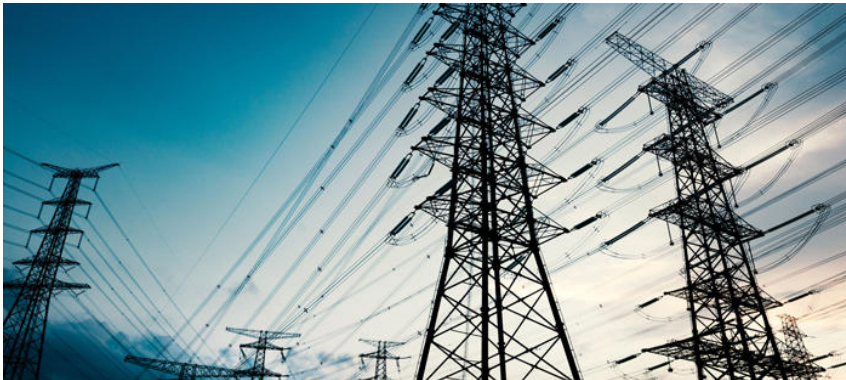
zenon is a comprehensive solution platform for IEC 61850 projects of any scale. It enables energy companies to develop their processes and equipment in a secure and sustainable way as part of a digitalization agenda.

2.9. Conclusion

IEC 61850 provides an impressive, comprehensive standard for transferring essential elements when advancing digitalization in the world of energy. Standardization based on IEC 61850 helps companies to make their equipment more flexible and harness significant synergy effects in project design, implementation, and maintenance. In the process, they can create a technology platform that allows for new usage models and considers the increasingly dynamic nature of the industry, as well as its cost pressures. An appropriate strategy is needed to introduce IEC 61850, starting with the formulation of business goals and the development of the required expertise, and extending all the way through to rollout. zenon promotes companies' freedom to select components and create flexible architecture designs for their PAC solutions and offers a unique set of functions and properties for implementing IEC 61850 projects on any scale.

3. Case Studies

3.1. 400/150 kV zenon SAS for Greek transmission operator (IPTOL)



Independent power transmission operator IPTO SA needed to build an air-insulated 400/150 kV substation in Megalopolis, Greece, and to modernize some of its older high-voltage substations. Using the zenon software platform, IPTO's implementation partner PROTASIS was able to bring these projects to fruition ahead of schedule.

[See full Success Story](#)

3.2. 30 x 110 kV substation HMI for EVN Hanoi in Vietnam



Local COPA-DATA distributor PETROLEC has been instrumental in helping EVN Hanoi, the board within Vietnam's national electricity operator that serves the Hanoi region, to

implement a new control system based on zenon software for more than 30 of its 110 kV substations.

[See full Success Story](#)

3.3. HV substation HMIs for Powerlink in Australia



Queensland's high-voltage electricity transmission network provider chose zenon to carry out a major upgrade to its HMI. COPA-DATA's commitment to "setting parameters instead of programming" enabled a cost-effective and highly functional solution without the need for expensive recommissioning work.

[See full Success Story](#)

COPA-DATA is an independent software manufacturer that specializes in digitalization for the manufacturing industry and energy sector. Its zenon® software platform enables users worldwide to automate, manage, monitor, integrate and optimize machines, equipment, buildings and power grids. COPA-DATA combines decades of experience in automation with the potential of digital transformation. In this way, the company supports its customers to achieve their objectives more easily, faster and more efficiently.

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