GE
Grid Solutions

WHY GO DIGITAL?

Evolving from Conventional to Intelligent Digital Substations

White Paper by:

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imagination at work

Substations are nodes or junctions in the electrical network, essential for linking generation, transmission and distribution assets with consumers. As the electrical network has evolved to meet the changing demands of consumers, substations have kept pace, bringing together improved technologies, engineering and operational strategies to improve the availability of the electrical network. This evolution has given rise to the intelligent digital substation.

Drivers for the Digital Substation

Substations, along with their stakeholders outlook, have undergone a gradual transformation over the past decade. The substation is regarded as a critical asset that needs to be managed in line with the organization's mission, which is a combination of customer, financial and legal deliverables.

Safety in the substation is rightly at the forefront of all deliverables. The installation, operation and maintenance of substations today involves not just the asset owner, but many subcontractors. It is necessary to provide a safe working environment for all of them, with minimal risks and limited requirement for supervision.

Asset performance needs closer monitoring, as it impacts all key deliverables of the organization – financial, contractual and regulatory. Performance parameters in both primary and secondary systems, need to be captured and presented in a 'smart' manner, considering the limited personnel resources available for asset management. Capturing data in detail and presenting it in an open, interoperable framework is among the drivers for IEC 61850 Edition 2 compliant products.

System-wide disturbances (such as blackouts) are unwelcome and thankfully rare events in the electrical network. Like every mature industry, the lessons learned with each such occurrence are used to improve the availability and reliability of the network. This calls for improvements in the substation infrastructure such as time synchronization, as well as in the secondary system components and architecture.

What is a Digital Substation?

As most substations today are switching and routing AC power at high/extra high voltage, it is not the primary flow which is digital. A digital substation refers to its secondary systems, including all the protection, control, measurement, condition monitoring, recording and supervisory systems associated with that primary "process".

In general terms, a full digital substation is one in which as much as possible of the data related to the primary process is digitized immediately, at the point where it is measured. Thereafter, the exchange of that data between devices occurs via Ethernet, as opposed to via the many kilometres of copper hardwiring which may exist in a conventional substation. Digital substations imply a solution and architecture in which the substation's functionality is predominantly achieved in software, with less reliance on hardware implementations such as hardwiring.

IEC 61850: The Key Technology Enabler

Modern sensors and other intelligent electronic devices (IEDs) must be connected to communicate within the substation and over the larger grid system. In the past, there were many different protocols for substation IEDs, requiring much effort to make them communicate with each other. Insufficient levels of standardization, fear of degraded reliability and lack of return on investment slowed down the emergence of the fully digital substation. But today, the IEC 61850 standard makes it possible to facilitate interoperability between different equipment and suppliers.

Introduced in 2004, the IEC 61850 standard is now accepted across the world. Its main objective is to ensure interoperability between equipment from various suppliers, as well as the long-term standardization of substation automation systems. IEC 61850 continues to evolve and encompass the needs identified by the industry's user group Utility Communication Architecture (UCA), ensuring that it addresses all substation needs. IEC 61850 is rapidly being enriched as new application areas are continually added, notably IEC 61850-9-3 and technical reports in the IEC 61850-90-x series. The standard permits full digitizing of signals in a substation so that large amounts of data can be managed and communicated for the real-time management of a modern power grid – a smarter grid.

Digital Substation Architecture

Process Level

The process level is the interface between the primary equipment in the substation and the secondary (protection & control) system. In a conventional substation, the interface is hard-wired with copper cabling; currents and voltages are routed to the protection and control panels at accepted secondary signal levels, and status information is sent and received via control cabling.

In the digital equivalent, all data – both analog and binary – is digitized as close to the source as possible, and sent to the IEDs over fiber-optic links. The acquisition, consolidation and processing of data may be managed directly by intelligent primary devices (such as digital instrument transformers, circuit breakers, disconnectors etc.) or by specialized stand-alone devices (such as merging units or switchgear control units) located strategically in the substation. The interface is fully defined by the use of IEC 61850-8-1 for status and trip signals, and IEC 61850-9-2LE (guideline) for analogs. The latter is evolving, with IEC 61869-9 published, and IEC 61869-13 on the way for instrument transformers and associated digital communications.

The process level interface also enhances the condition monitoring capability of the substation automation system; intelligence residing within or close to the primary equipment allows advanced sensors to be installed and interfaced to capture monitoring data. By subscribing as clients to the data flow over an Ethernet process bus, the information from the 'eyes and ears' of the power system is distributed and communicated much more efficiently to the bay level than in conventional hardwired schemes.

The separation of data acquisition from protection and control IEDs means that there must be a way to synchronize sampling. A protection function, for instance, may use current and voltage samples acquired by different field devices, and real-time comparative measurements may be incorrect if the sampling is not synchronized. Time synchronization over the process bus network is generally preferred, using the IEEE 1588 protocol, but there is also the option of synchronization with 1PPS signals. Clock redundancy is easier to implement when using IEEE 1588, as there is no need to duplicate the time distribution network. Satellite clocks available today are capable of receiving GPS as well as GLONASS signals to improve the reliability of the synchronizing signal, using different satellite constellations, especially for critical applications such as feeder differential protection.

The impact of process level change is significant and more visible in the case of air insulated substations, due to the cabling lengths involved. GIS substations are traditionally more compact, but the benefits of the digital substation go much beyond the savings on cabling, as will be seen later.

Bay Level

The bay level includes equipment normally referred to as 'secondary equipment' in the substation – protection relays, bay controllers, measuring and recording IEDs etc. These IEDs no longer have analog inputs, as the data acquisition occurs at the process level. There is limited or no need for binary inputs at the bay level either for the same reason, resulting in very compact devices, typically occupying only half the traditional footprint. The IEDs are responsible for hosting the protection and control algorithms and logic, making trip/no trip decisions, as well as the significant communication capabilities necessary for the lower (process) and upper (station) level Ethernet networks. Naturally there are different user preferences for the network architecture, but redundancy of the communication network is a typical requirement, ensuring the highest availability and dependability. The two IEC 62439 standards available – Parallel Redundancy Protocol (PRP), and High-Availability Seamless Redundancy (HSR) – facilitate interoperability and integration of IEDs from different vendors into the substation network.

The data flow from process level IEDs to the bay level is normally limited to one or two bays, as most protection and control functions are implemented within each bay. Selected data, such as line or bus voltages, are shared across bays for substation-level functions; filtering of the data is accomplished using features available in intelligent Ethernet switches. Data filtering is essential in the design of digital bays, as the process level IEDs generate a multitude of data which, if not restricted to relevant parts of the network, could impact the overall performance of the protection and control system.

Station Level

The digital substation station bus is much more than a traditional SCADA bus, as it permits multiple clients to exchange data, supports peer-to-peer device communication, and links to gateways for inter-substation wide-area communication. The equipment at the station level may comprise substation HMIs, engineering workstations for IED access or local concentration and archiving of power system data, SCADA gateways, proxy server links to remote HMIs, or controllers.

With richer data from sensors and additional processing capability, the station level brings more value to users by applying analytics and advanced modelling, providing diagnostics and the capability for advanced operator intervention. For instance, there may be dedicated workstations for on-line condition monitoring, managing the database history of primary system assets, and providing visualization unparalleled in earlier generation automation systems. The HMI visualization from an advanced transformer monitoring application is shown below in Figure 1, with the possibility of an accompanying 'smart cooling' application at the station level that dynamically manages the transformer cooling system, taking into account the instantaneous load, the internal status and ambient conditions.

Advanced Applications

The digital substation makes it possible to roll out advanced applications in the substation, contributing to a smarter power grid. Some examples are given below, but many other possibilities are on the horizon as the processing capability of the substation system and component IEDs grows in scale.

Situational Awareness

Situational awareness (SA) is a broad-based concept, with application in domains as varied as healthcare and aircraft navigation. In power systems, SA came into focus in the SCADA control rooms, where operators need to continuously make sense of data to ensure system stability. In substations, SA includes monitoring and understanding the state and environment in real time, and the ability to precisely anticipate future problems in order to take proactive corrective action. Digital substations offer local and wide-area situational awareness, allowing dynamic management of power flows, and optimum condition-based management of substation assets. At the station level, the digital substation is able to integrate, process and display - through clear and intuitive dashboards - a large array of monitored parameters, such as:

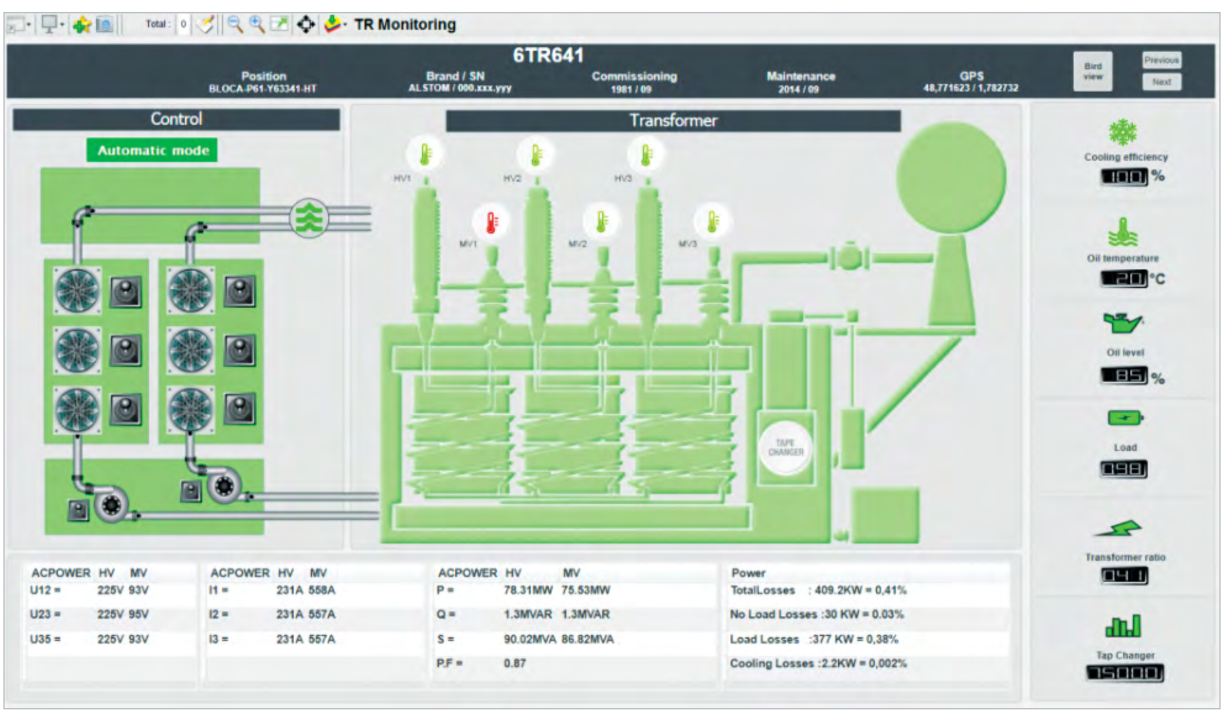


Figure 1: HMI visualization from an advanced transformer monitoring application.

- condition monitoring data for all primary and secondary equipment as well as auxiliary systems in the substation
- environmental and weather conditions
- thermal (infrared) camera imaging
- wide area state (surrounding substations)
- cyber- and physical intrusion

The situational information provided by the digital substation is an invaluable tool that simplifies and optimizes the decision-making of substation operators.

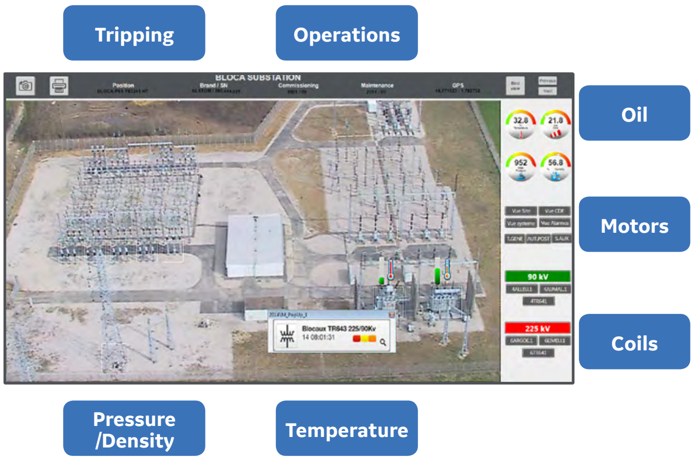


Figure 2: Using intuitive dashboards, the digital substation integrates and processes a large array of monitored parameters to allow local and wide-area situational awareness, allowing dynamic management of power flows, and optimum condition-based management of substation assets.

Wide Area Automation and Communication

A wide-area network interface can be integrated into the grid operator's wide area control systems and defense plans, which allows implementation of fast inter-substation control and protection schemes. The benefits of receiving and responding to the operational data from other substations within the network include a reduction in both the frequency of failures and the reaction time to network events.

Another application enabled by wide area automation is recording and collection by phasor measurement units (PMUs), which can also be concentrated and relayed to the control center and analyzed by online stability solutions to track power system oscillations and anticipate contingencies.

Digital substation sensors and control systems can be configured to work seamlessly with their software platforms for grid operator control rooms, allowing a real-time data exchange at both the substation operational and asset management levels. This substation/control room communication introduces smart grid and micro-grid capabilities to the network, bringing complete synergy between field equipment operations and network management systems.

Networks can be local to the substation or can interconnect several dispersed substations. All substations can be linked to one another and to the grid control room through gateway solutions. Inter-substation or inter-voltage level automation exchanges GOOSE messages for:

- Logic selectivity
- Fault location and service restoration (self-healing)
- Load-shedding and islanding
- Automatic setting of the relays

Routable GOOSE permits cybersecure fast transfer of the digitized analog and binary state data required to implement wide-area schemes.

Benefits of Digital Substation Technology

Increased Reliability and Availability

The extensive self-diagnostic capabilities of digital devices ensure maximum availability of the substation, as well as its full suite of functionalities. Any performance issue with an asset is pinpointed in real time, plus the flexibility in the secondary system architecture allows for redundancies, as well as troubleshooting without the need for an outage in the primary system.

Optimized Operation of Assets

The intelligence within digital substation schemes allows close monitoring of the load ampacity of plant equipment, based on their design ratings. For example, complex models for thermal loading can be configured and monitored in real-time. This dynamic load analysis means that the operator has the tools to push lines, cables, transformers and other grid equipment to operate closer to their limits when necessary.

Improved Safety

Removal of wired cross-site current transformer (CT) circuits reduces the risk of injury due to inadvertent opening of the circuit by personnel. Plus, there is no live 1A/5A cabling coming into the protection panels, providing a safer environment inside the control room, and the optical instrument transformers are oil-free, avoiding any risk of explosion. Finally, advanced self-monitoring of substation assets ensures that they are operating within the prescribed limits.

Standardization and Interoperability

Being IEC 61850 compliant, digital solutions and substations are designed to be interoperable with third-party equipment, with a strong degree of standardization at the interface level of secondary equipment systems. This simplifies many of the tasks associated with extending the substation, and allows for different vendor solutions to be available to the user.

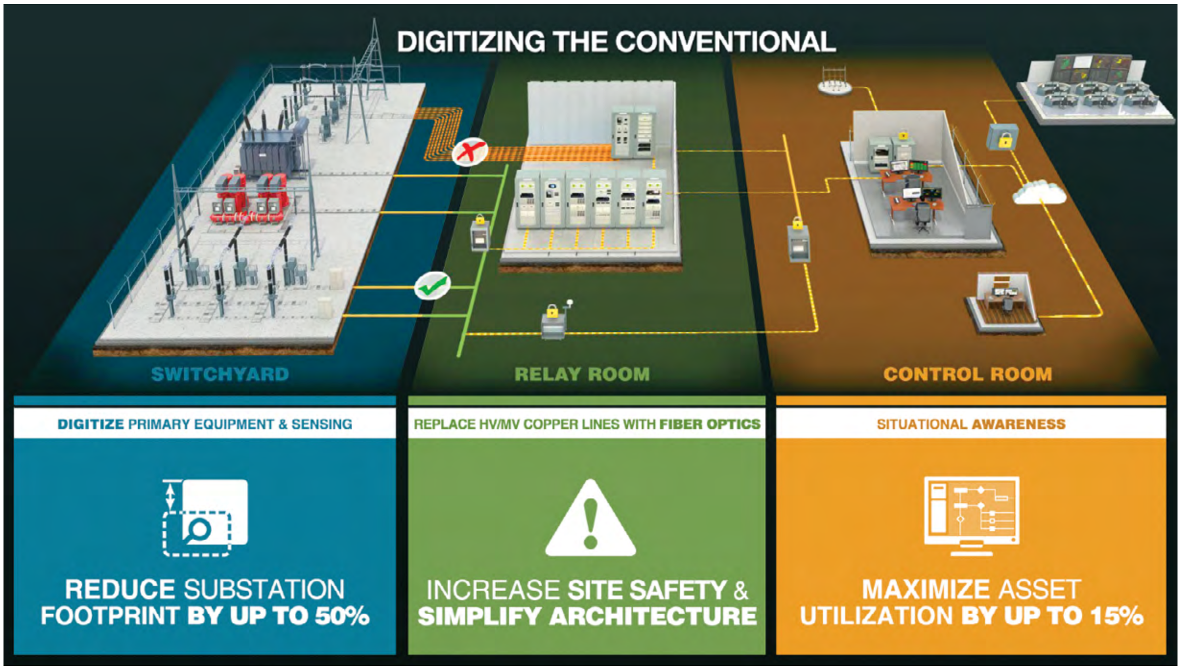
Improved Communication Capabilities

Ethernet facilitates the data exchange between intelligent devices, both intra- and inter-substation. Smart local and wide area control units allow data exchanges between voltage levels within substations, and between substations. This eliminates the need to transmit via a control center, which reduces response times, and enables rapid, real-time applications.

Investment Optimization

The capital cost of investment projects is reduced on many fronts:

- savings on the time needed to engineer and install substations
- reduced real estate needs
- copper cabling is cut by up to 80% through the use of optical fiber, with the associated reduction of many thousands of wiring terminations
- asset optimization tools allow faster targeting of weak areas which need to be reinforced, allowing for reduced operational costs



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Conclusion

Digital substations are a reality now. From petrochemical substations networked by fiber-optic for safer operation, through to utility substations ensuring optimized integration and transit of renewable energy across the grid, the technology is delivering results. Using enhanced visualization tools, the inherent software functions extract the highest performance from assets, within and beyond the substation's boundary. In a connected substation, we understand technical and physical measures are needed to minimize the risks imposed by cyber-security threats. GE continues to work with standards organizations and regulators to ensure we implement standards-based, proven solutions to mitigate these risks.

For each substation project, the capital expenditure is on par with that of conventional solutions, but is able to deliver much, much more. The investment is re-paid rapidly, and many times over as operational expenditure in maintenance is significantly optimized and ultimately reduced. The augmented reality views of the substation and all of its components, supplemented by condition monitoring algorithms digitally "twinning" exactly what the real primary apparatus is doing, instill the confidence to adopt more effective and efficient maintenance policies through actionable intelligence and condition based asset health analytics.

Moreover, the technology is very appealing to our next generation of power engineers, at a critical time when attracting fresh talent is proving to be difficult. What was once the future, is now a reality today, and offers exciting possibilities for our industry well into the future.

With the field data we need available through intuitive dashboards, a safer working environment, and a value proposition that appeals to regulators and investors alike, there's no question that substation digitization unlocks benefits. It's this very digitization that provides the primary building blocks required to integrate assets and operations across a power system.

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