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Entergy Development and Deployment of IEC 61850 Protection and Control Including Process Bus

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SUMMARY

In early 2014, Entergy Transmission began actively exploring the IEC 61850 substation communications and application modeling standard, to learn how this technology could be beneficial for storm and natural disaster resilience. Since then, Entergy has been carrying out IEC 61850 and process bus testing and system integration in collaboration with multiple vendors of protective relays, test sets, and system software products and tools. The Entergy team deployed a pilot trial system including process bus at Joliet 115 kV Substation. Currently, the Entergy engineering team is developing the design specifics for the IEC 61850 P&C system of a green-field distribution substation whose construction will begin in early 2018.

The new design implements the IEC 61850-9-2 LE or IEC 61869-9 sampled values service over process bus, Parallel Redundancy Protocol (PRP) for bumpless failover in the case of Ethernet networking equipment failures; and IEEE 1588 Precision Time Protocol (PTP) to achieve network-based redundant time synchronization of signal sampling. At the same time, Entergy wants to focus on developing a practical utility testing philosophy for this P&C design; and to develop a condition monitoring and failure alarming scheme to reduce time-based maintenance demands and to streamline recommissioning for fast storm recovery.

This paper describes how the Entergy business case for IEC 61850 rests in part on critical benefits of storm resilience and ability for rapid restoration after storm damage, especially with a process bus based design using a small number of water-resistant fibers to implement all of the point connections. The connections are created by standardized and archived configuration files quickly loaded into Protection and Control (P&C) system components.

The paper outlines the principal design features of the evolving Entergy IEC 61850 and process bus implementations.

KEYWORDS

IEC 61850, IEC 61850-9-2 LE, IEC 61869-9, process bus, sampled values, storm hardening, GOOSE, condition monitoring, condition-based maintenance, interoperability testing.

ENTERGY DEVELOPMENT OF IEC 61850-BASED PROTECTION AND CONTROL

In early 2014, Entergy Transmission began actively exploring the IEC 61850 substation communications and application modeling standard, to learn how this technology could be beneficial for storm and natural disaster resilience. Since then, Entergy has been carrying out testing and system integration in collaboration with multiple vendors of protective relays, test sets, and system software products and tools. Entergy is also working with developers and research institutes to assess the interoperability of available sampled-values or process bus components – merging units, and relays or IEDs that can communicate with them. Since starting the evaluation in 2014, Entergy has hosted three system integration trial events or *plugfests*, for which Entergy invited multiple vendors and their engineers to integrate and demonstrate interoperable products at the Entergy laboratory in Kenner, LA. It has taken all three plugfests to demonstrate interoperability of process bus devices from 5 vendors.

After this success, Entergy deployed a pilot trial system at Joliet 115 kV Substation, located conveniently for hands-on data and experience gathering. This non-tripping pilot monitors one feeder circuit in parallel with existing conventional protection. The fault responses of the IEC 61850 trial system and the legacy protection are recorded and compared for performance evaluation.

In 2017, Entergy purchased more laboratory development testing equipment, including a real time digital simulator and precision time protocol testing tools, while working closely with vendors to further streamline the IEC 61850 protection design. Entergy seeks to reduce the footprint the substation by configuring a single relay to protect 3 feeders. The new design implements Parallel Redundancy Protocol (PRP) per IEC 62439-3 for bumpless failover in the case of Ethernet networking equipment failures; and IEEE 1588 Precision Time Protocol (PTP) to achieve network-based redundant time synchronization of signal sampling and time-marking or time-tagging functions. At the same time, Entergy wants to focus on developing a practical utility testing philosophy for this P&C design; and to develop a condition monitoring and failure alarming scheme to reduce time-based maintenance demands.

Currently, the Entergy IEC 61850 engineering team is developing the design specifics for the Culicchia green-field distribution substation whose construction will begin in early 2018. This substation will consist of two transformer bays, two main breakers, and six feeder breakers plus bus tie breaker. Entergy believes that the implementation of IEC 61850 P&C, including sampled values service using the IEC 61869-9 merging unit (MU) standard based on IEC 61850-9-2, will result in data communications based interconnections throughout the substation that are much leaner, better organized, and better controlled than conventional wired solutions. Compared to copper-cable-based design, the new fiber-optic-based process bus technology promises better flood resistance, superior safety performance, and much faster storm recovery for the protection, control and automation infrastructure in an affected substation. The fiber-optic solution will thus reduce the construction and maintenance cost while optimizing the design and configuration process.

OVERVIEW OF NORTH AMERICAN EXPERIENCE WITH IEC 61850

IEC 61850 began its life in 1995 as a broad group of product manufacturers and users sought to advance beyond proprietary communications protocols to a single, international, interoperable, and open communications system for substation protection and control (P&C) applications. Since then, it has expanded beyond substations to include operational communications for the entire utility enterprise. New parts are continuously being published as IEC 61850 reaches across the transmission grid to generation sources, and out onto today's DG-equipped distribution feeders. Going forward, IEC 61850 will grow to support the operation of rapidly-evolving grids and utility businesses.

As Entergy is discovering, IEC 61850 brings major changes in how the utility designs installations and conducts business. Experience in North America has already shown how, without planning the organizational transformation, the benefits won't be achieved.

Internationally, manufacturers with IEC 61850 product lines have already fielded multiple generations and thousands of installations of substation P&C systems based on two editions of IEC 61850. Many of these are in turn-key substation projects where a single manufacturer has taken responsibility for design, integration, and commissioning.

Utilities in North America have taken a more deliberate approach. Most are organized to design, integrate, and maintain their own standard designs. Years ago, they observed problematic IEC 61850

trials in which imperfect first-generation products showed interoperability challenges, and were not well suited to the old methods of P&C design and support. At that time, IEC 61850 had its own problems – ineffective functioning of integration and configuration tools; limitations of the standard Edition 1 technical features, varying vendor implementations of standard-defined application models (the logical nodes and their process interfaces), and unspecified implementation details of included functions that prevented interoperation of products from different vendors. These issues had to be overcome – they occurred for reasons the developers and vendors understand and have been fixing. For newer process bus and merging unit systems, Entergy's participating vendors experienced interoperability problems during the first plugfest in 2015; they have revised their designs through plugfests 2 and 3 to achieve an interoperable configuration suitable for deployment in the Joliet Substation field installation.

Now senior management at an increasing number of utilities want their engineering organizations and team members to move forward, solving problems and work to achieve the economic benefits that IEC 61850 offers. As old designs become more costly to build or maintain, and as the industry faces growing cost and revenue pressure, business leaders press for potential savings. At the same time, IEC 61850 sees more interest and conditional acceptance at the engineering and first line management level as new generations of team members learn about the Ethernet-based technology.

Lab and field experimentation with IEC 61850 is critical at the time of introduction and first development of standard designs. However, the electric utility industry ultimately cannot support multiple design paths that are on fundamentally separate tracks and require duplicated resources. Users are no longer facing only competing vendor-specific operational protocols; the issue now is cost and difficulty of maintaining traditional and Ethernet network-based P&C in the same organization. It's not only that IEC 61850 can be less expensive, but that legacy utility P&C will become too expensive to sustain, on its own or in parallel with the new designs.

Figure 1 – Elevated control house resists flooding

Figure 2 – Joliet Sub, site of storm flooding, now process bus test site.

ENTERGY BUSINESS CASE FOR IEC 61850

Historically, hurricanes and superstorms have battered Entergy service territory. August 2015 marked the 10-year anniversary of Hurricane Katrina, a catastrophe for New Orleans residents and companies that damaged 260 substations and 1,550 feeders. Storm hardening and grid resiliency have never been more important for Entergy, which has received recognition and multiple awards for storm-recovery efforts. Entergy continually seeks new ways to reduce the recovery time of affected facilities. Recently, the utility has begun designing mobile control houses, and taller control houses for certain substations in Louisiana to resist flooding challenges there as shown in Figure 1. Figure 2 shows the switchyard of Joliet substation, flooded in past storms, and now the site of an IEC 61850 process bus test installation.

Protection and control systems based on IEC 61850 station bus and process bus add important new features and benefits to new storm-hardened substation designs:

- The construction savings achieved with the use of a limited number of fiber connections in place of legacy arrays of point-to-point wired interconnections also means far faster and simpler repair and restoration of an already-validated standard design in damaged or flooded substations.
- Fibers are resistant to flooding damage. Fiber terminations are more resistant than wires, and can be made impervious to water with ongoing design attention.
- Entergy has assembled tools and skills for installation of fibers by blowing through special conduits. Blowing fibers in this fashion installs in minutes the functionality of hundreds of wire and cable connections.
- Commissioning is far faster and easier, focusing on validating overall functional operation rather than checking of each connection – as long as the utility has created a strong configuration management and archiving system for its IEC 61850 standard designs and setting files.
- Recommissioning is further accelerated with a P&C design that has fully implemented the self-monitoring potential of microprocessor IEDs interconnected by IEC 61850 communications. In principle, the entire system continuously self-tests the functioning of all of its processing, interconnections, and data flows in the course of normal operation, and alarms for failures and irregularities. It can validate instrument transformer inputs, and some of the binary process I/O. Validation sequences can be reduced to tests of breaker tripping and status indication at only one interface point, with optional load and fault signal injection.
- Risk of human error in reconnecting IEDs and field wiring is mostly eliminated with strong configuration management, and self-monitoring checks of the restored system.

The extent and number of P&C circuits carrying hazardous voltages is vastly reduced, along with the safety risk to restoration personnel working under pressure. CT and VT circuits and trip circuits connect only at one nearby merging unit in the switchyard or breaker cabinet.

Wiring reduction and configuration management

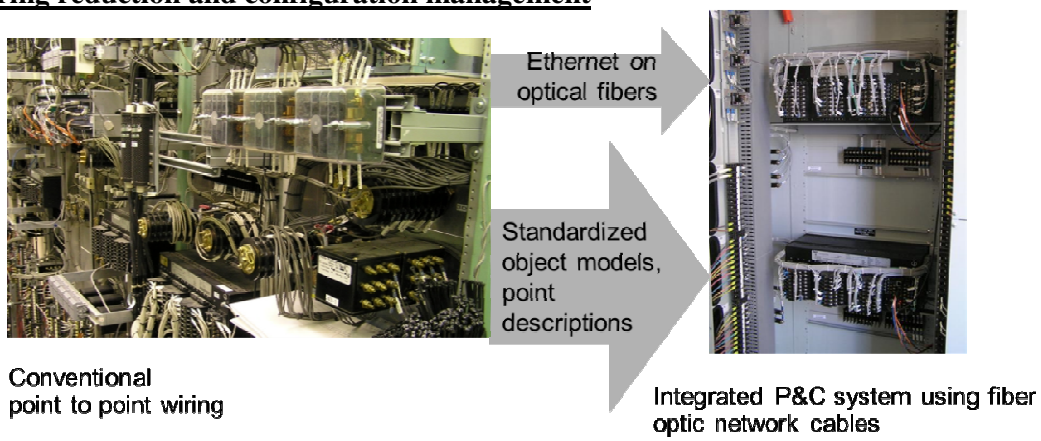

Figure 4 – Wiring reduction with IEC 61850 GOOSE messaging

Several of Entergy's business case bullets above rely on the widely-cited IEC 61850 benefit of elimination of most point-to-point wiring – the visible change is dramatic, as shown in the example of Figure 4. Many vendors present these before-and-after images; process bus installation greatly multiples the effect as it eliminates the switchyard point connections and leads to stark panels with just a few wires and fibers. Most of the total conventional installation time is avoided with a stable standard design. These same savings accrue at the time of any upgrade or restoration, and also at the time of next P&C replacement.

In Figure 4 or in other low-wiring designs, the functional complexity of the wiring did not go away with the wires. In an IEC 61850-based design, all of the functional interconnections that used to be discretely wired are now defined by additional arrays of configuration settings in relays and IEDs. The business case bullets above identify strong configuration management as a key success factor for these new designs. Without rigid control of product versions and setting files, maintenance or repair replacements risk breaking of functions and disrupting operation of the P&C system. Engineering and

maintenance personnel working together must embrace tight configuration or settings management tools to reap the benefits of these new designs and to avoid delays in restoration.

FEATURES OF THE ENTERGY IEC 61850 DESIGN

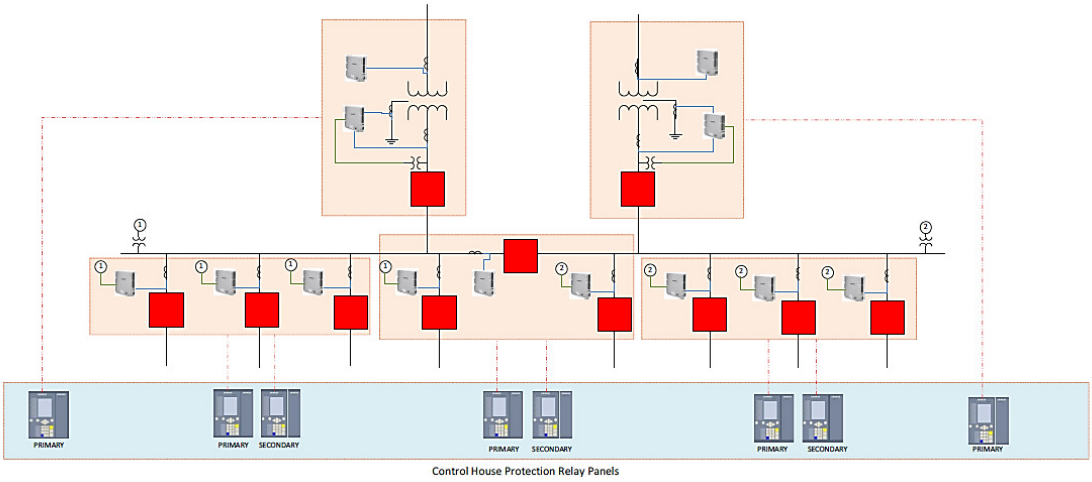

Figure 5 – Full IEC 61850 protection and control for a new distribution substation

Figure 5 shows the configuration of the protection and control design for the planned 2018 green-field project installation. This development anticipates full utilization of IEC 61850 services, including process bus and the merging units (MUs) that interface the process bus to the switchyard signal and control connections. MUs at each feeder breaker location digitize current signals from CTs and connect to status contacts and trip circuits for breakers on bus sections 1 (left) and 2 (right). Bus 1 and 2 voltage measurements also connect to nearby MUs. The bus tie breaker has its own MU. Each transformer is equipped with two merging units to collect all the voltage and current signals. The process bus network connects the MUs to primary and secondary feeder and transformer relays in the control building. The first trial installation will also include conventionally-wired backup relays, to be later deleted from standard designs when Entergy gains more in-service operating experience.

The design features include:

1. GOOSE messaging on the substation LAN and on the process bus – publishes all millisecond-speed control and status signaling among relays and IEDs. GOOSE messages also publish trip or control requests over the process bus network from relays to merging unit interfaces of breakers.
2. Sampled values service – the streaming of voltage, current, and status samples from MUs to control building relays over the process bus network, according to IEC 61850-9-2. In today's laboratory demonstrations and in first field deployments at Joliet and Culicchia substations, the MUs and relay message formats comply with the implementation agreement IEC 61850-9-2 Lite Edition (9-2 LE). Entergy is watching for availability of merging units and relays that comply with the new Merging Unit Standard IEC 61869-9, which starts with IEC 61850-9-2 but imposes rigid requirements on data formats, sampling rates, and MU preprocessing of voltage and current signals as they are digitized. This reduces risk of interoperability issues among compliant products. Entergy participates in CIGRÉ Working Group A3.31 to help with determination of how and when it can migrate from 9-2 LE to IEC 61869-9 products.
3. Parallel Redundancy Protocol (PRP) according to IEC 62439-3 – PRP fiber interconnections between MUs and relays or IEDs comprise a pair of parallel fibers carrying duplicate data packets. A tag in each packet allows the receiving relay or IED to use the first packet that arrives and to discard the duplicate. If one of the fiber paths fails, the subscribing IED then uses the one remaining packet of each pair, and never experiences even a bump in its performance for a single network connection failure. This covers failures of fibers, connectors, and the optical emitter and detector circuits in the IEDs at each end.

4. MU timing fibers and Precision Timing Protocol (PTP) per IEEE 1588 – MUs using 9-2 LE require dedicated timing fibers to synchronize sampling across the switchyard and allow addition of sample values. IEC 61869-9 MUs are synchronized over the same PTP network fibers that carry the sampled value, GOOSE, and other operational traffic. Entergy will implement PTP as MUs and IEDs are available to directly use this precision network timing signal.
5. Multivendor direction – With plugfest experiences of multiple vendors still working to achieve process bus interoperability, Entergy is initially deploying only a single vendor's devices, to ensure a practical initial training regimen and learning curve for the field crews, engineers, and other stakeholders. Entergy has not yet found a system integration tool that can interact with all vendors – a multivendor installation still requires manual file transfer to configure GOOSE mapping. The IEC 61850 core project team continues to evaluate products in the lab to qualify subsequent deployments of multivendor systems.
6. Condition monitoring and condition-based maintenance (CBM) design - When the individual products and the overall P&C system are designed for gapless monitoring of continuing performance and failures, time-based maintenance testing is mostly eliminated. All system interconnections are continuously monitored and will alarm the moment they cease to function. GOOSE messaging and sampled values services continuously monitor interconnecting wiring in a way that wasn't possible with conventional wiring. Only certain unmonitored peripheral connections – notably breaker tripping capability – need occasional testing. With correct design, this residue of required time-based testing can be carried out by a normal operational trip, or by natural operations or fault exposures. In North America, the opportunity for CBM has been included in the NERC standard for protection system maintenance PRC-005-6. As pointed out above, condition monitoring also reports integrity or problems when a station is being restored after storm damage, saving a great deal of testing under critical time pressure.

CONCLUSION

Entergy Transmission Protection and Control engineers, collaborating with field personnel and other organizational stakeholders, have carried out laboratory development and first field trials of IEC 61850 based designs which include station bus and process bus. The development, in progress since 2014, included three multivendor plugfests or interoperability tests in which early design incompatibilities have been found and corrected. A trial system is installed in monitoring mode as the core team designs a full-substation IEC 61850 P&C system for a 2018 green-field substation.

While IEC 61850 offers benefits documented in industry literature for years, the project team is particularly focused on achieving the storm resiliency benefits of a fiber-based, self-testing design. Fiber connections are more flood-resistant. Standard P&C designs are embodied in a list of components with archived and quickly-loaded standard interconnection configuration files. In a restoration emergency, installations can efficiently recommissioned with low risk of human error. Customer service is restored faster than was possible in past events.

The authors propose that this concept can be expanded beyond the boundaries of one utility organization. Consider the opportunity IEC 61850 presents to standardize major portions of designs, including setting and configuration templates and tools, across utilities such that development effort is reduced and training is streamlined. With this, emergency response can be carried out with mutual support across companies as we do today for distribution circuit restoration after a storm.

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