IEC 61850
What are you waiting for?

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I. Abstract

Since its release in 2003, IEC 61850 has been rapidly adopted by most of utilities around the world. The main exception seems to be in North America. The reasons for this lack of adoption generally center upon the perceived risks of moving to IEC 61850 without an adequate vision of the benefits of this technology.

IEC 61850 is simply a series of well-defined applications built upon existing protocols such as TCP/IP, and other IEEE, and IEC standards. It is a toolkit of best practices for substation automation as well as other application domains.

This paper begins with a very high-level introduction to the main features IEC 61850 with emphasis on the advantages (and disadvantages) of IEC 61850 compared to other utility automation protocols such as DNP3 and Modbus.

The paper continues with mappings from these existing widely-adopted protocols to the corresponding features of IEC 61850. A compelling argument will be made that further delay in IEC 61850 adoption by utilities is not in the best interest of a majority of users.

The paper then provides the vision of the “Wireless Substation” where most of the devices have only power and fiber Ethernet connections made to them. This vision shows the ultimate potential that can be achieved using IEC 16850.

A number of suggested paths to IEC 61850 will be shown which can reduce the risk of an all-or-nothing adoption. Simple examples of these paths include distributed fault records, interlocking, breaker failure detection/recovery, and HMI operation.

Upon successful realization of the simple parts of IEC 61850, a utility can then embark upon the journey towards the “Wireless Substation”.

The paper concludes with a rebuttal to many of the reasons for d of IEC 61850 by users

II. Introduction

The purpose of this paper is to encourage users to consider adoption of the IEC 61850 standard, abbreviated 61850. 61850 was designed by leading substation automation experts throughout the world to simplify the process of automation. It is much more than a communication protocol; it is “a way of life”: The penetration of 61850 in most parts of the world approach 100% while adoption rates in North America remain much lower. This paper seeks to understand the reasons for the slow adoption of the standard and to provide compelling reasons for embracing the 61850 standard.

III. Introduction to IEC 61850

IEC Technical Committee 57 began work on an automation standard to replace the IEC 60870-5 set of standards in 1996. It had the following high-level goals:

- Expanding the protocol standard to become a comprehensive automation standard
- Use existing standards where possible; specifically Ethernet and MMS
- Well-designed object definition methodology
- XML-based System Configuration Language for all aspects of the automation
- High-speed peer-to-peer communication for distributed control system (not Master-Slave)
- Integrated conformance testing requirements

The resulting standard was released by IEC in 2005 and accomplished all of the goals. Specifically, 61850 includes the following major features:

- Device specifications (surge withstand, temperature, EMI, EMC, etc.)
- Project management (signal names, top-down design, testing aspects)
- System requirements
- Configuration language
- Abstract services and models
- Mappings to protocols (ISO 8606 MMS and 802.3 Ethernet)
- Conformance testing

Several specific features of 61850 should be emphasized at this point.

The configuration language has been designed for 3 purposes:

- Declare the high-level design to enough detail for use as a procurement document
- Allow devices to advertise their capabilities
- Prepare a final configuration for containing the as-built model of the complete system. This final configuration file can be used to generate documentation and be input into simulation and test devices during the maintenance phase of the automation system.

The abstract services include:

- Connection-oriented messaging mode
- Device data model discovery over-the-wire
- Basic read/write services
- Low-speed spontaneous reporting: unbuffered, buffered, logging
- High-speed spontaneous reporting: GOOSE (aperiodic) and Sampled Values (periodic)
- Control Models
- Time synchronization
- File transfer and file directory services

Abstract modelling includes:

- Signal naming standards
- Semantically concrete object definitions using primary units and defined time scales

IV. Advantages of IEC 61850 over legacy protocols

IEC 61850 attempts to create a “cookbook” approach for the construction of automation systems. Legacy protocols such as Modbus and DNP3 (IEEE 1815) and IEC 60870-5 mostly focused upon the data transfer portion of the automation system. This cookbook approach has resulted in a very detailed 61850 specification with a large amount of detail. This level of detail is the main advantage of 61850 compared to legacy protocols. The standard released in 2005 contains 14 parts with about 1500 pages; the 2009 version contains over 40 parts with many more pages.

61850 establishes a consistent naming convention for signals and data objects which span the entire hierarchy from the central system database to individual signals and objects within each device. Because of this consistency, it is much easier for systems are various levels to aggregate information from individual devices. As an example, most 61850 servers will have a least one object containing the “system frequency”. The top-level object will always be named “Hz” with data attributes including the deadbanded value, instantaneous value, value quality, value timestamp, deadbanding rules, alarm limits, and base unit names (such as “Hz”). These attributes (and others) are directly associated with the data object “Hz” and can be used throughout the system.

61850 supports a variety of methods to transfer these data object/attribute values including polling by object, polling by dataset, a variety of server-pushed aperiodic reporting schemes (unbuffered reports, buffered reports, logging, and GOOSE), and periodic reporting (Sampled Values).

A well-defined configuration language is defined by 61850 which can be used during all stages of the automation system design including definition of the physical equipment (breakers, busbars, instrument transformers, etc), declaration of devices capabilities (detailed lists of supported services and objects), and the final as-built functional and communication systems including signal flows.

61850 communications can be of two types: point-to-point as well as point-to-multipoint. The first type is used for standard client/server communications while the point-to-multipoint communication is used for high-speed data transfers to eliminate the need for device-to-device wiring.

The standard was designed for extensibility in that future capabilities are fully backwards compatible with previous equipment versions. This is very important to protect the investment in an automation system from the need for a complete retrofit as technology advances. For example, older 61850 devices designed for 10 Megabit Ethernet communications are still compatible with newer Gigabit infrastructure with no changes. The extensibility also allows vendors to offer capabilities beyond what is written in the standard as product differentiators. Many of these vendor-defined extensions eventually become part of future standards; again with no problems of interoperability.

61850 address the issue of standards updates in an innovative way. Each message transmitted contains enough information for the receiver to recognize the parts which are understood and which parts are not understood. For this, 61850 uses a Layer 6 technology named Basic Encoding Rules (BER) which defines a tag-length-value (TLV) format to identify contents of this message. In fact, messages can be decoded using the (free) Internet sniffer named “WireShark” which will interpret messages down to the floating point value or text string.

The final major advantage of 61850 is the ability to define the “wireless substation” where most pieces of equipment comprising the automation system contain only a single power connection and an Ethernet port. This is made possible by the use of GOOSE to transport signals between the various parts as well as Sampled Values to transport the analog voltage and current information throughout the system.

V. Disadvantages of IEC 61850

The IEC 61850 concept has been criticized in many ways. It is not always the perfect solution to every problem.

The first criticism is that the standard is very large. This is a true fact but is a necessity to describe enough detail to accomplish the “cookbook” approach. In fact, other protocols such as IEEE 1815 (DNP3) are approaching the bulk of IEC 61850 (IEEE 1815, DNP3, is over 800 pages in length).

61850 has also been criticized for using cryptic names instead of point numbers. The naming rules for 61850 use well-defined abbreviations in order to minimize the resource requirements to communicate the data objects. For example, “MMXU1.PPV.phsAB.cVal.mag.f” is the name of the single-precision floating point value of the deadbanded voltage primary magnitude on a 3-wire delta power system from phase A-to-B. While not exactly human-readable at first glance, each of the components are actually well defined. In legacy protocols such as DNP3, this might ne indicated as “Analog-Input point number 352” and the individual product documentation would be consulted to determine where the corresponding data scaling factors are located.

The requirement for Ethernet transport is another criticism of 61850. The original writers of the standard first assumed that communication bandwidth constraints did not apply to 61850 and specified Ethernet as the underlying transport “to make the problem go away”. However, most modern automation systems use Ethernet in some form to avoid problems of distance and noise immunity. Furthermore, serial communication is prone to the multitude of connections, baud rates, handshaking, etc. which are all avoided by Ethernet communications. In the final standard, many of the 61850 message are actually very close the minimum length of an Ethernet frame (64 bytes) and this very compact.

Another perceived disadvantage of 61850 is the rapid pace of the standard evolution. This is the same set of “growing pains” that all standards experience. However, it is a particular concern to automation systems which are expected to be in service for a longer time than the standards update periodicity. The only solution, which has also been adopted by other automation protocols, is to strive for both forwards and backwards compatibility. As previously mentioned, 61850 solves this problem using BER but legacy protocols continue to struggle with the extensibility concept.

The configuration language of 61850 is very complex and difficult to read. This is a valid concern but it must be kept in mind that the language is meant to information exchange between computer applications and is NOT meant to be changed by humans.

61850 defines a very rigorous approach to substation design. Some users believe that there are parts of 61850 which do not need to be followed. The users believe that the same approach taken with legacy protocols will suffice for a 61850 system. For example, users may wish to bypass the portion of the configuration which assigns the IP addressing within the System Configuration Description (SCD) file because this was not needed in legacy systems. However, this seemingly small change to the “61850 cookbook” results in a system where verification of address assignment is impossible, leading to possible failures in the operational system and it also complicates diagnosis of problems during maintenance. Furthermore, an estimation of traffic volumes using the SCD file becomes impossible. For this reason, 61850 is seen as “too difficult to configure”.

Some users believe that 61850 should use the same design techniques as legacy protocols and thus deem 61850 systems as “too different from legacy systems”. However, the design rules of 61850 were design to reduce the effort of generating valid automation configurations. The legacy technique of using spreadsheets to transfer information between systems is considered to be prone to errors and the usage of consistent parameters between systems reduces the chances that systems cannot communicate the correct semantics. For example, 61850 allows scaling of values in powers of ten which is communicated via the *object*.SIUnit.multiplier attribute. 61850 defines a method to communicate this intention from the end device all the way to the central database without modification. Attempts to bypass this mechanism are prone to errors.

VI. Object Mappings

In the real world, measurements and controls will rarely align exactly with any standard. Automation standards provide the mechanism to create a “virtual view” of the real world. In legacy system, these mapping are normally constrained to integer values which somehow scale into the actual engineering units used by engineers. In 61850, this mapping is one-to-one with primary unit values mapped directly onto objects. For example, energy metering values are mapped onto 64-bit integers in units of watt-hours with optional multiplier values (for example, to map integers as MegaWatt-hours). The measurement value multipliers are contained within the SCD configuration file and may also be optionally transmitted with each measurement.

This contrast sharply with legacy protocols where the values are typically in secondary units with multipliers specified somewhere in the product documentation. The advantage of 61850 can be seen where values can be easily aggregated. For example, one method of bus protection involves applying Kirchhoff's Current Law to bus currents (sums of currents must be near zero). With legacy systems, this involves implicit scaling constants whereas in 61850 the currents may be directly summed. Similar calculations can also be used to aggregate sub-metering kWh measurements into total energy values.

VII. The “wireless” substation

If 61850 is fully applied to a system, then the automation system merely becomes a supervision system for remote sensors. Two elements of 61850 are key to this concept: Sampled-Values and GOOSE.

Devices called “merging units” are placed near the current/voltage sensors and convert to analog values (sampled at dozens of samples per second) into digital data streams. Fiber optic interfaces transport this information to the control house using Ethernet multicast techniques where the protection and measurement units convert these into useful information. The advantages of merging are many:

- Shorter Current Transformer wiring means lower probability of CT saturation
- Shorter Current Transformer connection reduces the probability of an open-CT (very bad)
- Only one fiber optic connection is needed for up to 8 signals rather than 16 individual wires
- No 10-guage wires are needed in the control house (this make electricians very happy)
- The large number of terminal blocks for the analog signals are eliminated (only connections to Ethernet switches are needed)

Similarly, GOOSE messages replace the wiring between devices in the automation system. For example, a single GOOSE message can transport the state of one automation device (such as disconnector status) to all interested devices using that status for interlocking. GOOSE can even be used to transport tripping decisions between devices and cause remote tripping to take place for breaker failure conditions.

If fully implemented, all point-to-point wiring can be eliminated and the individual devices can suffice with a single power and Ethernet connection. Since wiring faults in automation systems contribute a significant number of failures, the reliability of the system increases dramatically. Also note that both SV and GOOSE inherently contain “heartbeat” signals; which allow the automation system to monitor itself for faults and place themselves into “safe” mode when equipment failures occur.

VIII. Path to implementation of 61850

For users new to 61850, the migration might look very difficult but there are ways to mitigate the risks. Two approaches have been successfully used by US utilities: “baby steps” and full 61850.

The “baby steps” approach is essentially “cherry-picking” 61850 for the lowest risk to the user as an extension to an existing automation system. For example, a GOOSE scheme can be employed to provide interlocking of control decisions and the controls can be implemented in 61850. This has the advantage that only very small parts of 61850 need to be understood in order to successfully implement. The disadvantage of this approach is that it is very easy to take shortcuts to the standard 61850 configuration system which will result in a later possible re-design.

Another path for “baby steps” is to implement a distributed fault recorder with each device detecting an “event” transmitting GOOSE messages to other devices to begin recording. Collection of the fault records can then be accomplished over 61850 or legacy collection techniques.

The full 61850 approach involves a deep dive into the 61850 standard to build a completely new automation system for a new application. This requires a major commitment by the user and a full understanding that the first (and second and maybe third) implementation of 61850 will be more expensive than the corresponding legacy system. This technique has the advantage that no false-starts are generated and the full power of 61850 will become apparent in the first implementation. One “problem” with this approach is that the large amount of potential data may be requested by other departments within the company which will require a small amount of re-work shortly after the implementation is “complete”.

IX. What are you waiting for?

Users may have difficulties convincing their management that 61850 implementation is in the best interest of their company. The following list of concerns/responses should be helpful:

- Q: Our legacy systems seem to work, why transition to 61850?
  A; 61850 provides many long-term advantages including the ability to attract young engineers into the field of automation and simplified "back-end" processing of the automation data
- Q: What's wrong with Modbus
  A: 3 things: only master/slave; constant polling of every object is needed; and every data object is completely opaque requiring custom handling
- Q: What's wrong with DNP3?
  A: 2 things: Master/slave and every object is semi-opaque (analogs and binaries and counters are differentiated but not much else)
- Q: What short-term benefits will accrue with a 61850 transition?
  A: There are very few short-term benefits. A long-term view (3+ years) must be taken
- Q: Will consultants need to be hired to assist in the transition?
  A: Yes. As with any other major projects, the hiring of consultants will be more economical in the long run. The key is to ensure that complete technology transfer takes place before the consultants are dismissed.
- Q: If I implement 61850 in the automation system, am I required to change all back-end processing?
  A: No. Many 61850 transport DNP3 and/or IEC 61870-5 data to/from the back-end systems
- Q: Can I delay implementation of 61850?
  A: Yes, but the sooner 61850 is implemented the more benefits will be seen
- Q: Other users are not implementing 61850. Why should we do it?
  A: Other users are not taking a long-term approach with significant benefits
- Q: Will the author of this paper see a direct financial benefit if we adopt 61850?
  A: No. but … "a rising tide raises all boats" principle is used by the author with a long-term approach