



Next Generation of IED's Communication Networks and Systems And Their Role in Power Substation Automation

Saeid Khademi, Mustafa Rajabi Mashhadi

Khorasan Regional Electricity Company (KREC), Dispatching Center (NE-AOC)
Mashhad, I.I.RAN

Keywords : Substation Automation, IEC61850, Next Generation Communication Systems

Abstract :

Legacy substation automation protocols and architectures typically provided basic functionality for power system automation and were designed to accommodate the technical limitations of the networking technology available for implementation. There has recently been a vast improvement in networking technology that has changed dramatically what is now feasible for power system automation in the substation. Technologies such as switched Ethernet, TCP/IP, high-speed wide area networks, and high-performance low-cost computers are providing capabilities that could barely be imagined when most legacy substation automation protocols were designed. IEC61850 is a part of the International Electro-technical Commission's (IEC) Technical Committee 57 (TC57) architecture for electric power systems. The model-driven approach of the TC57 standards, including IEC61850, is an innovative approach that requires a new way of thinking about substation automation that will result in very

significant improvements in both costs and performance of electric power systems. This paper describes the evolution of communications in Intelligent Electronic Devices (IEDs), the drive for standardization early on in the process, the platform required to fuel this migration, and the issues raised in testing for interoperability among these new devices.

1. Introduction

Process automation solutions are widely accepted for power systems. They are mostly based on a huge number of proprietary specifications or (de facto) standards. Globally, utility deregulation is expanding. It requires integrating, consolidating, disseminating, and interpreting real time information quickly and accurately within a utility – from power plants to the power consumer in the shop floor or domestic user. Future electric power systems face a growing demand of configuration information (meta information) that describes the process data, the automation device, and – possibly – the primary equipment. To meet

the future requirements, three new standards have been defined: IEC 61850, IEC 61400-25, and IEC 61970.

Systems that only produce, transmit, or distribute electric power need more and more – seamlessly supervised – automation systems that require little or no human intervention for the configuration and operation. Technologies bundled into the electric power system, therefore, have to include system configuration, protection and control equipment, as well as interfaces to supervisory control and data acquisition (SCADA) of control centers. Other applications that have already started to rely on these standards are: remote monitoring and fault diagnosis, power quality, automated dispatch and control, site optimization of electrical/thermal outputs, asset management, as well as condition monitoring, and diagnosis.

The future power systems will – thanks to a seamless information and communication system – be smart at the top and smart at the bottom, self-regulated by millions of communicating devices connected to form feedback loops, and permanently aware of the world around them.

Utilities and vendors take advantage of the new seamless use of the standards, and make the electric power systems safer and more efficient than before – all critical information is available (at any time and any where), is reliable, and could be understood easily and unambiguously when making control decisions.

Data Communications in Intelligent Electronic Devices (IEDs) has taken the leap into the next generation with the migration to Ethernet as the primary communications medium. In an effort to achieve interoperability early on in this migration process, the Electric Power Research Institute (EPRI) and a group known as the “Utility Initiative” have worked together to proffer a common solution for utility enterprise communications known as the Utility Communication Architecture or UCA. UCA [1], [3] describes a “suite” of solutions to cover all communications aspects of the utility

enterprise. UCA provides a “network” solution to the interconnection of data sources – similar to the web solution used throughout the world to interconnect computers.

A recent focus of this effort has been communications in the utility substation where the application of a common protocol and peer-to-peer communications can be shown to have demonstrable savings. For example, integration systems today often require gateways to “communize” the various protocols and data elements found in today’s IEDs into a common database of values. Implementation of a common protocol eliminates the need for gateway solutions. In the area of protection wiring, all signaling between devices is performed via point to point wiring. Peer-to-peer communications can provide a flexible, low cost alternative.

2. Communication System Needs

Communication has always played a critical role in the real-time operation of the power system. In the beginning, the telephone was used to communicate line loadings back to the control center as well as to dispatch operators to perform switching operations at substations. Telephone-switching based remote control units were available as early as the 1930’s and were able to provide status and control for a few points. As digital communications became a viable option in the 1960’s, data acquisition systems (DAS) were installed to automatically collect measurement data from the substations. Since bandwidth was limited, DAS communication protocols were optimized to operate over low-bandwidth communication channels. The “cost” of this optimization was the time it took to configure, map, and document the location of the various data bits received by the protocol.

As we move into the digital age, literally thousands of analog and digital data points are available in a single Intelligent Electronic Device (IED) and communication bandwidth is no longer a limiting factor. Substation to master communication data paths operating at 64,000 bits per second are becoming very

commonplace with an obvious migration path to much high rates. With this migration in technology, the “cost” component of a data acquisition system has now become the configuration and documentation component. Consequently, a key component of a communication system is the ability to describe themselves from both a data and services (communication functions that an IED performs) perspective. Other “key” requirements include:

- High-speed IED to IED communication
- Networkable throughout the utility enterprise
- High-availability
- Guaranteed delivery times
- Standards based
- Multi-vendor interoperability
- Support for Voltage and Current samples data
- Support for File Transfer
- Auto-configurable / configuration support
- Support for security

Given these requirements, work on “next generation” communication architecture began with the development of the Utility Communication Architecture (UCA) in 1988. The result of this work was a profile of “recommended” protocols for the various layers of the International Standards Organization (ISO) Open System Interconnect (OSI) communication system model. This architecture resulted in the definition of a “profile” of protocols, data models, and abstract service definitions that became known as UCA. The concepts and fundamental work done in UCA became the foundation for the work done in the IEC TC57 Working Groups 10, 11, and 12 which resulted in the International Standard – IEC 61850 – Communication Networks and Systems in Substations [2].

3. Communication Profile

In creating the next generation communication profile, it was decided to base the model on both the International Standards

Organization (ISO) and Internet communication models (figure 1). These models are commonly portrayed as 7 layer and 5 layer models respectively. For simplicity, however, the model can be broken down into 3 primary categories, namely, the application layer, the network layers, and the physical layers. These layers perform communication functions as follow:

3-1. Application Layer

The application layer is a set of services for moving and operating on data. The application layer can be compared to the system functions that are a part of “C” or other languages. In these languages, there are “system calls” to perform such function as “Open File”, “Read File”, “Write File”, etc. that communicate between the user program and the operating

Figure 1: Substation Network Profile

Manufacturing Messaging Specification (MMS)		Application Layer
International Standards Organization - OSI Networking Stack	TCP/IP Networking Stack	Network Layer
10Mb Ethernet 10BaseT and 10BaseFL Media (Twisted pair and Fiber)		Data Link and Physical Layer

system. The application layer performs these kinds of services but communicating between devices over a network. As such, one can speak of reading or writing data and other services among devices not only on the local network but also through a Wide Area Network (WAN).

The application layer chosen for the utility profile is the Manufacturing Messaging Specification (MMS). MMS provides a rich set of some 87 services for this function, however, it was determined that only a small subset of these services were necessary to meet the functional requirements spelled out by the industry [22]. The required generic services have been defined in the Common Application Service

Module (CASM) document [1] and subsequently mapped to the appropriate MMS services.

There are a number of key services (besides read and write) that facilitate the operation and integration of a network relay in an enterprise, namely: Get Object Definition, Named Variable Lists (such as SCADA Data, Power Quality, Outage Report, Demand Data, and Equipment Health), Unsolicited Event Notification, and File Transfer.

3-2. Network Layer

As it was deemed desirable to be able to access data from any device from anywhere in the corporate enterprise, a complete Network communication layer (the software that handles getting data from here to there) was included in the profile. Two solutions were adopted for the Network layer - TCP/IP and the International Standards Organization -Open System Interconnect. TCP/IP stands for Transmission Control Protocol / Internet Protocol which is the ubiquitous transport/network layer used over the Internet. The inclusion of TCP/IP in the substation allows access to IED data through the Internet or an intranet. TCP/IP is a streaming protocol which means that transmission of a packet of data waits for a "stream" of data (such as that from a teletype terminal) to fill a buffer before the buffer is transmitted. This mode of operation could potentially slow down the communication of small packets of data. It should be noted, however, that there are controls available on the size and delays times of sending a packet of data. In addition to the streaming aspect, TCP/IP has built in congestion control that will drop packets of data if the network is deemed too busy. This feature is not desirable in the delivery of real time data.

The other Network layer included is the ISO-OSI network layers. ISO is the International Standards Organization which has established the Open System Interconnect (OSI) seven layer model. This model is implemented through a number of standard protocols in the Network layer and does not suffer from the need to wait until a buffer is full before transmitting. Both network layers support the

concept of "broadcasting" a message for all devices on the bus to hear. This feature is very desirable for functions such as data capture triggering, time synchronization, and even control messages to multiple devices.

3-3. Physical / Data Link layer

Ethernet was chosen as the Physical / Data Link layer inside the substation due to its predominance in the marketplace and the subsequent availability of low-cost implementations and associated network hardware (such as bridges and routers). In addition, Ethernet's fiber implementations are very desirable in the substation environment and the scalability of Ethernet is well defined with 100Mb implementations being fairly common and 1Gb Ethernet well on its way into vogue. Processors are available today with multiple 10 Mb Ethernet ports integrated into the chip and next generation designs are due out shortly that include 100 Mb ports.

4. Scope and Outline of IEC 61850

The stated scope of IEC 61850 was communications within the substation. The document defines the various aspects of the substation communication network in 10 major sections as shown in Table 1 below. Parts 3, 4, and 5 of the standard start by identifying the general and specific functional requirements for communications in a substation (key requirements stated above). These requirements are then used as forcing functions to aid in the identification of the services and data models needed, application protocol required, and the underlying transport, network, data link, and physical layers that will meet the overall requirements [10], [11], [12].

The major architectural construct that 61850 adopts is that of "abstracting" the definition of the data items and the services, that is, creating data items/objects and services that are independent of any underlying protocols. The abstract definitions then allow "mapping" of the data objects and services to any other protocol that can meet the data and service requirements. The definition of the abstract

services is found in part 7.2 of the standard and the abstraction of the data objects (referred to as Logical Nodes) is found in part 7.4. In as much as many of the data objects are made up of common pieces (such as Status, Control, Measurement, Substitution), the concept of “Common Data Classes” or “CDC” was developed which defined common building blocks for creating the larger data objects. The CDC elements are defined in part 7.3 [14], [15], [16], [17].

Given the data and services abstract definitions, the final step was one of “mapping” the abstract services into an actual protocol. Section 8.1 [18] defines the mapping of the abstract data object and services onto the Manufacturing Messaging Specification – MMS and sections 9.1 and 9.2 define the mapping of the Sample Measured Values (unidirectional point-to-point and bi-directional multipoint accordingly) onto an Ethernet data frame. The 9.2 document

defines what has become known as the Process Bus [19], [20].

From a system perspective, there is a significant amount of configuration that is required in order to put all the pieces together and have them work. In order to facilitate this process and to eliminate much of the human error component, an XML based Substation Configuration Language (SCL) was defined in part 6. It allows the formal description of the relations between the substation automation system and the substation (switchyard). At the application level, the switchyard topology itself and the relation of the switchyard structure to the SAS functions (logical nodes) configured on the IEDs can be described. Each device must provide an SCL file that describes the configuration of itself.

Although the scope of 61850 was originally focused “inside” the substation, discussions are underway to look at defining 61850 for the Substation to Master communication protocol (already in service in several installations). In addition, applications are in service that uses various components of 61850 for wide area substation-to-substation communication.

Finally, part 10 of the document defines a testing methodology in order to determine “conformance” with the numerous protocol definitions and constraints defined in the document.

5. Process Bus

As technology migrates to “next generation” low-energy voltage and current sensors, the ability to digitize the base quantities at the source and transmit the resulting sample values back to the substation becomes a need. In addition to Sampled Values, the ability to remotely acquire status information as well as set output controls is very desirable. IEC 61850 addresses this need through the definition of Sampled Measured Values services and the implementation of a Process Bus. The Process layer of the substation is related to gathering information, such as Voltage, Current, and status information, from the transformers and transducers

Table 1. Structure of the IEC 61850 Standard

Part #	Title
1	Introduction and Overview [8]
2	Glossary of terms [9]
3	General Requirements [10]
4	System and Project Management [11]
5	Communication Requirements for Functions and Device Models [12]
6	Configuration Description Language for Communication in Electrical Substations Related to IEDs [13]
7	Basic Communication Structure for Substation and Feeder Equipment
7.1	Principles and Models [14]
7.2	Abstract Communication Service Interface (ACSI) [15]
7.3	Common Data Classes (CDC) [16]
7.4	Compatible logical node classes and data classes [17]
8	Specific Communication Service Mapping (SCSM)
8.1	Mappings to MMS(ISO/IEC 9506 – Part 1 and Part 2) and to ISO/IEC 8802-3 [18]
9	Specific Communication Service Mapping (SCSM)
9.1	Sampled Values over Serial Unidirectional Multipoint-to-Point Link [19]
9.2	Sampled Values over ISO/IEC 8802-3 [20]
10	Conformance Testing [21]

connected to the primary power system process – the transmission of electricity. IEC 61850 defines the collection of this data via two different protocol definitions, namely, Part 9.1 which defines a Unidirectional Multidrop Point-to-Point fixed link carrying a fixed dataset and Part 9.2 which defines a “configurable” dataset that can be transmitted on a multi-cast basis from one publisher to multiple subscribers [19], [20].

Figure 2, below, shows the basic concept of the Process Bus. Signals from voltage and current sources (low or high energy) as well as status information are input into a “Merging Unit”(MU). The Merging Units in a station sample the signals at an agreed, synchronized rate. In this manner, any IED can input data from multiple MUs and automatically align and process the data. At this time, there is an implementation agreement that defines a base sample rate of 80 samples per power system cycle for basic protection and monitoring and a “high” rate of 256 samples per power system cycle for high-frequency applications such as power quality and high-resolution oscillography.

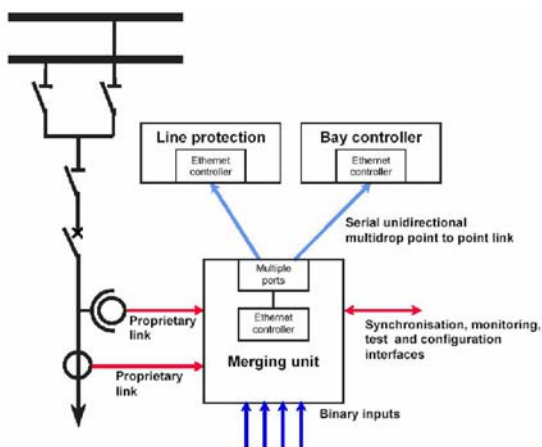


Fig. 2. Sample Measured Value Concept

Part 9.1 specifies a pre-configured or “universal” dataset as defined in IEC60044-8. This dataset includes 3-phase voltage, bus voltage, neutral voltage, 3-phase currents for protection, 3-phase currents for measurement

and two 16-bit status words. Note that the analog data values are mapped into 16 bit registers in this mapping.

Part 9.2 is a more generalized implementation of Sampled Measured Values (SMV) data transfer. In 9.2, the dataset or “payload” is user-defined using the SCL. As a dataset, data values of various sizes and types can be integrated together. Note that the existing implementation agreement proposed a data value size of 32 bits with a scale factor of 1 count = 1ma.

Both 9.1 and 9.2 specify mapping directly onto an Ethernet transport (see figure 4 above). Depending on the sample data rate, anywhere from 1 to 5 devices can be mapped onto a single 100MB Ethernet link. Multiple 100MB Ethernet data streams can then be combined into a single Ethernet switch with a 1GB backbone. In this configuration, 50 or more datasets can be published to multiple subscribers.

6. Design of a Network IED

The primary enabler of the Network IED has been the exponential increase in microprocessor performance and subsequent integration of communication interfaces onto the microprocessor chip – the “engine” of a Network IED. Additionally, price/performance ratios have decreased to the point where the performance requirements of a distance relay and the cost effective requirements of a feeder relay can be met by the same microprocessor and digital technology.

Recognizing that the “engine” of a Network IED is going to continue to increase in horsepower, the platform that houses the engine must be designed to accommodate the future changes. An excellent model to observe for this purpose is the Personal Computer or PC. The PC has become a general-purpose tool that can be used for numerous tasks by running different application programs on the same platform. Additionally, the basic platform can be upgraded as new CPUs become available and expanded by the addition of special purpose hardware modules to perform special functions

as required. Another aspect of the PC that has fostered its acceptance has been the common look and feel of the Human-Machine interface on an international basis. As such, employee training is minimized – a major expense in any industry [5].

It is desirable to emulate the PC in the design of a universal Network IED, that is, an IED that is modular in both hardware and software and a common look and feel in a user interface. The primary functional building blocks required in such an IED include:

- a) Algorithmic and control logic processing, usually performed by the main 'protection' microprocessor. Note that most digital relays have multiple processors for different functions.
- b) Power system current and voltage acquisition with interposing current and voltage transformers and an analog-to-digital converter that is tightly integrated with a dedicated digital signal processor (DSP).
- c) Digital inputs and outputs for control interfaces, usually required to handle a variety of current and voltage ratings as well as actuation speed, actuation thresholds and different output types (e.g. Form-A, Form-C, Solid-State).
- d) Analog inputs and outputs for interfacing to transducer and SCADA systems, usually required to sense or output dcmA currents.
- e) Communications to station computers or SCADA systems, usually requiring a variety of physical interfaces (e.g. RS485, Fiber Optical, etc.) as well as a variety of protocols (e.g. Modbus, DNP, IEC-870- 5, UCA 2.0, etc.) [2] .
- f) Local HMI for local operator control and device status annunciation
- g) Power supply circuitry for control power, usually required to support a wide range of AC and DC voltage inputs (e.g. 24-300 VDC, 20-265 VAC).

The design of a Network IED requires an architecture that can accommodate all of the above functional blocks in a modular manner and allow for scalability, flexibility, and

upgradability in a cost effective manner for all applications.

6-1. Hardware Architecture

The architecture which best implements hardware modularity is that of a plug-in card system similar to that found in programmable logic controllers (PLCs) as well as PCs. Key to the performance of such a system is the high-speed parallel bus which provides the modules with a common power connection and high-speed data interface to the master processor (CPU) as well as to each other. Figure 3 shows such a system with all the core functional blocks implemented as modules. Modularity can also be extended to the HMI where the front of the IED can be configured as needed with indicating lights, displays, and keypad.

6-2. Software Architecture

A modular architecture which provides scalability and flexibility from a hardware perspective requires software that supports the same features. In fact, the software has its own form of modularity based on functionality:

- Protection elements
- Programmable logic and I/O control
- Metering
- Data and Event capture/storage
- Digital signal processing
- HMI control
- Communications

The key advancement in software engineering which has become predominant in the software industry is Object Oriented Programming and Design (OOP/OOD). This involves the use of 'objects' and 'classes'. An object is defined as: "a logical entity that contains both data and code that manipulates that data". A class is the general form of the object. By using this concept one can create a protection class and objects of the class such as Time Over current, Instantaneous Over current , Current Differential, Under Voltage, Over Voltage, Under Frequency, Distance Mho, Distance Quadrilateral, etc. These represent software modules that are completely self-contained or 'encapsulated' which is the term used in the industry. The same can be done for metering,

programmable logic, and I/O control functions, HMI and communications or for that matter any functional entity in the system. By employing OOP/OOD in the design of the software architecture of the universal relay we have been able to achieve the same features as the hardware architecture: modularity, scalability, and flexibility.

7. Network Solution

Given a network IED, one can now configure a substation network architecture. Figure 3 illustrates a network architecture of such a system. In this implementation, operation of the

IEDs, the Network, and the Host computers / Operator Interfaces is totally separated. In other words, failure of the host computers would have no effect on the inherent operation of the system. All IEDs on the network respond to requests from any other IED on the network. “Next Generation” SCADA is effected as a Bridge or Router interface onto the utility WAN. All data available in the connected IEDs (including the object definitions) become available to any networked device. User defined information, through the implementation of user defined Name Lists, can now be selectively delivered

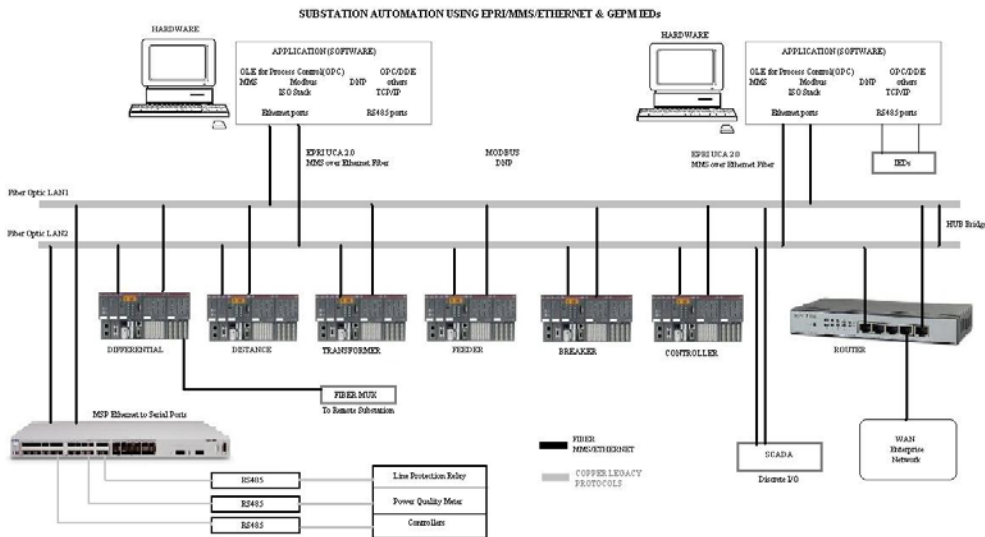


Figure 3: Substation Network architecture

7-1. Network Solution Features

It is understood that the transition from present SCADA to next generation SCADA will not take place overnight. Nevertheless, the illustrated architecture accommodates legacy SCADA interface through the use of SCADA Gateways. These gateways act as protocol translators from the MMS objects available on the LAN to the traditional SCADA data required by the remote SCADA Master. Additionally, it is recognized that many substations will contain “legacy” IEDs whose data would be desired in an integrated environment. As such, a similar gateway

function can be effected by the Host computer or any other independent computer. Ultimately, data retrieved from the legacy IEDs can be made MMS accessible.

7-2. Peer-to-Peer Communications

The peer to peer communication environment opens up new vistas for protection applications in the electrical plant. Traditional protection schemes used hard wires and wired logic to implement the various protection schemes. Peer to Peer communications now allows for information transfer through the use of Remote Inputs (RIs) and Remote Outputs (ROs). Any

device can define a RI that is linked to an object in another IED (either local or literally anywhere on the network). Linkage would be specified by IED address, object name, object pe, and security. The requesting device gets access to the desired object either on request, on change of state (or deadband), or periodically. Since plant control requires a high degree of reliability, provision is made to implement redundant communications from the IEDs and subsequently, support for a redundant LAN.

The GOMSFE document provides a mechanism for efficient transfer of digital messages through the use of a connection-less multicast message. The format of the message is specifically defined and is known as the Generic Object Oriented Substation Event or GOOSE. GOOSE messages are periodically launched upon the change of state of any of the digital elements and are periodically re-transmitted to confirm delivery.

7-3. Interoperability Testing

Communications among a system of Network IEDs can be broken down into three primary areas, namely, host to IED, IED to IED via multicast (local network only), and general IED to IED (both intra and inter substation). As such, interoperability testing in such a system must take place over these three fronts – each with some similarities but also different functionality and performance requirements [6], [7].

7-4. Host to IED Communications

One of the possible network configurations incorporates a host computer located on the network for functions such as user interface, data logging, legacy SCADA interface, PC Control, etc. In this configuration, the host needs to be able to establish a database of all variables from all IEDs in the network and subsequently be able to refresh this database in less than 1 second. The interface with the various IEDs is established on a “connection oriented” basis, that is, there is a request and response based on a user assigned address.

Testing of the host/IED interoperability involves validating operation in four areas as discussed below:

1. Conformance to CASM and appropriate mapping into MMS. As stated earlier, CASM is a generic application layer. The implementer needs to make sure that the MMS services installed in the IED completely overlay the CASM services. As most implementations will use commercially available MMS software, this task is done primarily by the primary software vendor and only validated by the implementer.
2. Proper functionality of the MMS services. Given that the proper services have been included in the MMS package, the question now is whether the service is interoperable with other manufacturers' implementation. Again, this primarily falls under the scope of the primary software supplier. The IED manufacturer is obliged to do some testing with other manufacturers' MMS clients, however, this function primarily falls under the scope of independent testing labs.
3. Proper mapping of the GOMSFE and Vendor Specific objects. The manufacturer is responsible for first correlating the GOMSFE objects with the internal objects of the IED. In most cases, the basic object will need to be extended. Once mapped, the mapping needs to be checked against the GOMSFE document to make sure all mandatory objects have been instantiated and that any GOMSFE objects used have been spelled properly. This process is done manually today and is a candidate for automation in the near future.
4. Proper mapping of values into the GOMSFE and Vendor Specific objects. Part of the implementation process is mapping a pointer to the value of the GOMSFE variable. Again, this falls under the purview of the implementer. As a manual process, a known quantity (such as an input voltage) needs to be verified to be in the proper location in the appropriate GOMSFE model. Similarly, GOMSFE objects for settings need to be validated against factory settings and verified to change when changed in the primary location.

7-4. Multicast IED Communication

As discussed earlier, high speed peer-to-peer communication within the substation is performed via a connectionless mechanism known as GOOSE. The GOOSE contains two parts: a pre-defined set of 32 data items such as "Trip", "Close", "Lockout", etc. and up to 96 "user defined" remote outputs. Testing of the GOOSE message includes checking for proper bit mapping (i.e. – receiving a lockout message when a lockout message was sent) but also measuring performance under heavy network loading conditions. All pre-defined data items (if supported) must be tested. Additionally, all positions of the user-defined bits must be tested for proper transmission and receipt.

As the source of GOOSE messages could be digital inputs or internal Virtual Inputs, timing of the messages should be checked over two different timing paths. One path should be from issuance of a digital input to the closing of a contact output. This path includes the digital input debounce delay, stack processing time, logic processing time, and output relay operate time. The second timing path should be the internal messaging time – independent of the input and output delays. This timing is typically available from the event recorder inside the IED. Set-up for this test is facilitated by the use of IRIG-B time stamping that can be used to synchronize the event clocks in the IEDs under test.

7-5. Client / Server Based IED to IED Communication

This third mode of communication is a connection oriented service which permits IED data sharing outside the confines of the local network. This type of communication would need to be transactionally set up by the user. As such, testing of this mode of operation needs to be done by the user. Testing would include establishing the condition(s) for the transmission and verifying that the requested message is properly received by the client. Note that the condition(s) for transmission could be triggered either at the client side or at the server side as established by previous agreement (e.g. – change of state of a variable). At this time, the

IED to IED exchange parameters have not been established within the substation documents, however, the pieces are in place to proceed once agreement is reached on "how".

7-6. External Test Equipment

In the test scenarios described above, the IED was an integral part of the test equipment. There are other operational and performance measures that require additional equipment in order to quantify. In particular, basic Ethernet information such as LAN loading, peak loading, failed packets, collision count, trace recording, etc. are required. There is off the shelf equipment that can be purchased that measure these quantities and numerous others. These tools allow manufacturers to share communication messages as a means of validating interoperability. For example, the issuance of a GOOSE message to trip a breaker can be captured by one manufacturer, E-Mailed to another, and played back to the other manufacturers' IED to verify proper execution of the GOOSE message. It is expected that in the near future, libraries of such recording will be made available as part of interoperability validation.

In addition to the standard Ethernet test equipment, MMS Data Analyzers are starting to appear. An analyzer not only captures the raw data packet but also decodes the MMS messages contained within the data packets thereby providing both the developer and the user extensive debug capabilities.

8. Conclusions

IEC61850 is now released to the industry. Nine out of ten parts of the standard are now International Standards (part 10 on testing is in the CDV stage). This standard addresses most of the issues that migration to the digital world entails, especially, standardization of data names, creation of a comprehensive set of services, implementation over standard protocols and hardware, and definition of a process bus. Multi-vendor interoperability has been demonstrated and compliance certification processes are being established. Discussions are underway to utilize IEC61850

as the substation to control center communication protocol. IEC61850 will become the protocol of choice as utilities migrate to network solutions for the substations and beyond.

The hardware and software technology to create a “Network” IED is ready now. The roadmap to a networked substation automation system has been drawn. The utilities of the world are waiting for vehicles to drive down today’s automation highway and they expect a vehicle that will be upgradable to drive down tomorrow’s automation highway. In all cases, the buyer needs to make sure that the manufacturer has properly road tested the vehicle and he also needs to be aware of the field tests required by each IED.

9. Bibliography

- [1] IEEE Technical Report 1550 (1999): Utility Communications Architecture, UCA; http://www.nettedautomation.com/standardization/IEEE_SCC36_UCA
- [2] Comparison of IEC 60870-5-101 (-103, 104), DNP3, IEC 60870-6-TASE.2 with the new standard IEC61850 http://www.nettedautomation.com/news/n_51.html
- [3] Object Models for Power Quality Monitoring in UCA2.0 and IEC 61850, A. Apostolov, Dis-tribuTech 2003, February 4-6, 2003, Las Vegas, NV
- [4] Object Modeling of Metering Functions in IEC 61850 Based IEDs, A. Apostolov, Distributed Generation and Advanced Metering Conference, March 12-14, 2003, Clemson, SC
- [5] Substation Automation based on IEC 61850 with new process-close Technologies, L.
- [6] Andersson, Ch. Brunner, F. Engler; IEEE Powertech 2003, June 23-26, 2003, Bologna, Italy
- [7] Christoph Brunner (ABB) and Holger Schubert, (SIEMENS); The ABB - SIEMENS IEC 61850 interoperability projects, (January 2002); <http://www.nettedautomation.com/solutions/uca/products/9-1/index.html>
- [8] IEC 61850-1, Communication networks and systems in substations – Part 1: Introduction and overview
- [9] IEC 61850-2, Communication networks and systems in substations – Part 2: Glossary
- [10] IEC 61850-3, Communication networks and systems in substations – Part 3: General requirements
- [11] IEC 61850-4, Communication networks and systems in substations – Part 4: System and project management
- [12] IEC 61850-5, Communication networks and systems in substations – Part 5: Communication requirements for functions and devices models
- [13] IEC 61850-6, Communication networks and systems in substations – Part 6: Configuration description language for communication in electrical substations related to IEDs
- [14] IEC 61850-7-1, Communication networks and systems in substations – Part 7-1: Basic communication structure for substation and feeder equipment – Principles and models
- [15] IEC 61850-7-2, Communication networks and systems in substations – Part 7-2: Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)
- [16] IEC 61850-7-3, Communication networks and systems in substations – Part 7-3: Basic communication structure for substation and feeder equipment – Common data classes
- [17] IEC 61850-7-4, Communication networks and systems in substations – Part 7-4: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data classes
- [18] IEC 61850-8-1, Communication networks and systems in substations – Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO/IEC 9506-1 and ISO/IEC 9506-2) and to ISO/IEC 8802-3
- [19] IEC 61850-9-1, Communication networks and systems in substations – Part 9-1: Specific communication service mapping (SCSM) – Sampled values over serial unidirectional multidrop point to point link
- [20] IEC 61850-9-2, Communication networks and systems in substations – Part 9-2: Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3
- [21] IEC 61850-10, Communication networks and systems in substations – Part 10: Conformance testing Excerpt of the IEC 61850 information model; <http://www.nettedautomation.com/qanda/iec61850/information-service.html#>
- [22] Substation Integrated Protection, Control, and Data Acquisition Phase 1, Task 2 Requirements Specification; EPRI – RP3599-01.