Significant Substation Communication Standardization Developments

Eric Udren
Cutler-Hammer

Steven Kunsman
ABB Automation, Inc.

Dave Dolezilek
Schweitzer Engineering Laboratories, Inc.

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SIGNIFICANT SUBSTATION COMMUNICATION STANDARDIZATION DEVELOPMENTS

Eric Udren
Cutler-Hammer
Pittsburgh, PA USA

Steven Kunsman
ABB Automation, Inc.
Allentown, PA USA

Dave Dolezilek
Schweitzer Engineering Laboratories, Inc.
Pullman, WA USA

ABSTRACT

The International Electrotechnical Committee (IEC) Technical Committee (TC) 57 was established in 1964 because of an urgent need to produce international standards in the field of communications between the equipment and systems for the electric power process, including telecontrol, teleprotection, and all other telecommunications to control the electric power system.

Having to take into consideration not only equipment aspects, but more and more system parameters, the scope was modified to prepare standards for power systems control equipment and control systems, including supervisory control and data acquisition (SCADA), energy management systems (EMS), distribution management systems (DMS), distribution automation (DA), teleprotection, and associated communications.

The technical experts of 22 participating countries have recognized that the increasing competition among electric utilities due to the deregulation of the energy markets asks more and more of systems. The integration of equipment and systems for controlling the electric power process into integrated system solutions is needed to support the utilities' core processes. Equipment and systems have to be interoperable, and interfaces, protocols and data models must be compatible to reach this goal.

The North American Utility Communications Architecture (UCA™) Initiative is working under a similar charter to create recommendations for implementation of interfaces, protocols, and data models. It is expected that upon completion, the IEC TC 57 will adopt these recommendations and make them a subset of the IEC 61850 Standard, currently under development.

This paper describes the intent and expected results of ongoing communication standardization efforts as well as the current state of affairs. The key to standardization is interoperability between vendors and systems. This paper, jointly authored by three vendors within the electric power industry, demonstrates the open nature of the standards and the vendors' commitment to interoperability. Of particular interest are discussions of functional interoperability, hardware, and software interfaces, protocols, data models, and interchangeability.

INTRODUCTION

Of all the changes that microprocessors brought to the practice of substation protective relaying and metering over the last two decades, the most visible has been the ability of the new devices to communicate information to the user. In fact, engineers tend to view the relaying and measurement tasks themselves as well understood and standardized. By contrast, the technical methods and operating impact of data communications continue to evolve dramatically. Users still face the frustration of choosing among a variety of incompatible communications approaches and systems in the marketplace, and invest great effort in guessing at the lowest-risk path to gain the operating benefits which communications can bring.

The main uses for communications interfaces have been to acquire ac voltage and current metering; power system and relay status reporting; event records and oscillographic sampled data gathering for disturbance analysis; and checking or changing the large number of settings in these flexible multifunctional intelligent electronic devices (IEDs). Some IEDs provide basic low-speed remote control capability as well.

Competing manufacturers have designed the communications interface circuits with the same individual creativity they demonstrate in the design of the power-system functions. Each vendor started with a unique approach. These included a variety of types of serial ports intended for convenient straightforward linked communications with a single computer. Other IED makers designed networks that would tie together a number of devices in one substation to a single local or remote host that could dynamically address requests for data to any unit. The protocol, or sequence and structure of messages, was and still is unique for each system. In general, the user could not directly interconnect competing products.

First-time users would identify, with some effort, the vendor that seemed to have the best solution. Some users needed the variety of protection and monitoring capabilities from many vendors; they found themselves frustrated by the communications variations. They couldn't interconnect the devices; they had to provide a different communications system for each vendor, and to learn the operating idiosyncrasies and software packages of each vendor. All this work mitigates the benefits of using the data in operations.

Today, all of the utility users and manufacturers recognize the desire and the need to merge the communications capabilities of all of the IEDs in a substation, or even across the entire power network. This wide-area interconnection can provide not only data gathering and setting capability, but remote control. Furthermore, multiple IEDs can share data or control commands at high speed to perform new distributed protection and control functions. This sort of cooperative control operation has the potential to supersede and eliminate much of the dedicated control wiring in a substation, as well as costly special-purpose communications channels among the stations and around the power network.

Many utilities have already installed systems of interconnected IEDs for some degree of centralized substation and system monitoring and control. Because of the variety of communications dialects, system integrators employ gateway or translator devices to get all the data into a common format. Design and programming of the gateways interfacing to a variety of top-level system designs is inefficient and expensive.

ORIGIN OF UCA™ SUBSTATION COMMUNICATIONS PROJECT – NORTH AMERICA

The Electric Power Research Institute (EPRI) has existed since the 1970s to develop technologies for the benefit of electric utilities. It manages research and development projects with funds supplied by those utilities as a group and other sources.

Since the 1980s, EPRI has recognized the potential benefits of a unified scheme of data communications for all operating purposes across the entire utility enterprise. They focused on the ease of combining a broad range of devices and systems; and the resultant sharing of management and control information among all departments of the utility organization. EPRI commissioned the Utility Communications Architecture (UCA) project which identified the requirements, the overall structure, and the specific communications technologies and layers to implement the scheme.

By 1994, EPRI had recognized the importance of tying substation control equipment and power apparatus into the UCA scheme, but had not defined a particular approach. They were hearing the outcries of frustrated utility engineers and managers over the difficulty of integrating substation IEDs. Accordingly, they launched Research Project 3599 to define, demonstrate, and promote an industry-wide UCA-compatible communications approach for substations. The objective was, and is, to avoid a frustrating and expensive marketplace shakeout of extremely complex incompatible systems.

Many progressive utilities, and most of the relay and IED manufacturers, took an immediate interest in UCA work and joined in the effort to define and demonstrate a communications network stack. The forward-looking approach was to define the technical requirements for a system to control and monitor substations large and small. The specification includes the requirement for fast messaging - in milliseconds - among peer IEDs to achieve fault-related control over the data communications system. The objective is to use the substation local area network (LAN) messaging to ultimately replace the mass of dedicated wiring among the IEDs and power apparatus.

Another sensible feature of the approach was to identify communications system layers which might already exist in widespread use, which would meet the requirements for substation control. This would allow the project workers to buy widely used hardware and software components, and focus their development efforts on the layers which really have to deal specifically with the needs of an electric utility substation control system.

For lower layers of the system, the project investigators looked at a variety of industrial fieldbus solutions, as well as office-LAN technologies like Ethernet and Internet protocol layers. These were not obviously suited to fast substation control, but had the benefit of huge worldwide usage to support a rich array of affordable system components that *might* be adapted to substation use.

Around 1996, after a period of detailed study by EPRI-sponsored researchers, a group of prominent utilities lead by American Electric Power (AEP) forged ahead in an initiative to select specific layers and make demonstration systems. These users were scheduling projects to equip substations with the most modern LAN-based and standardized control schemes, and pushed ahead to demonstrate a working result. The objective was to define a standard which independent, competing makers of relays, meters, controllers, user interfaces, and other IEDs could implement for interoperable communications, eventually using the LAN for all control.

With continued EPRI support, a long list of relay, meter, and IED vendors have built UCA-compliant versions of products. As we explain further below, the elaborate specification for a communications protocol which handles all the data collection and high-speed control functions continues to evolve even at the time of this writing. The equipment makers continue to modify and update the implementations in each of the products. Meanwhile, over two dozen utilities in the US and overseas have signed up to demonstrate UCA substation systems. The UCA Substation Initiative Project holds meetings several times a year at which users can see an impressive and elaborate demonstration of interoperability among a broad variety of equipment from competing manufacturers. Those who attend immediately notice the atmosphere of collegial cooperation among these competitors who recognize the importance of achieving interoperable communications. These vendors see individual-product features and performance as the proper ground for competition.

START OF COMMUNICATIONS STANDARDS PROJECT – INTERNATIONAL

The call for an international standard began as different vendors introduced proprietary solutions into the market. Many manufacturers had already developed earlier renditions of integrated, LAN-based systems for communications and control of substations. Each such design had a proprietary communications scheme and the buyer was committed to a full system of the chosen vendor's equipment.

At the request of users in the late 1980s, European suppliers worked within the International Electrotechnical Commission (IEC) to create the communications standard IEC 60870-5. Subsections of 61870-5 provided for basic information transfer and control between one vendor's IED and the overall system of another vendor. However, the markets where these vendors sold their products tended to support more expensive, futuristic systems as part of a major project. These systems could not be sold in North America due to their complexity and cost, and the North American market being in the infancy of substation automation.

In 1995, IEC commissioned a new project, 61850, to define the next generation of standardized high-speed substation control and protection communications. The main objective, as with EPRI, was to have vendors and utilities work together in the definition of the communications infrastructure for substation monitoring and control. The generation of this standard would assure interoperability of the various vendors' IEDs avoiding the extremely complex incompatible systems.

The IEC project organization, tasked with defining the communications standard, resides under the Technical Committee 57 (TC 57), Teleprotection and Power System Control. Working Groups (WG) 10, 11 and 12 are formally responsible for the various parts of the IEC 61850 Standard:

- WG10 - Functional Architecture, Communication Structure and General Requirements
- WG11 - Communication within and between Unit and Substation Levels
- WG12 - Communication within and between Process and Unit Levels

However, most of the standardization work has actually been accomplished through formation of Joint Task Forces (JTF) composed of members from the different WGs.

THE PROJECT TEAMS JOIN FORCES

By 1996, the EPRI UCA 2.0 and IEC 61850 groups were both working on standards to address the interoperability of different vendor IEDs in substation automation applications. It was clear that both of the standardization efforts should be harmonized resulting in a single communication standard for the world market. In October of 1997, the Edinburgh TC 57 WG10-12 meeting concluded with the agreement that only one standard for Substation Automation and Communication should be developed and to merge the North American and European approaches. A joint task force was established to prove the feasibility of harmonization of certain parts of the UCA standardization.

Meanwhile, the UCA project continued pushing for vendor implementation, product demonstration, and to say the least, increased interest from the utility base. The results from the North American specifications and modeling approach were offered to the IEC working groups and in January of 1998, it was concluded that harmonization was feasible. Major UCA models, data definitions, data types, and services would be included in the final standard. Therefore, IEC

61850 was intended to be a *superset* of UCA. To date, teams of developers in the joint task forces are working in a continuous writing, editing, and negotiating process to create a standard that embraces both the UCA and European manufacturer directions and preferences.

SUBSTATION COMMUNICATIONS AND CONTROL ARCHITECTURE OVERVIEW

The communications architecture needs to be capable of data acquisition and control to and from each IED in the substation. The standardization working groups recognized the value in leveraging the technology being created for business and administrative local area networks (LANs) within the substation. Products developed for this huge information technology (IT) market are plentiful and cost effective. Existing and modified products will serve to create LANs in the substation.

Although the standard may specify other mechanisms as well, the working groups recognize Ethernet, more appropriately identified by the standard IEEE 802.3, is powerful and popular and are using it to define communications. The books "PC Week Switched and Fast Ethernet" available from Ziff Davis Press, ISBN 1-56276-426-8 and "Designing and Implementing Ethernet Networks" available from QED Information Sciences Incorporated ISBN 0-89435-366-7 are useful references for background information as is "Networking Standards, A Guide to OSI, ISDN, LAN, and WAN Standards," William Stallings, Addison-Wesley Publishing Company, ISBN 0-201-56357-6.

It is important to note that though the standardization relies on business office IT technology, the office and substation IT needs are quite different. The office IT environment supports few data servers and many data clients with little or no peer-to-peer communications. Substation LANs require many peer-to-peer connections and support many data servers with few data clients. Also, the operating environment in the substation and on the pole top requires much more robust components and devices. Communications systems need to function on a cold start during an ice storm and communicate from unventilated cabinets in direct sunlight on distribution poles. Work is ongoing to enhance office IT technology security, determinism, reliability, and maintainability for use in the substation.

Station and Process LAN

Within the standardization work, two separate substation LANs are being considered; the station LAN and the process LAN or bus. The station LAN connects all of the IEDs to one another and to a router or other device for communicating outside the substation onto a wide area network (WAN). The process bus conveys unprocessed power system information - voltage and current samples and apparatus status - from switchyard source devices to the relays or IEDs which process the data into measurements and decisions. For the process side of this bus, many manufacturers are creating microprocessor-based data acquisition units (DAUs) which act as Current Transformers (CTs), Potential Transformers (PTs), and status indicators. These forward data via a communication connection to the IED rather than the traditional hard wired method. When these data are communicated over fiber connections, isolation is provided between the DAU and the IED. The process LAN will support a single DAU, such as a CT, providing data to several IEDs, such as protective relays. DAUs also include intelligent processors imbedded directly in the switch or circuit breaker and merging units (MUs) that merge data from several devices such as CTs or PTs and communicate the values on the process LAN. It is possible to merge the station and process LANs into one physical communication network.

Peer-to-peer communications are accomplished through direct physical connections or via a virtual direct connection passing through multiple network connections.

A station LAN with all IEDs on one segment and a multiple segment process LAN design is shown in Figure 1. A merged station and process LAN is shown in Figure 2.

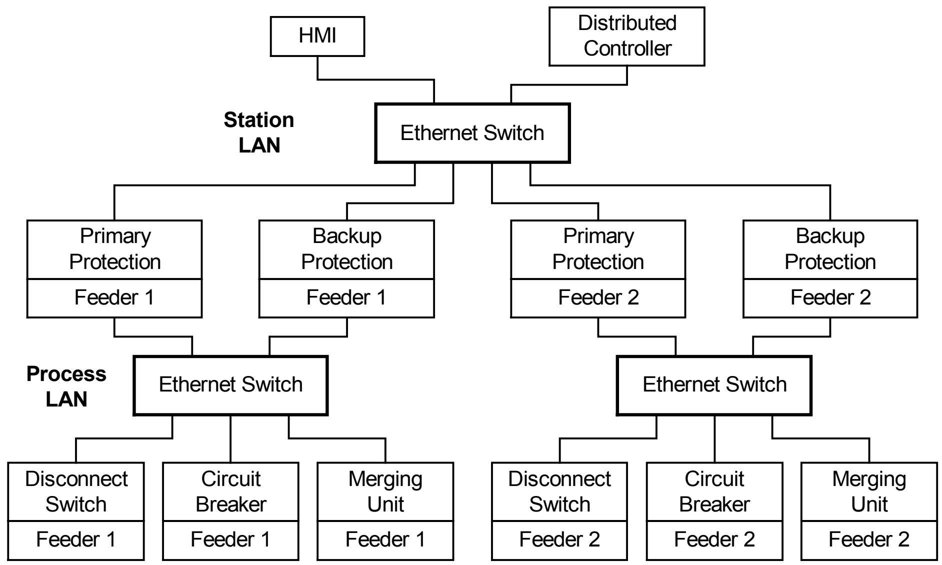

Figure 1: Station LAN and Multiple Segment Process LAN Design

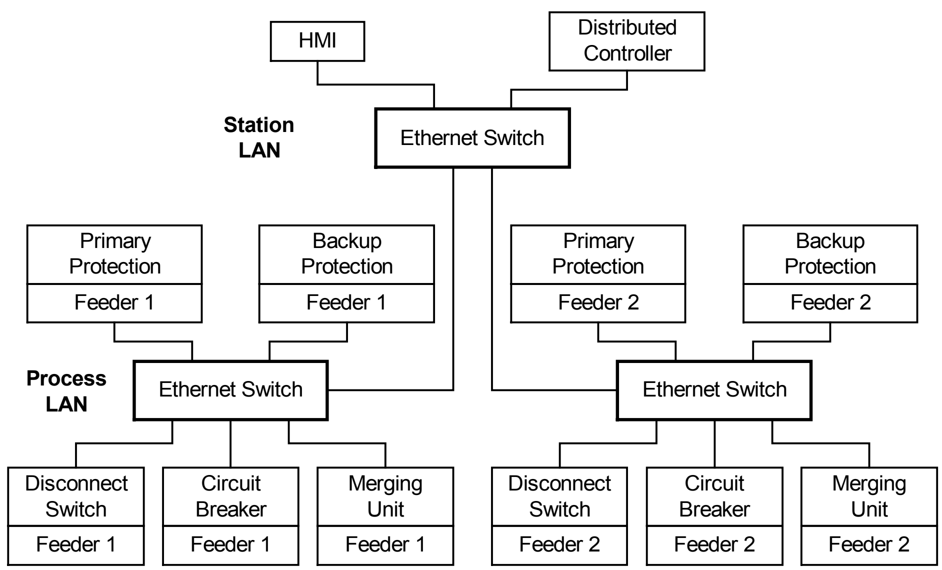

Figure 2: Merged Station and Process LAN Design

LAN Design Considerations

The example LAN designs in Figure 1 and Figure 2 are two of many different ways to configure the network. Other design methods improve reliability, speed, and maintainability. Optimizing reliability and speed create conflicting substation LAN designs. Speed is especially important for sophisticated distributed protection, synchro-check, and time synchronization of IED clocks. Peer-to-peer speed is fastest when all IEDs are connected on a single LAN segment but communication functions are more reliable when systems are redundant and without a single point of failure. It is important to keep in mind that if the mediation of data transmission control should fail, none of the devices on a LAN segment could communicate. This can be caused by the IED communications interface failing in such a way as to corrupt the network. The Ethernet phenomenon “broadcast data storm” is a failure where the Ethernet network interface of a device fails and begins to continuously broadcast messages corrupting communications with any recipient of the data. Switches and routers can prevent a broadcast data storm from influencing communications on other segments of the network but no data can be retrieved from the failed segment. Shared hubs pass on the broadcast data storm which therefore affects other connected segments.

Ultimately, the designer balances the needs to create isolated LAN segments for security, redundant systems for reliability, and monolithic and single segment LANs for high speed. The value of each need will be compared against the cost in dollars and additional processor burden within devices.

External Substation Connections

The IT products in the substation facilitate easy connection to other corporate systems through WAN or Internet connections. These connection possibilities highlight the importance of securing connections into the substation LAN. Figure 3 shows a previous substation network design with the addition of external connections.

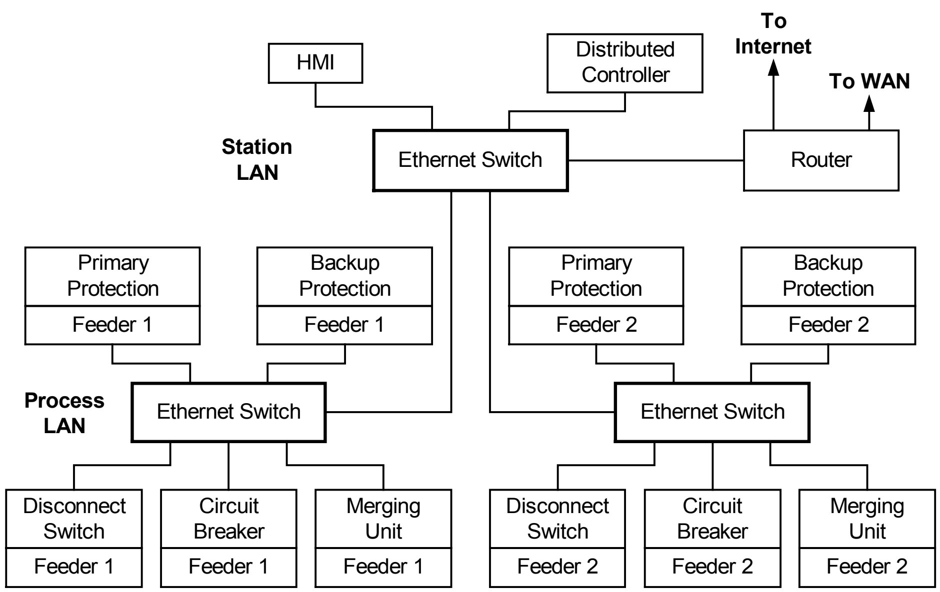

Figure 3: External Connections to Substation Communication Network

NETWORK COMMUNICATIONS ARCHITECTURE OVERVIEW

Communications Protocol Stack

The International Standards Organization (ISO) created the Open System Interconnection (OSI) reference model to define standardized methods for computers to communicate over networks. The OSI model is a conceptual reference that breaks the communications process into seven different layers. Each layer provides a small set of specific services to the layer below and the layer above, which provides independence. The functions of a specific layer can be modified without changing the overall structure of the model. The protocols defined at each layer establish a peer-to-peer relationship with the corresponding layer of the receiving device. The IEEE 802 specifications define Ethernet to be a subset of the OSI model defined as IEEE 802.3 Carrier-Sense Multiple Access with Collision Detection (CSMA/CD). The levels of the OSI reference model are shown in Figure 4 and described below.

- Application Layer – Provides a set of interfaces for applications to use to gain access to networked services.
- Presentation Layer – Converts application data into a generic format for network transmission and vice versa.
- Session Layer – Enables two parties to hold ongoing communications, called sessions, across a network.
- Transport Layer – Manages the transmission of data across a network.
- Network Layer – Handles addressing messages for delivery, as well as translates logical network addresses and names into their physical counterparts.
- Data Link Layer – Handles special data frames between the Network layer and the Physical layer.
- Physical Layer – Converts bits into signals for outgoing messages and converts signals into bits for incoming messages.

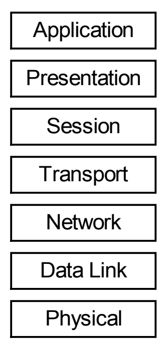

Figure 4: ISO OSI Model

Network Communications Devices

Hubs

A hub is a relatively simple multi-port device that rebroadcasts all data that it receives on each port to all remaining ports. It operates at the Physical layer of the OSI network model, so it does not use any of the data to determine routing actions.

Switches

A switch is an intelligent multiplexing device that monitors the data received on one port to determine its disposition. A switch operates at the Data Link layer of the OSI network model. If a data packet is incomplete or indecipherable, the switch ignores it and does not rebroadcast it. If a data packet is intact, the switch rebroadcasts it to another port, based on the addressing data included in the packet and the addresses associated with each port of the switch. Newer switches today can operate on the Layer 3 (Network) or Layer 4 (Transport) packet information.

Routers

A router is an intelligent multiplexing device used to connect two networks together. It can be a complex device, with many features. It operates at the Network layer of the OSI network model. A router is programmed to ignore intra-segment traffic and to route inter-segment traffic to the appropriate destination segment.

Servers

A server collects data from all of the local devices and creates a substation database. Often a local human machine interface graphics package uses data from this database. Servers function at the Application layer of the OSI model.

Media

Most Ethernet networks employ one of the following media.

- BaseT: specialized copper twisted-pair cable connections
- BaseF: fiber-optic cable (10BaseFL vs. 100BaseFX)

A data-rate indicator of 10 for 10, or 100 for 100 megabits per second commonly precedes the media designation. Engineers often select fiber-optic cable for substation monitoring and control system communications because it:

- isolates equipment from hazardous and damaging ground potential rise
- is immune to radio frequency interference and other electromagnetic interference
- eliminates data errors caused by communications ground-loop problems
- allows longer signal paths than copper connections.

Copper connections are sometimes selected for locations where the items above do not apply. This is because generally:

- copper costs less than fiber
- the equipment connected by copper costs less than equipment connected by fiber
- fewer special tools and skills are required to terminate copper.

Figure 5 shows the layer at which the various network devices interact with the messaging traversing the network layers.

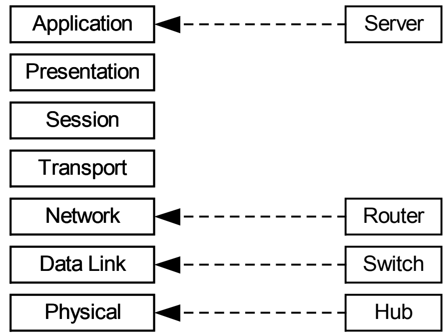

Figure 5: Network Device OSI Model Interaction

SPECIFIC IEC 61850 AND EPRI UCA 2.0 PROTOCOL STACKS AND DATA PROFILES

The layers of the seven-layer stack are logically separated to ease troubleshooting and to allow levels to be replaced without affecting neighboring levels. The more sophisticated Application layer provides the services necessary to perform data acquisition and control in the substation and also allows data sharing. This layer is expensive to develop and needs to be maintained longer than the quickly changing Physical layer. The Physical layer describes the signal transmission media independent of the communications protocols, i.e., copper, wireless, or fiber. The middle five OSI layers are often referred to as the protocol stack. The protocol stack describes a combination of protocols that work together to achieve network communications. Three common stack combinations are the OSI protocol stack, the combination of the transmission control protocol (TCP) and internet protocol (IP), and the combination of the user datagram protocol (UDP) and IP. The relationship of these protocol stacks within the Physical and Application layers is shown in Figure 6.

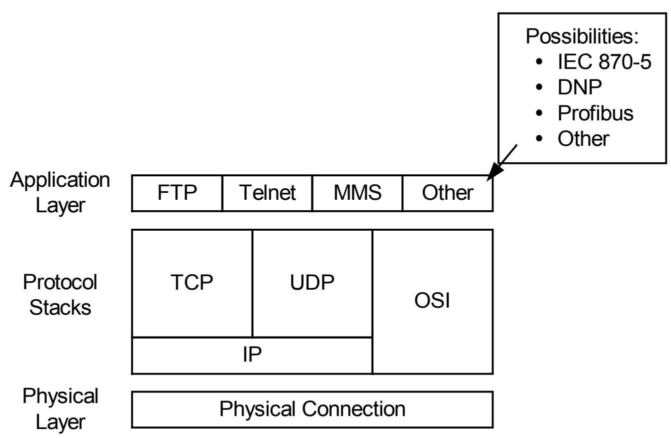

Figure 6: Parallel Protocol Stacks

Data Modeling Overview

One purpose of the IEC 61850 Standard is to completely and accurately define data representation and communication to accommodate systems built of IEDs and system components from multiple vendors. Rules are being created to uniformly identify data elements. Common data elements, defined in the standard, are described by these rules. The rules allow data elements, not identified in the standard, to be described in a standard format. Rules are being created to organize data elements into groups based on function or logical association. And finally, rules are being created to communicate these data using several different communication protocols and communication media. The design allows IED compatibility when using the same protocol and media but the different standard protocols and media are not intended to be interoperable. Therefore, the standard will support several non-interoperable communication methods that will use a single collection of data description rules.

The UCA Initiative has chosen the manufacturing message specification (MMS) protocol. Others under development or consideration include Profibus DP and FMS. Proponents have the option to pursue mapping of still other protocols.

Even though the standard has been derived within the context of the substation environment, its application is not limited to substation use but may be used for:

- Information exchange within the substation
- Substation to substation information exchange
- Substation to control center information exchange
- Distributed automation communication
- Metering related communications.

Standard Definitions

The following definitions of terms apply to the IEC 61850 Standard.

Class – A description of a set of objects that share the same attributes, services, and semantics.

Client – An entity that requests a service from a server.

Data (synonym data class) – An aggregation of named data attributes (the name represents semantic, e.g., “Temp” stands for Temperature)

Data attribute (synonym data attribute class) – Defines the name (semantic), format, range of possible values, and representation of values while being communicated.

Data attribute object – An instance of a data attribute class.

Data object – An instance of a data class.

Data object class – A specific instance of a data object.

Data set (synonym data set class) – A named list of ordered references to one or more data objects.

Data set object – An instance of a data set class.

Instance – An entity to which a set of services can be applied and which has a state that stores the effects of the services.

Logical device (synonym logical device class) – A grouping of logical nodes with a common relationship.

Logical device object – An instance of a logical device class.

Logical node (synonym logical node class) – An aggregation of data objects, data set objects, report control objects, log control objects, log objects, GOOSE control, and list of sampled values.

Logical node object – An instance of a logical node class.

Logical node zero – A special logical node class that represents information on the logical node object like name-plate.

Message – A specification of a communication between instances that conveys service specific information with the expectation that activity will ensue.

Object – An entity with a well-defined boundary and identity that encapsulates state and behavior. State is represented by attributes, behavior is represented by services and state machines. An object is an instance of a class.

Server (synonym server class) – Comprises the externally visible behavior of an application process.

State machine – A behavior that specifies the sequences of states that an object or an interaction goes through during its life in response to services, together with its responses and actions.

System – Refers to a specific substation system.

Standard Abbreviations

Abbreviations of commonly used terms within the IEC 61850 Standard include the following.

ACSI	Abstract Communication Service Interface
CDC	Common Data Class
DO	Data Object
GOMSFE	Generic Object Models for Substation and Feeder Equipment
GOOSE	Generic Object Oriented Substation Event
LD	Logical Device
LN	Logical Node
LNG	Logical Node Group
MMS	Manufacturing Message Specification
SCSM	Specific Communication Service Mapping

Virtual and Physical Devices

As shown in Figure 7 the ACSI data objects may reside in different places and in different device types. The physical source of the instrumentation is not always the server of the data. Some IEDs communicate data to another IED that acts as a gateway for the source IED and performs the server functions. In this way, the connected IED is represented as a virtual device within the gateway server and is not physically connected directly to the substation network.

The objects are the same regardless of where they exist. In addition, the server provides the complete self-description of the source IED.

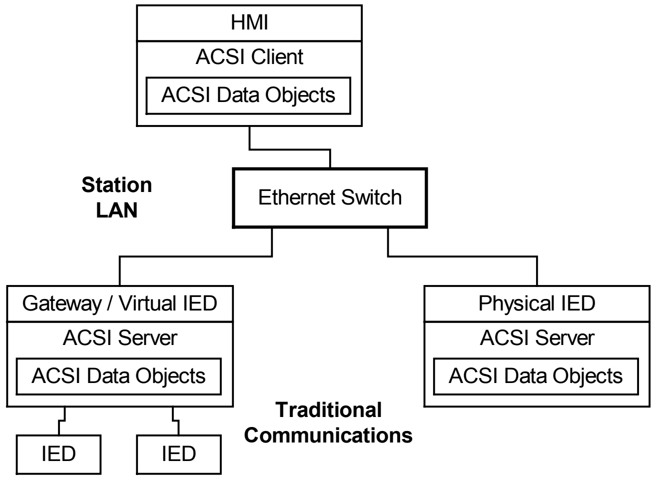

Figure 7: Where ACSI Server Can Reside

Compatible Logical Node Classes and Data Classes

The identification and description explicitly and uniquely identifies each data object within an IED in a standard way. In this way, data objects are uniformly defined by name and function across all IEDs. Logical node classes, data object classes and their relationship in the context of substations and feeder equipment are defined and used to build the hierarchical names and groups that reference the objects in the IEDs.

Common Data Object Classes

The IEC 61850 Standard identifies the different types of data objects and their association as listed below.

Status Information (objChar = ST):

- Single Point Status (SPS)
- Double Point Status (DPS)
- Step Position Information (SPI)
- Status Indication Group (SIG)
- Integer Status Information (ISI)

Control Information (objChar = CO)

- Single Point Control (SPC)
- Double Point Control (DPC)

Measurand Information (objChar = MX)

- Measured Value (MV)
- Binary Counter Reading (BCR)
- Harmonic Value (HV)
- WYE (WYE)
- Delta (DEL)

- Sequence (SEQ)
- Phase (PH)

Setpoint (objChar = SP)

- Analog Setpoint (ASP)
- Integer Setpoint (ISP)

Specialized Data Objects and Data Object Classes

A specialized data object is a collection of all attributes associated with a specific data value such as total current on line 1 i.e., "IL1", whereas a data object class is a named instance of a specific data object such as A-phase total amps i.e., "APhsA."

An example of specialized data objects and data object classes is in Table 1.

Table 1: Example of Specialized Data Object and Data Object Class

	Data Object	Data Object Class
Current	Total I	TotA
	IL1	APhsA
	IL2	APhsB
	IL3	APhsC
	INP (neutral, polarized)	ANeut
	INR (neutral, residual)	ARes

Logical Nodes and Logical Devices

A logical node is a collection of data objects, data set objects, report control objects, log control objects, log objects, GOOSE control, and a list of sampled values which define the boundaries of an entity and its state and behavior. Examples include IEEE elements such as logical node "distance protection" with logical node class name "PDIS" and IEEE number 21.

A logical device is a grouping of logical nodes with a common relationship such as the logical nodes representing the data and behavior of a protective relay including a device description node (logical node zero), protection node, supervisory control node, automatic switchgear control node and the instrument transformer node.

Logical Node Groups

The logical nodes are logical groupings of data objects and are grouped in the following 7 LNGs:

1. Logical Node Zero
2. Protection
   a. Protection functions
   b. Protection related functions
3. Supervisory Control
4. Switchgear

5. Instrument Transformer
6. Power Transformer
7. Further Power System Equipment

Logical Node Zero

Each Logical Device (LD) has a global logical node "zero" which is independent of all other logical nodes included in the LD. The Logical Node Zero (LLN0) is used to communicate the following:

- System commands and system return information
- System diagnosis information
- Settings and indication of a device status
- Time synchronization information from an internal or external clock.

Example logical node and logical node class naming is shown in Table 2 and Table 3. Protection function LN class names start with P. Switchgear LN class names start with X.

Table 2: Example Logical Node and Logical Node Class Names for Protection

LN	IEEE	LN Class
Basic relay object		PBRO
Zero speed and under speed	14	PZSU
Distance protection	21	PDIS
Volts per Hz relay	24	PVPH
Undervoltage	27	PUVR
Directional power	32	PDPR
Undercurrent or underpower	37	PUCP
Underexcitation	40	PUEX
Reverse phase or phase balance current	46	PPBR
Phase-Seq. or phase balance voltage	47	PPBV
Incomplete sequence relay	48	PISR
Thermal overload relay	49	PTTR
Rotor thermal overload	49R	PROL
Stator thermal overload	49S	PSOL
Instantaneous overcurrent	50	PIOC
Time overcurrent	51	PTOC
Power factor relay	55	PPFR
Field application relay	56	PFAR
Overvoltage	59	POVR

LN	IEEE	LN Class
Overexcitation	59/81	POEX
Voltage or current balance relay	60	PVCB
Earth fault protection (ground detector)	64	PHIZ
Rotor earth fault	64R	PREF
Stator earth fault	64S	PSEF
DC-overvoltage	64-DC	PDOV
Interturn fault	64W	PITF
Directional overcurrent	67	PDOC
Directional earth fault	67N	PDEF
DC-time overcurrent	76	PDCO
Phase-angle or out-of-step relay	78	PPAM
Frequency protection	81	PFRQ
Lockout relay, start inhibit	86	PLOR
Transformer differential	87T	PTDF
Line differential	87L	PLDF
Generator differential	87G	PGDF
Busbar or station protection	87B	PBDF
Restricted earth fault	87N	PNDF
Motor differential	87M	PMDF
Transient earth fault		PTEF

Table 3: Example Logical Node and Logical Node Class Names for Switchgear

LN	LN class
Circuit breaker	XCBR
Load break switch	XLSW
Disconnector / Earthing switch	XDIS
High Speed Earthing Switch	XHSW
Controlled switching device	XCSD
Gas measurement unit	XGMU
Monitoring and diagnostics for arcs	XARC
Monitoring and diagnostics for partial discharge	XPDC

Protection-related logical nodes are within the protection group abbreviated as P. As an example, the basic relay object reference abbreviation is P, for protection, followed by BRO for basic relay object or PBRO.

Table 4: Basic Relay Object Logical Node Data Objects

LN: Basic Relay Object Ref: PBRO Group: P (protection)		
Data Object Name	**Data Object**	**Data Object Class**
System Commands and System Return Information		
Blocking of LN function	BlFct	SPC
Set "test mode"	Test	SPC
Blocking information exchange	IEBl	SPC
Reset operation counter	OperCntR	ISC
Reset operation hours	OperhR	ISC
System Information		
General interrogation	GI	SPS
Operation counter, not resetable	OperCnt	ISI
Operation hours, not resetable	Operh	ISI
Group warning	GrWr	SPS
Protection Commands and Return Information		
Reset all targets	RsTar	SPS
Reset all latched outputs	RsLat	SPS
Enable resetting latch inputs	EnaRsLat	SPS
Protection Monitoring Indications		
Measurand supervision I	SupA	SPS
Measurand supervision V	SupV	SPS
Phase sequence supervision	SupSeq	SPS
Trip circuit supervision	SupTrCir	SPS
I>> back-up operation	TrOCOper	SPS
TVTR fuse failure	FuFail	SPS
Protection Fault Indications		
General alarm	GAl	SPS
General trip	GTr	SPS
Single Point Status Groups		
Protection phase targets (alarms)	PhsTar	ISI

Control related logical nodes are within the control group abbreviated as C. As an example, the switch controller object reference abbreviation will be C, for control, followed by SWI for switch object or CSWI.

Table 5: Switch Controller Object Logical Node Data Objects

LN: Switch Controller Ref: CSWI Group: C (control)		
Data Object Name	**Data Object**	**Data Object Class**
Measurand Identification		
Currents Total I	TotA	MV
Currents Total I	TotA (2)	ASP
System Commands and System Return Information		
LN ON (not OFF)	EnaFct	SPC
Blocking of LN function	BlFct	SPC
Blocking information exchange	IEBl	SPC
Active operation (not stand by)	AcOp	SPC
Local operation (not remote)	Loc	SPC
Activate characteristic	Ch	ISC
Reset operation counter	OperCntR	ISC
Reset operation hours	OperhR	ISC
System Information		
General interrogation	GI	SPS
LN Disturbance	DisDS	SPS
LN not ready	NtRd	SPS
Supervision alarm	SupAl	SPS
Parameter setting	PaSet	SPS
Operation counter, not resetable	OperCnt	ISI
Operation hours, not resetable	Operh	ISI
Switchgear Commands and Return Information		
Switch, general	Pos	DPC
Switch L1	PosA	DPC
Switch L2	PosB	DPC
Switch L3	PosC	DPC

As shown in Table 1, a specialized data object is a collection of all attributes associated with a specific data value and a data object class is a named instance of a specific data object. Table 6 lists the entries from Table 1 with an additional column demonstrating the logical nodes that reference the specific data object classes.

Table 6: Specialized Data Objects, Data Object Classes, and Associated Logical Node Example

	Data Object	Data Object Class	Logical Nodes
Currents	Total I	TotA	MMXU, TCTR, CSWI
	IL1	APhsA	MMXU, TCTR, AVCO, RDRE
	IL2	APhsB	MMXU, TCTR, AVCO, RDRE
	IL3	APhsC	MMXU, TCTR, AVCO, RDRE
	INP (neutral, polarized)	ANeut	PDIS, PIOC, PTOC, PDEF, RDRE
	INR (neutral, residual)	ARes	PDIS, PIOC, PTOC, PDEF, RDRE

THRUST OF THE STANDARDIZATION PROJECTS

We have presented a great deal of detail on specifics of the IEC 61850 Standard project and related UCA architecture. We now step back to consider the impact of the specific design presented in the standard.

Designers of the earlier generations of communications systems created a unique and specific format from bottom layer to top. They chose only certain layers from any existing standards, and the standardized layers in the stack were different for each design, so that there could be no interoperation.

In the IEC work, notice that the approach is completely different. The IEC 61850 Standard project has made its primary goal the creation of a substation-specific, object-oriented user layer, along with a specification of services or capabilities required of the Application and lower layers to support the user-layer design. Furthermore, it includes a list of stacks or profiles that can give this support, and maps the requirements of the user layer to the specific services and functions of a particular stack or profile. This list is subject to continual future updating, allowing adaptation of the substation layer to future advances in base communications technology. Separate sections of the IEC standard will define profiles such as Ethernet, OSI, and MMS; or Profibus with FMS. Every IED manufacturer then designs compatible, interoperable device models into the products. The user may still need to verify that the complete profiles for a selected array of IEDs for control of a particular substation match up and will interoperate.

The UCA project uses a compatible top-level modeling approach, but further specifies a limited set of profiles allowed in UCA-compatible devices. This supports immediately forthcoming demonstrations and follow-up commercial sales of multivendor substation control systems that can plug together and interoperate. The UCA-compatible profile used in virtually all of the equipment demonstrated at recent meetings uses Ethernet-based layers up through the Network layer; OSI Transport, Session, and Presentation layers; and the MMS Application layer. GOMSFE and GOOSE are the primary user object-oriented definitions that reside on top of the MMS Application layer; the IEC 61850 Standard is to include these as subsets of its more generic modeling.

While the IEC approach to process bus communications has been developed later than the substation LAN modeling, the approach is exactly the same. Object definitions will provide the bricks for construction of streaming data messages from the DAUs to the receiving IEDs. In addition, all the objects defined for the substation LAN are also valid for the process bus. With this process bus LAN, a relay can transmit settings or control commands to DAUs, merging units, or intelligent switchgear in the same way as with other substation IEDs.

Physical Connection Choices

It is interesting to point out again here that there is no required relationship between the communicated objects and the physical segments of the LAN. In principle, a relay that depends on an external DAU for a stream of data to process, and also interacts with its protection peers, need only have a single communications port. All the information to and from the relay can flow over the single connected LAN, which carries the entire substation data traffic load. For example, in Figure 5, all the IEDs and DAUs could connect to a single Ethernet switch.

This method of standardization ignores all questions of how much data can actually flow in any physical segment of the network. This must be verified by implementing system engineers, who must choose the routing or switching capabilities of the LAN to isolate elements of data flow and make the whole system work reliably. The new standards pay no attention to the most important traditional requirements for primary and backup redundancy, and for isolation of zones of protection.

The actual degree of isolation provided by Ethernet switches and routers has a big impact on these reliability factors. These interconnecting devices are complex, remarkably sophisticated, very fast special-purpose communicating computers, carrying brand names mostly unfamiliar to relay engineers - Cisco, Xylan, 3Com, and many others. They are standard products manufactured in large volumes, and have demonstrated excellent hardware and functional reliability in benign office or protected industrial environments. Because of the volumes, the cost for such a complex and intelligent device is surprisingly low. Nonetheless, these switches add significant cost to the substation control system total. The switch makers are still addressing the issue of electrical-environment robustness for substations. A few vendors have products that claim to address this need. Some experience may be needed to convince everyone that these general-purpose network nodes will survive, and are free of subtle design or programming features that could interfere in critical substation control situations. Some switch vendors are paying attention to the substation and industrial automation market, and there is reason to be optimistic about the prospect of improved reliability of these critical system components.

ADDITIONAL GOALS WITHIN THE STANDARDIZATION EFFORT

Though the groups involved agree on the value of standardizing communications processes and protocols, different factions within the standardization effort attach different levels of importance to the other various objectives. These other objectives include:

- Comprehensive modeling of substation equipment communications and functionality. Some intend to describe devices thoroughly enough to allow one type of device to be replaced by another from any manufacturer. This is referred to as interchangeability. Replacement of one device by another must not affect the function of the coordinated system and will be difficult to achieve due to the different operating principles used by different IED vendors.

- Self description. The purpose of self description is to reduce the engineering associated with configuration of data clients by having the IED describe its capabilities and communication parameters. This will be successful to the degree that the data client is equipped to make use of the information. Also, this process does not reduce the effort necessary to configure the IED itself or the effort necessary to maintain unique configuration software tools for each product or vendor.
- Power apparatus communication capability. As depicted in Figure 1, Figure 2, and Figure 3, the expectation is that communication, data acquisition, and control capabilities will be directly imbedded into the power apparatus and that they will communicate on the LAN.
- Reduction of conventional wiring. Figure 1, Figure 2, and Figure 3, while demonstrating IEDs, power apparatus and merging units communicating over LANs, also demonstrate the replacement of conventional wiring with simple communication connections. Data are communicated between devices via a single communication channel rather than the traditional method of a dedicated pair of copper conductors to sense every contact and measured value.
- High speed LAN. Most communication applications will be served by conventional office IT equipment if the devices are made more reliable and robust. However, some applications require very high speed and deterministic LAN communications. Examples include peer-to-peer control (GOOSE), and high resolution common time base synchronization for event recording, synchronized control, and high speed value sampling.

STATUS OF THE UCA PROJECT

The status of the UCA project has the major IED manufacturer implementations available during the year 2000 as either products or demonstration units. Most of the real world experiences to date have been limited to demonstrations and utility field installations. Unlike the formal IEC process, the UCA work is completed at the Utility LAN Initiative meetings held in conjunction with the IEEE/PSRC meetings. These meeting serve as a forum to discuss the progress of vendor implementation, utility demonstration sites, and address technical issues that remain open with some aspects of the implementation like the GOMSFE.

The main effort is focusing around the technical issues of the GOMSFE document. Many of these issues are related to the modeling aspects of the various protections and metering functionality and are a result of actual field usage, vendor implementation and other interoperability issues.

Key documents and elements of UCA 2.0 are:

- CASM V 1.5 – Common Application Service Models and Mapping to MMS
- GOMSFE V 1.0 – the Generic Object Models for Substation and Feeder Equipment
- GOOSE – Generic Object Oriented Substation Event for fast binary control of equipment like breakers
- Modeling Guide V 0.1 – Common Application Services Model: Guide to Device Modelers
- UCA Version 2.0 Profiles V 1.0 – Communications stacks and protocols
- IEEE SA TR 1550 – UCA 2.0 Technical report issued by IEEE SCC 36

Table 7 lists the active participants in the UCA projects (Source: Substation Communications Demonstration Initiative Meeting – September 1999).

Table 7: Utility and Vendor Participants

Participating Utilities	
1. AEP	16. NSP
2. AEPCO	17. NUON - TB
3. Ameren	18. OHSC
4. BE	19. PEPCO
5. BG&E	20. PPGC (Poland)
6. BPA	21. PP&L
7. Cinergy	22. ETS (SCE)
8. ComEd	23. TE
9. Coned	24. TU
10. Duke	25. TVA
11. Duquesne	
12. FPC	
13. GPU	
14. IP&L	
15. Nat'l Grid (England)	

Participating Vendors
1. ABB
2. Alstom
3. Basler
4. Beckwith
5. Bitronics
6. Cooper
7. Doble
8. Dranetz/BMI
9. GE/Multilin
10. GE/Harris
11. Telegyr (Formerly L&G)
12. Modicon/Square D
13. SEL
14. Siemens
15. Tasnet

STATUS OF THE IEC 61850 PROJECT

The IEC 61850 Standard has been organized by content as listed in Table 8.

Table 8: IEC 61850 Standard Contents

Part	Title
1	Basic Principles
2	Glossary of Terms
3	General Requirements
4	System and Project Management
5	Communication Requirements – Substation Automation System Functions
6	Substation Automation System Configuration
7	Basic Communication Structure – Principles and Models
8	Specific Communication Service Mapping (SCSM) – Mapping to MMS
9	Specific Communication Service Mapping (SCSM) – Mapping to point-to-point link with Ethernet
10	Conformance Testing

Each part is in a various stage of completeness. The IEC formal process requires each part to go through various stages, as defined in Table 9, prior to becoming an international standard. Table 10 indicates the various parts and clauses and their associated stage in the formal IEC standards process. Table 10 also indicates the maturity of the document by passing through the certain stages (PD, WD, CD, CDV, DIS, IS). Note a stage of 2CD indicates that the part status is on the second Comments Draft.

Table 9: IEC Document Status Process

Code	Name	Comments
PD	Personal Draft	Submitted by WG member for consideration.
WD	Working Draft	Not yet consensus, but agree that CD will be based on this text.
CD	Committee Draft	Agreement on basics, still undergoing technical revisions.
CDV	Committee Draft for Vote	WG consensus, balloted by National Committees.
DIS	Draft International Standard	Technical content agreed to by voting members, may require editorial changes.
IS	International Standard	Agreed to by voting members.

Table 10: IEC 61850 Part Status

Part	Title	Stage
1	Basic Principles	2CD
2	Glossary	1CD
3	General Requirements	2CD
4	System and Project Management	CDV
5 cl 1-3	Communication Requirements - Introduction	2CD
5 cl 4	Communication Requirements - Substation Automation System Functions	2CD
5 cl 5	Communication Requirements - Allocation of Functions	2CD
5 cl 6	Communication Requirements - Message Types	2CD
5 cl 7	Communication Requirements - Dynamic Performance Requirements	2CD
5 cl 8	Communication Requirements - Summary	2CD
6	SAS Configuration	1WD
7-1	Basic Communication Structure - Principles and Models	2CD
7-2	Basic Communication Structure - Abstract Communication Service Interface (ACSI)	2CD

Part	Title	Stage
7-3	Basic Communication Structure - Data Types for Data Object Classes	2CD
7-4	Basic Communication Structure - Compatible Data Objects	2CD
8-1	SCSM - Mapping to MMS	1CD
8-2	SCSM - Mapping to FMS/Profibus	PD
9-1	SCSM - Mapping to point to point link with Ethernet	CDV
10	Testing	1WD

The present goal of the IEC 61850 Standard is to have all of the parts issued in the calendar year 2001. At present, the issues surrounding the modeling and process bus may result in a delay of the issuance, but highly cooperative work amongst the members will attempt to deliver the standard on schedule.

PROSPECTS FOR UTILITIES AND OTHER USERS

Many vendors of Table 7 are on the verge of offering relays, meters, user interfaces, and integration tools which support UCA and/or IEC systems, and have demonstrated key capabilities in a multivendor environment. The vendor community and pioneer users have invested huge effort and money – helping to insure the likelihood of a successful commercial outcome and a robust supply of compatible equipment. Furthermore, the UCA and IEC projects have both shown an unusually high level of collegial cooperation and sharing among vendors with regard to the standardized communications interface.

It should be apparent, from earlier discussions in this paper, that these standards are not yet developed to the point where users can specify UCA-compliant or IEC 61850 compliant substation IEDs and know exactly what they are getting. Both efforts are complex and are behind the schedules put forth at the outset. However, the advanced state of the documentation, and the impressive demonstrations of interoperability at UCA meetings for the last year, give good confidence that dozens of manufacturers and utilities are deeply committed, and are reaching the goal.

Both projects include development of procedures by which manufacturers can demonstrate that their equipment complies with requirements of the standard, and is likely to interoperate with other devices from other vendors in a substation LAN. Independent test laboratories will conduct these conformance tests. This further assures potential buyers that certified equipment will connect together to successfully control a substation. Note that for both the IEC and UCA projects, the conformance testing definition still needs a lot of work - there are only incomplete paper documents so far.

Considering all this, a utility that wishes to use the standard communications system design in a near-term construction or refurbishment may need to regard this installation as an experiment. The prospective user should be prepared for changes to equipment in the field as the details are resolved. Those utilities listed in Table 7 who are installing UCA demonstrations are, for the most part, participating in the project meetings and keeping closely abreast of the status of the work. Only a few have limited interoperable demonstrations installed at the time of this writing.

Not surprisingly, no one has yet embarked on construction of a substation without dedicated control wires, although this is a key objective which drives the most demanding performance requirements. Quite a bit of experience will be needed with the full LAN control implementation before anyone will be in a position to delete the safety net of familiar, reliable, but expensive cable trays full of heavy dedicated-function wires.

LEGACY SUBSTATIONS AND EQUIPMENT

Vendors and utilities alike recognize the need to continue use of IEDs that do not directly support the new communications functions described within the standards. There is a huge installed base of existing IEDs that still have value. Many available IEDs needed to complete automated systems today and in the near future, will not be compliant to the new communication standards. Therefore, many new and retrofit station designs will be a hybrid of existing non-compliant products and new compliant products. Successful hybrid designs can be accomplished through the use of gateway devices that support traditional communications to previously installed and traditional, new non-compliant IEDs and then translate these communications onto a compliant LAN connection.

The gateway method is essential for the inclusion of some devices that simply cannot accommodate the complexity, additional cost, and processor burden required to become compliant with the new LAN communications. In this method, effective solutions for complete substations or subsystems built with lower cost devices can be connected to a Station LAN.

CONCLUSIONS

1. In North America and in Europe, major manufacturers and users of relays, meters, user interfaces, and other IEDs have recognized the need for a common data communications interface, allowing devices from all vendors to interoperate in the substation.

2. In North America, the EPRI UCA project has taken up the cause of interoperable multivendor substation communications and control systems, developing the detailed specifications and sponsoring or coordinating demonstration projects.

3. In Europe, the IEC has embarked on a parallel standards project 61850 for data communications systems for substation control and protection.

4. The two development teams have committed to develop compatible standards in which the UCA specification is a subset of the more general IEC standards group. This should lead to a single standard communications design approach for all future equipment from around the world.

5. Both projects include not only the now-familiar data gathering and IED setting capabilities, but also high-speed peer-to-peer control messaging and process streaming data acquisition from switchyard transducers and sources. The objective is to ultimately replace all of the wiring in the substation with multiplexed LAN connections, greatly reducing wiring and commissioning costs in substation construction or refurbishment projects.

6. A specific profile of communications layers, shown for both projects, uses Ethernet implementations for the three bottom layers. Substation IEDs connect through networks of Ethernet switches, with routers for connection of the substation LAN to the utility enterprise WAN.

7. The paper has provided a body of technical explanation, plus a compendium of technical terms and acronyms appearing in the literature on these projects.

8. While neither the IEC nor UCA project is complete, there is strong movement towards the goal within the next two years. UCA has already been showing impressive live laboratory demonstrations for a year, plus a few limited field demonstrations.

9. The time has not yet arrived for users to routinely specify or order IEC/UCA compatible IEDs. However, there is a massive commitment by the community of manufacturers and users. Over two dozen utilities have undertaken installation projects. These technical developments are exciting to those who have sought a common communications approach, and many are participating in one or both specification projects to contribute or to monitor progress.

10. The standardization approach allows for connection of IEDs designed before these standards come into widespread use, or which are too small and simple to support the most sophisticated communications stack. Interfacing devices are already available which can handle the transfer of messages between the non-Ethernet IEDs and the upcoming Ethernet substation LAN.

BIOGRAPHY

Eric A. Udren received his BSEE from Michigan State University in 1969. He joined the Westinghouse Relay Division, where he developed software for the world's first computer-based line relay. He worked in relay design and application until 1978, when he supervised system design, and relaying and control software development, for the EPRI-sponsored development of the first LAN-based substation protection and control system. In 1986 he returned to relay application with Westinghouse in Coral Springs, FL, later a part of ABB. In 1996, he joined Cutler-Hammer in Pittsburgh as a development manager for relays. He presently serves as Engineering Manager for the Cutler-Hammer Power Management Products Center. Mr. Udren received the MSEE from New Jersey Institute of Technology in 1981, and the Certificate of Post-Graduate Study in Engineering from the Cambridge University (UK) in 1978. He is a Fellow of IEEE; and chairman of two Working Groups and a Task Force in the IEEE Power System Relaying Committee (PSRC). He is the Technical Advisor to the US National Committee of the IEC for Protective Relays. He is lead US Delegate to IEC TC 57 Working Group 12 on switchyard data communications. He has presented over 35 technical papers on relaying topics, including an IEEE Prize Paper; two papers in the new IEEE Press Book on Protective Relaying, Vol. II.; and is a contributor to the Westinghouse/ABB Applied Protective Relaying reference volumes.

Steven A. Kunsman joined the ABB Automation Inc., formerly known as Brown Boveri Corporation, in 1984 in the Design Support Group. He graduated from NCC with an AS Design Technology and from Lafayette College with a BSEE. He is presently in pursuit of an MBA with a concentration in Management of Technology at Lehigh University, School of Business and Economics. In 1992, Steve transferred into the microprocessor Product Development Group and was a core team member in the development of the DPU2000 and later the 2000/R series product line and the Modbus Plus communication interfaces. He presently holds the position of Manager, Product Technology and Engineering for the ABB Substation Automation and Protection Division. He is Member of the IEEE Power Engineering Society and is a US delegate to the IEC TC57 Working Group 12.

David J. Dolezilek received his BSEE from Montana State University in 1987. In addition to independent control system project consulting, he worked for the State of California, Department of Water Resources, and the Montana Power Company before joining Schweitzer Engineering Laboratories, Inc. in 1996 as a system integration project engineer. In 1997 Dave became the Director of Sales for the United States and Canada and he now serves as the Engineering Manager of Research and Development in SEL's Automation and Communications Engineering group. In 2000, Dolezilek was promoted to Automation Technology Manager to research and design automated systems. He continues to research and write technical papers about innovative design and implementation affecting our industry, as well as participate in working groups and technical committees. He is a member of the IEEE, the IEEE Reliability Society, and the International Electrotechnical Commission (IEC) Technical Committee 57 tasked with global standardization of communication networks and systems in substations.

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