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Design and Implementation of a UCA-based Substation Control System

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ABSTRACT: With the maturing of the Utility Communication Architecture (UCA), utilities are beginning to implement substation protection and control systems that are based on this technology. This paper describes such an implementation for the control of the Bateias 525kV substation on the COPEL power system in Brazil. In particular, the paper will describe the customer's requirements and expectations with regard to the information flow, control sequences, automation functions, and reliability. The design of the substation automation architecture to meet these customer requirements will be presented including the communication network structure, and redundancy software. Also to be discussed will be the installation issues encountered and system performance levels achieved.

In addition to the above, the paper will include a brief tutorial on UCA.

KEYWORDS: UCA2.0, CASM, Substation Architecture, High Availability, Redundancy, SCADA, GOOSE, GOMSFE, IEC-61850, ECS

I. NEEDS OF COPEL

Bateias substation is an important high Voltage transmission substation for COPEL. There are four voltage levels in the substation: 525 kV, 239 kV, 138 kV and 13.8 kV. The major needs for the automation system as outlined by the customer were as follows:

Collection of Information: COPEL needed to collect analog and digital information from the equipment in the substation. This was to facilitate local operations by providing the consolidated metering values, alarm and status information. A substation level sequence of event recorder was required to monitor various events up to millisecond accuracy.

Control and Monitoring: A need for substation level control and monitoring was specified. COPEL wanted a defined control hierarchy to be implemented between the three Energy Control Stations (ECS), local substation and IEDs. Monitoring for various alarm conditions, demand reports, energy reports were also specified. The ECS specified required three different SCADA communication protocols, hence a protocol translator was required to communicate to the various ECS systems

High Availability / Redundancy: A requirement for "no single point of failure" was specified to provide high availability of the system. This required a redundant architecture for the system. Two independent communication systems and substation control computers were subsequently supplied. In the event of failure of one communication network or computer, the other component was required to perform the tasks needed for the automation system.

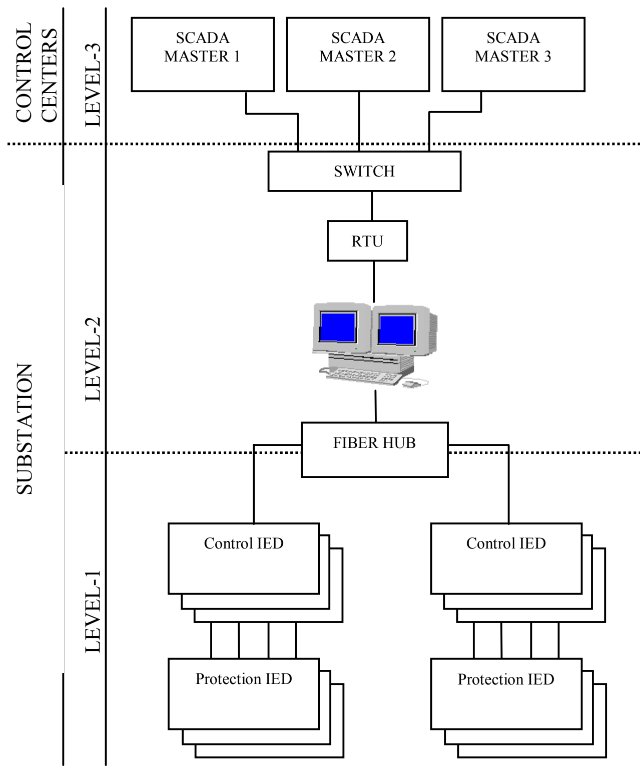

FIG. 1. AUTOMATION SYSTEM OVERVIEW

Automation Functions: COPEL specified a detailed interlocking schema for control of the substation. The control scheme required a bay controller type of application to be implemented. I/Os from the various field equipment were involved in the logic decision for the control operations. An automated control model was specified by COPEL for all the breakers and switches in the substation. Transformer thermal curve calculation was required as part of the automation functions. Features like check for mutual exclusivity between various binary contacts and Select Before Operate (SBO) for controls were also among the needs defined by the customer.

Capability for Future Expansion: Two bays were identified as future bays in the system. A requirement for a modular and extensible architecture was specified.

Fig. 1 describes the system overview for the Bateias substation.

II. INTRODUCTION OF UCA 2.0 / IEC-61850

Electric Power Research Institute (EPRI) launched a concept in 1990 known as the Utility Communication Architecture or UCA. The goal behind UCA was to identify a suite of existing communication protocols that could be easily mixed and matched, provide the foundation for the functionality required to solve the utility enterprise communication issues, and be extensible for the future. UCA provides a "network" solution to the interconnection of data sources – similar to the web solution used throughout the world to interconnect computers.

At this time, the next generation of Intelligent Electronic Devices (IEDs) based on UCA are available. These devices are focused on networking in the substation and are based on the Manufacturing Messaging Specification (MMS) / Ethernet profile with one of two "networking" layers in-between (see figure 2).

Generic Object Models for Substation and Feeder Equipment (GOMSFE)	
Common Application Service Models (CASM)	
Manufacturing Messaging Specification (MMS)	
International Standards Organization (ISO) Networking Layers	TCP/IP Network Layers
10/100/1000 MB Ethernet Twisted Pair / Redundant Fiber	

FIG. 2. UCA2 – SUBSTATION COMMUNICATION PROFILE

Ethernet: Ethernet was chosen as the Physical / Data Link layer 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, the scalability of Ethernet is well defined with 100Mb implementations becoming the standard, 1Gb gaining acceptance, and 10Gb Ethernet well on its way into hardware. Processors are available today with multiple 10/100 Mb Ethernet ports integrated into the chip.

A concern was raised early on as to the reliability of the "on time" message delivery capability of Ethernet due to the Carrier Sense Multiple Access (CSMA) nature of Ethernet. When two or more IEDs desire access to the Local Area Network (LAN) simultaneously, a data collision may occur. When this happens, all colliding devices set a random delay time and try again, after the delay, to get access to the bus. There is a probability that subsequent collisions may occur which could delay critical messages from being delivered in a timely manner. For the substation environment, "timely" was defined to be 4ms in order to perform functions such as, tripping over the LAN. To quantitatively address this concern, a study was undertaken by EPRI where the performance of Ethernet was evaluated under a "worst case" scenario in comparison to a 12 MB Token Passing Profibus network. Results of this study [1] showed that either 100Mb Ethernet on a shared hub or 10Mb Ethernet connected via a switched hub could meet the 4ms network communication time - both of which were faster than the token bus solution operating at 12Mb.

TCP/IP, OSI Network Layers: As it was deemed desirable to be able 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 networking layers.

TCP/IP stands for Transmission Control Protocol / Internet Protocol which is the ubiquitous network layer used over the Internet. Its inclusion in the profile is due to its omnipresence and overall acceptance in the marketplace. TCP/IP is a streaming protocol which means that transmission of a packet of data waits for either a "stream" of data (such as that from a teletype terminal) to fill a buffer or a time-out 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 control messages to multiple devices.

MMS: MMS is an ISO defined (ISO 9506) protocol that provides application services. MMS provides services such as read, write, get file, get list of file, etc. to the relays. It supports object oriented data definitions, which makes self-description a reality. Support for unsolicited data reports and file transfers are also some of the services offered by MMS.

CASM: CASM (Common Application Service Models) provides the mapping of the substation specific applications (such as Select Before Operate, Exception Reporting, File operations) into the underlying MMS services. For example, the Select Before Operate service is broken down into multiple MMS Reads and Writes, File services defines the file formats and file access mechanisms. CASM makes it possible to easily map these services onto other application layers.

The ability to perform exception reporting is also defined in CASM. Exception reporting is the concept of only sending data items when one of them has changed. This is a major paradigm shift from traditional SCADA that has to constantly poll the source to detect changes in data.

GOMSFE: GOMSFE or Generic Object Models for Substation & Feeder equipment defines standard data models for equipment and functions found in the substation. By defining and using common objects, UCA provides intra-operability between different devices and user interfaces. GOMSFE provides the guidelines on how to model an IED and it also defines, in detail, the protection setting objects and the peer to peer communication object model - GOOSE (Generic Object Oriented Substation Event).

GOMSFE uses the basic data types like Integer, Float, String etc. to define more complex data models specific for the application. For example, a data measurement on a three phase system (WYE class) may have up to ten data members {PhsAi, PhsAf, PhsBi, PhsBf, PhsCi, PhsCf, Neuti, Neutf, q, t} where PhsAi represent the phase A value in 32 bit signed integer format, PhsAf, represent phase A value in 32 bit float and so on. Furthermore, GOMSFE defines combined models known as Bricks that aggregate similar types of data. See Fig. 3 for an example of a measurement unit brick

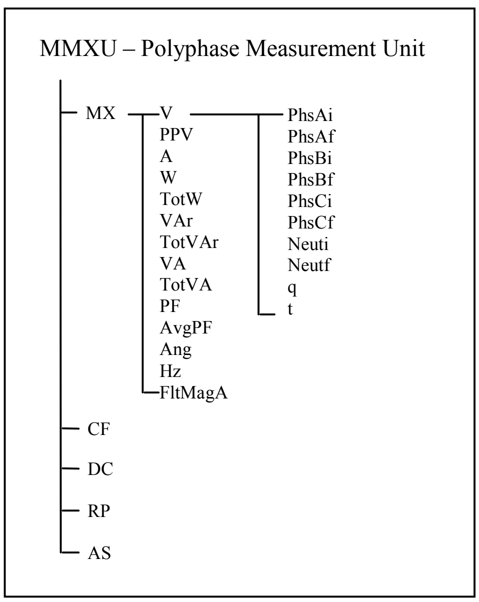

FIG. 3. UCA2 – GOMSFE – MMXU BRICK DEFINITION

The current version of GOMSFE defines 55 different bricks. Among the GOMSFE defined bricks, only the GLOBE brick is mandatory. GLOBE defines the device level status, set points, controls, configurations, description, access mechanism and reports. One of the reporting models is GOOSE. GOOSE allows the IEDs to communicate state and control information amongst themselves using an MMS based publisher and subscriber mechanism. By publishing a GOOSE message, an IED can report its status or request a control action to any device on the network. One GOOSE message can carry up to 96 control or status points. The IEDs subscribing to the GOOSE reports from remote peers can use the information to perform any logic or control associated with the GOOSE bit pairs. Fig. 4 illustrates the GOOSE operation model.

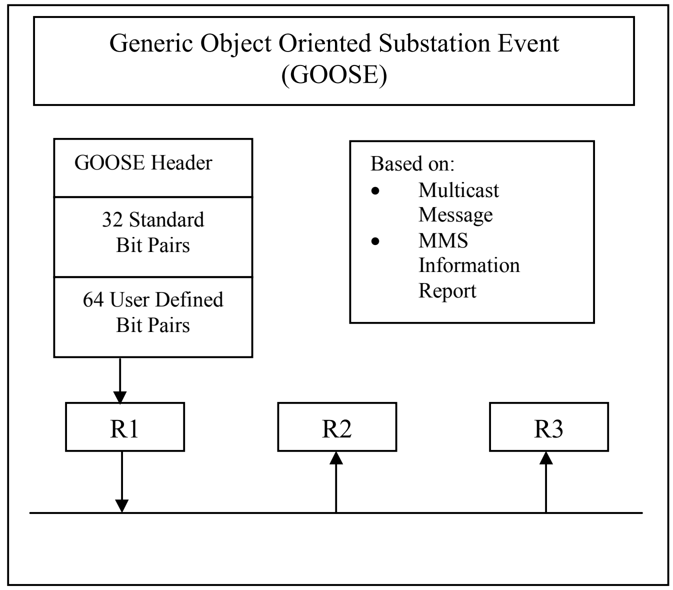

FIG. 4. UCA2 – GOMSFE – GOOSE APPLICATION

The following features of UCA made it a simple choice for COPEL's Bateias substation system:

1. High performance based on 10Base-F network with ease for future upgrade to 100Base-F
2. Simultaneous dual accesses to IEDs for real time data transfers and controls. UCA IEDs support multiple concurrent connections eliminating duplicate wiring for communication. Each computer makes a separate connection to the IEDs, thus providing built-in redundancy for communications.
3. Standard application definitions for network and protocol independence
4. GOMSFE / GOOSE definitions for interoperability between the current selection of IEDs. In the future, the current IEDs can be replaced with only a few changes to client applications in the substation computers
5. Elimination of wiring between IEDs by maximizing the use of GOOSE for the transfer of status and control information
6. Low cost for Application development, as there is high re-usability in terms of configuration and scripting for the HMI tools.

III. SUBSTATION ARCHITECTURE

The system architecture for Bateias (shown in Fig. 1) is divided into three levels. Level-1involves IEDs connected to process equipment in the substation. The IEDs are classified as either protection or control IEDs. Protection IEDs provide all the status information to the control IEDs that in turn implement the control logic for the substation operation. The protection IEDs do not directly communicate to the higher levels in the architecture. The control IEDs act as UCA servers and allow multiple UCA clients to make

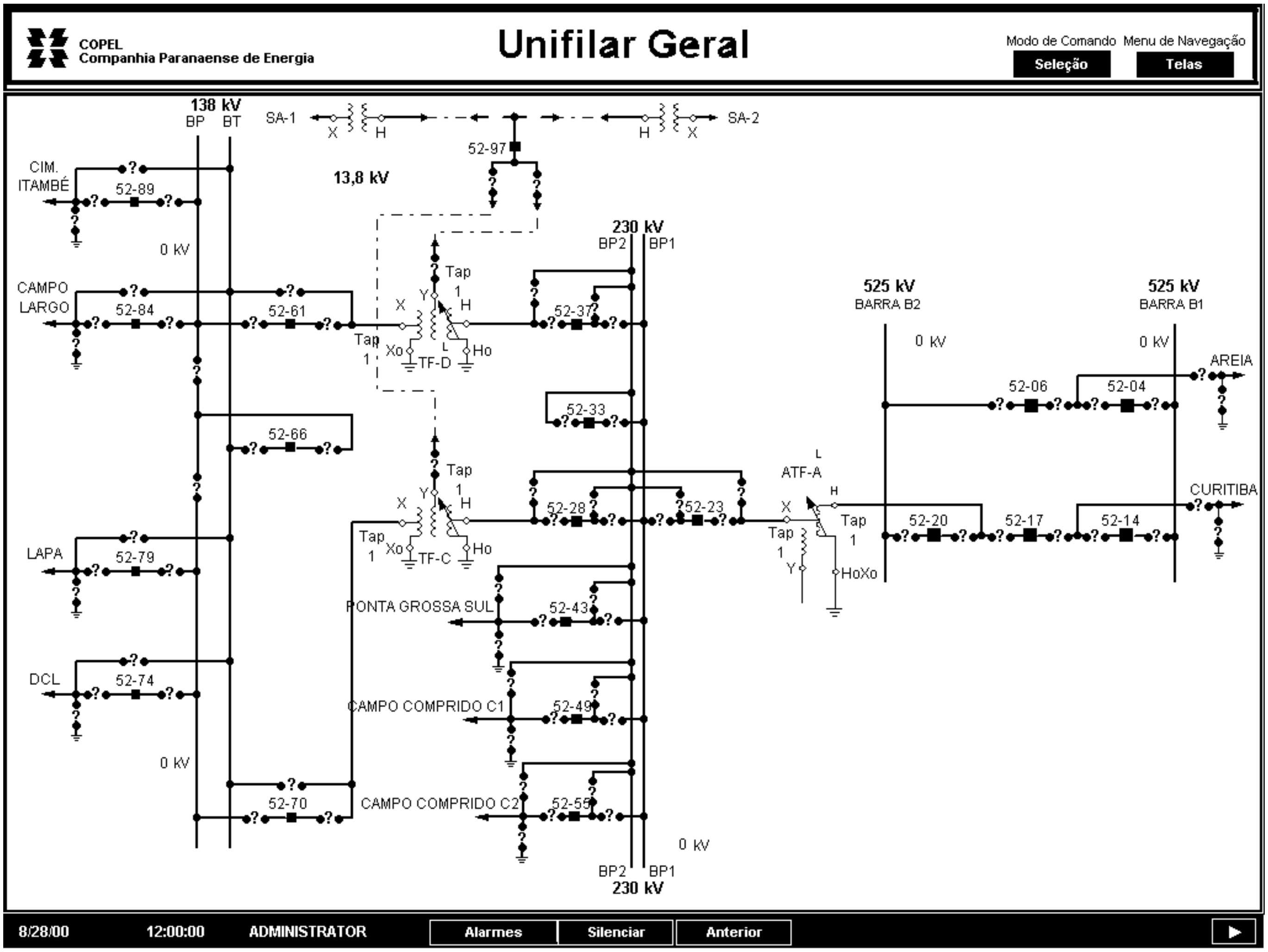

FIG. 5. BATEIAS SUBSTATION ONELINE DIAGRAM

simultaneous connections to it. Control IEDs also send and receive GOOSE messages to each other using the substation fiber LAN. There are 42 control IEDs in this substation. Each control IED provides redundant 10BaseFl - ST type connections to itself. The fiber cables from the IEDs are connected to two layers of switched HUBs.

The HUBs are smart enough to recognize and break loops of messages. They run spanning tree algorithm using SNMP (Simple Network Management Protocol) to ensure a path to the device and to realize and break duplicate paths to the device.

Level-2 consists of the two substation computers with dual monitor displays. Each computer system runs its own UCA client to connect in real time to all 42 UCA IEDs. TCP/IP is used as the choice for the network protocol to run MMS requests between the UCA clients and servers. Fig 6 shows the software architecture used inside the computers. For simplicity sake, only important software components are displayed. Both computer systems run asynchronous to each other. A user can perform all monitoring and control operations from either computer at any given instance of time. Special redundancy software in each computer monitors the tasks in each computer to determine failures. It also maintains the latest configuration using database replication between the two computers.

Level-2 also emulates RTU (Remote Terminal Unit) functionality for three remote ECS locations using three different SCADA master protocols, namely: DNP3.0, Microplex 5000 and Conitel. Since both host computers share the same data and can run the SCADA emulation software, a cross-over network was designed that allows the SCADA emulation to be provided by either host computer. Mapping tools were developed to map UCA data onto the various ECS protocols.

Level-3 refers to the Energy Control Systems of the utility. As mentioned, Bateias interfaces with three ECS systems named COE, SE and Electrosul.

IV. PERFORMANCE

The substation system offers high performance for data updates and controls when compared to traditional non-UCA system. A typical data update rate for a brick of data like MMXU (Measurement Unit) takes 20 to 30 milliseconds. The following performance figures are achieved for the various IEDs:

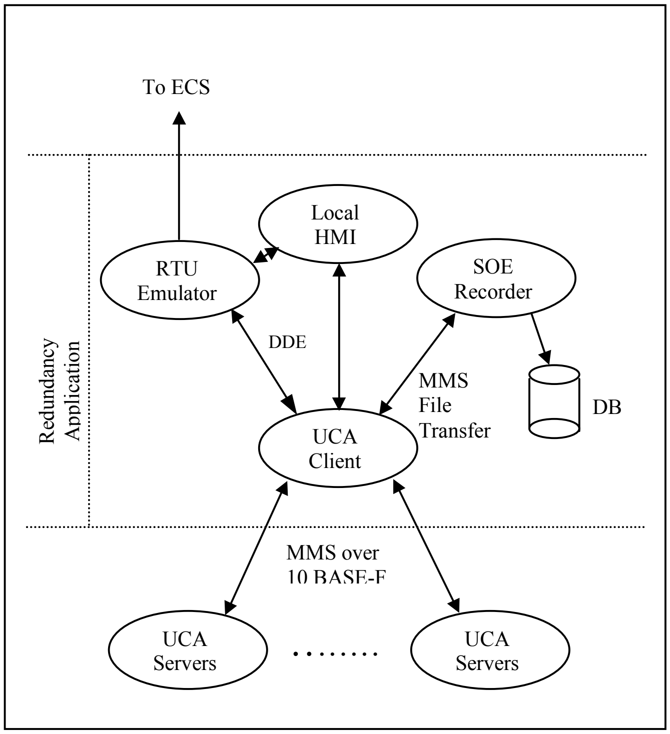

FIG. 6. BATEIAS LEVEL-2 SOFTWARE ARCHITECTURE

- Data Update rate at the HMI - under 1 second
- Site Event recorder update - under 2 seconds (when 10 events are generated every second at the IEDs)
- Site Event recorder update - under 3 seconds (when 100 events are generated every second at the IEDs)
- Control execution - less than 1 second.
- During commissioning, 14 million GOOSE messages were recorded during one 18 hour period. The system ran flawlessly during the GOOSE flood.

V. INSTALLATION ISSUES

While performing the system integration for the Bateias substation, some installation issues were encountered and addressed. Since a relatively newer technology was used, a number of firmware and software revisions were required before an acceptable performance level was achieved. From our installation experience, there are a number of areas that we feel that could be addressed to facilitate the integration of UCA based systems:

- A smart IED settings program is required to cross check the GOOSE settings between various IEDs in the system. IEDs now subscribe many remote IED GOOSE messages. Since a unique user bit pair is mapped from a remote IED, changing that bit pair combination requires all subscribers to be notified. This may be an easy task with few IEDs but with 42 IEDs it wasn't so simple.
- A GOOSE Monitor / Historian program is required to facilitate the debugging of the distributed logic that one can now create. Specifically, the ability to trigger a GOOSE capture based on logical expressions of GOOSE bits would be very useful. In general, a GOOSE GOOSE historian to monitor traffic and other performance features is desirable.
- UCA is still evolving and merging with the IEC-61850 standard. The current version of the object models (GOMSFE 0.91) is due to be revised shortly. With the new version of GOMSFE, some object models may not be downward compatible. As such, tools to re-map objects from one version of GOMSFE to another would save time in an upgrade situation.

VI. BENEFITS

In implementing the Bateias integration system, a number of benefits were identified as a result of using the UCA substation network approach:

- Lower cost of Engineering as drawings were simplified
- Lower cost of installation as less wiring was needed
- Standard object models for data names and Self describing feature of the UCA reduced the time to map data to the HMI
- Lower cost of commissioning as most of the operation errors could be correct via logic re-configuration. Minimal re-wiring was required.
- Modular HMI screens design gave high re-usability of screens and set the stage for future expansion and upgrades
- Data values were reported directly in engineering values so no scaling was required
- The choice of standard Ethernet for the substation LAN allowed the use of off the shelf hubs, Network Interface Cards (NICs), and other communication equipment and tools
- All fibers based Ethernet network basically eliminated the effects of electrical noise on communications.
- Twist in and out connectors meant no communication wiring screws to undo

Although not required on this job, the use of standard UCA communications would have facilitated the integration of other manufacturer's equipment into the system.

VII. SUMMARY

This paper documents the design of a substation integration system from functional specification to system design to implementation and commissioning. A system solution based on UCA was presented and the benefits (including performance) were identified.

VIII. REFERENCES

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IX. BIOGRAPHIES

Mark Adamiak received his Bachelor of Science and Master of Engineering degrees from Cornell University in Electrical Engineering and an MS-EE degree from the Polytechnic Institute of New York. From 1976 through 1990, Mark worked for American Electric Power (AEP) in the System Protection and Control section where his assignments included R&D in Digital Protection and Control, relay and fault analysis, and system responsibility for Power Line Carrier and Fault Recorders.

In 1990, Mark joined General Electric where his activities have ranged from development, product planning, and system integration. He is presently Manager of Advanced Technology Programs and is responsible for identifying and developing next generation technologies for the utility and industrial protection and control markets. In addition, Mr. Adamiak has been actively involved in developing the framework for the implementation of the MMS/Ethernet peer-to-peer communication solutions for next generation relay communications. In 1986, Mark was the winner of the Eta Kappa Nu (HKN) society's "Outstanding Young Electrical Engineer" award. Mark is a member of HKN, a Senior Member of IEEE, past Chairman of the IEEE Relay Communication Sub Committee, a member of the US team on IEC TC57 - Working Group 11 on Substation Communication, and a registered Professional Engineer in the State of Ohio.

Ashish Kulshrestha received his Bachelor of Engineering degree from S.G.S. Institute of Technology and Science (Indore, India) in Electronics & Instrumentation Engineering. From 1993 to 1998, Ashish worked at CMC Limited (a leading company in India to provide systems services and consulting). His assignments included working on various Information Technology projects involving high availability and redundancy for financial systems.

Since 1995, Ashish was involved in the system integration of Power Substation Systems (while consulting at General Electric). In 1998, Ashish joined KVB-Enertec where his activities have ranged from development, product planning, and system integration. He is presently Manager of Products and Software for Power Systems. Ashish was the primary project engineer for the COPEL Bateias system.