Integrating UCA at the TVA/Tiptonville Switching Station for SCADA and Relay Protection Applications

By

Brian Smith
Tennessee Valley Authority
Chattanooga, TN

Craig McClure
Tennessee Valley Authority
Chattanooga, TN

Randy Ehlers
Utility Consulting International
Cupertino, CA

INTRODUCTION

The difficulties and complexities of integrating Intelligent Electronic Devices (IEDs) from different vendors equipped with different communication protocols have bedeviled the electric utility industry since the introduction of IEDs in the 1980's. In response to this problem, the Tennessee Valley Authority (TVA) began shifting its attention to Utility Communications Architecture (UCA) in the mid-1990s. Intent on getting experience with this new technology, TVA completed a demonstration UCA project at its Paradise Power Plant in Kentucky in May 1999. In September of 2003 it completed a second UCA project at its Tiptonville switching station site in northwest Tennessee, not far from Reelfoot Lake.

The Tiptonville project broke new ground, integrating both Supervisory Control and Data Acquisition (SCADA) and relay protection applications into a networked, multi-vendor IED product environment. Tiptonville is a two-year old switching station that includes four 161KV power circuit breakers in a main and transfer bus arrangement that provides for connection to three transmission lines and a customer's local distribution substation. From the very beginning, construction plans focused on UCA networked communications as the basis for station management.

BACKGROUND

The Tennessee Valley Authority, set up by the U.S. Congress in 1933, is a federal corporation and the nation's largest public power company. Eleven coal fired plants, three nuclear plants, 29 hydro-electric plants, six combustion turbine plants, and one pumped storage plant make up the bulk of TVA's generation assets. TVA's power service area, with 17,000 circuit miles of transmission lines, covers 80,000 square miles in the southeastern United States. It includes almost all of Tennessee and parts of Mississippi, Kentucky, Alabama, Georgia, North Carolina, and Virginia. TVA's customer base comprises 158 municipal and cooperative power distributors and 62 large directly served industries and government installations.

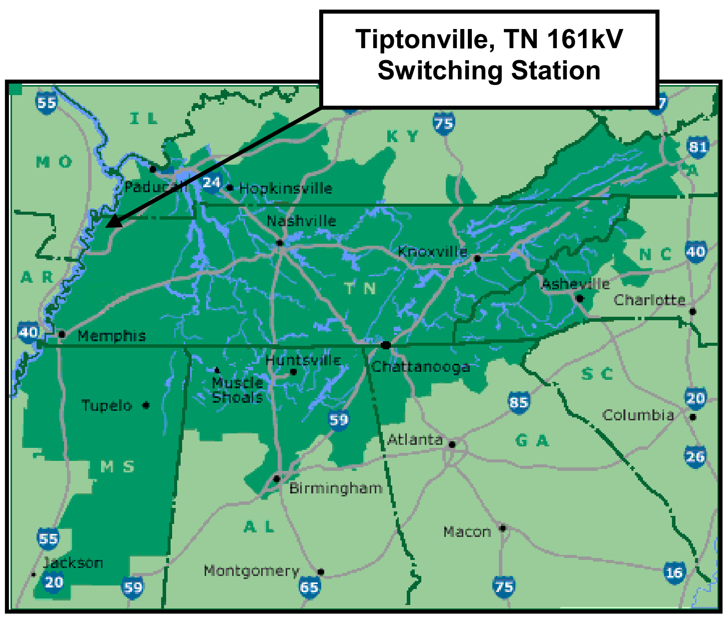

Figure 1 – TVA Service Territory

PROJECT OVERVIEW

The overall scope of this project provided additional transmission capacity in the NE Tennessee region of the TVA system by building a new 161kV transmission line and the Tiptonville switching station.

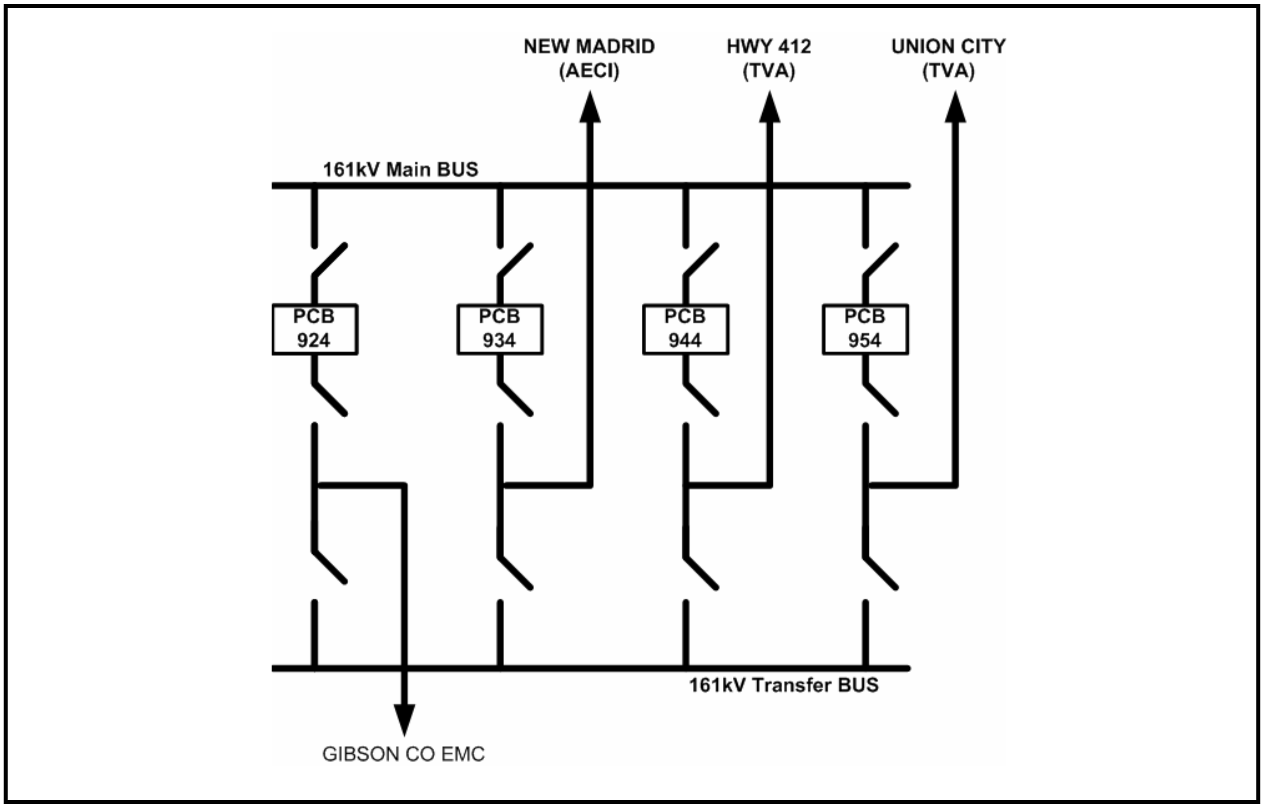

Figure 2 – Tiptonville One Line Diagram

Figure 3 – View of 161kV Switchyard

Design Objectives

The decision to use a common, UCA-compliant LAN was perhaps the single most important key for enabling broad use of advanced technologies within the substation environment. This key unlocks the potential to access a wealth of data and functionality from IEDs. It enables the deployment of distributed applications that require peer-to-peer communication among IED devices. It enables centralized control systems to provide strategic guidance to those distributed applications, while receiving continual feedback from them for system-level assessment. Most importantly, the approach offers an abundance of flexibility, in contrast to the rigidly wired systems that precede it, so that systems can continue evolving without undue economic constraint. Clearly, powerful communication capabilities that promote interoperability among connected devices and systems represent a breakthrough toward achieving long-thwarted utility business objectives.

This installation realized multiple goals. Firstly, it provided a test bed to demonstrate how these new technologies can be deployed to advantage in a widespread manner over the TVA system. Secondly, it served as a “proof of concept” demonstration of multi-vendor interoperability. Thirdly, it demonstrated that these new technological approaches can be incrementally melded with traditional practice. This is essential for effective management of system migration; introduction of new technology must be accomplished in ways that avoid operational disruption and avoid the need for wholesale replacement of existing solutions. At Tiptonville, for example, conventional relays and communication techniques (e.g. contact closures) are used alongside UCA-capable relays in transmission line and bus protection schemes designed to minimize project risk and provide redundancy for critical protection functions.

Delving into Tiptonville’s protection implementation a little more deeply, the line protection scheme is implemented with two different methodologies. One set of relays uses a conventional approach, while the other uses UCA Generic Object Oriented Substation Event (GOOSE) messaging. A third relay provides breaker failure and reclosing functions, using only UCA/GOOSE messaging. Two sets of relays are also used to provide bus protection; again, one uses a conventional approach and the other, UCA/GOOSE messaging. All of these relays can be coordinated; those that can exchange UCA/GOOSE messages do so. Otherwise, contact closures are used.

SCADA functions operate over the UCA network as well, using UCA Generic Object Models for Substation & Feeder Equipment (GOMSFE) to represent the structured data and functionality held by the IED device servers and aggregated in the UCA Client/Server repository. Separate network transducers have been installed for line and bus readings, reducing the vulnerability of critical analog data needed by the operations group to relay outages and testing. Although the vast majority of site data is acquired from IEDs, there are some ancillary “hardwired” I/O points that are used to provide access to data not accessible via UCA. This legacy data is seamlessly integrated into the UCA Client/Server repository, just as if it were derived via UCA services. This is another mainstay support for continual system migration.

Network design utilizes a switched Ethernet environment, supported by fiber-optic cable for network connections, to ensure reliable operation. Future addition of a router and other components for enterprise connectivity were also factored into the final system design.

Aside from technical issues, perhaps the most important design goal was to conduct the project and deploy the system in a manner that would effectively impact daily TVA practice. The path here, of course, is to gain acceptance and confidence in these new technologies and practices from affected line groups. These include the O&M organization, which is responsible for the station once the project is completed. It makes all the difference in the world, as time passes, whether a demonstration project is successfully integrated into continuing practice or bypassed, For example, it was helpful to make interaction with the new technology more transparent, by ensuring that existing functional testing and switching procedures could be used. Ideally, we wanted line group personnel to be confronted with few functional differences from TVA’s conventional practice.

System Components

Fourteen IEDs of three different types are used to manage the station via the UCA network. All are UCA-server devices, interconnected via a fiber-optic, Ethernet station LAN. Four of these are distance line relays (UR-D60 units provided by GE Power Management), five are line and bus protection relays (EdisonPro units provided by Cooper Power Systems), and five are network transducers (PowerServe units provided by Alstom/Bitronics). Additionally, one set of non-UCA relays (four SEL-321 relays and one SEL-551 relay) is installed to meet TVA's redundant system design criteria for transmission line and bus protection. These SEL relays are connected indirectly to the UCA network using a SEL-2030 as a gateway. This configuration allows data from all station IEDs to be accessible via the UCA network for future enterprise connectivity.

Supervisory control at the station is managed by a UCA Client/Server (a StationManager unit provided by Siemens), which is also connected to the station LAN.

RuggedComm RS-1600 fiber-optic Ethernet switches and media converters provide the LAN connectivity for the project. A dedicated PC is installed at the station for use with vender configuration software as well as SISCO's AXS-4-MMS, MMS Object Explorer, and GOOSEMON software for system configuration and testing.

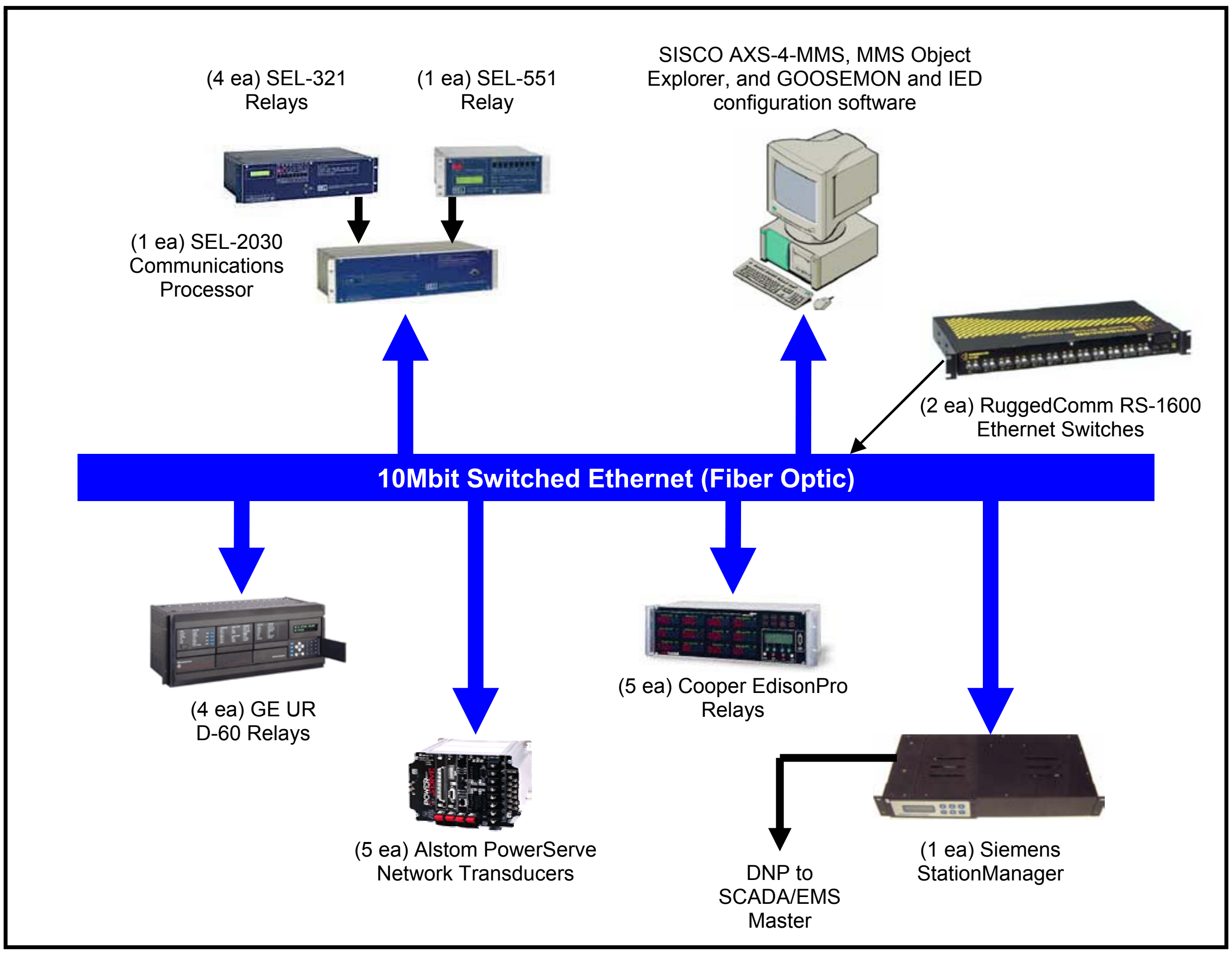

Figure 4 – Tiptonville Network Overview

Supervisory Control Application

The UCA Client/Server gathers data from IEDs via UCA reports and polls, storing that data in a UCA-compliant repository. The repository is both locally and remotely browsable as a proxy server. The UCA Client/Server and all IEDs use common GOMSFE information models and Common Application Services Model (CASM) to exchange data and complete commands. The UCA Client/Server system acts as gateway to the station, responding to Distributed Network Protocol (DNP) requests for data and commands issued by the TVA SCADA/EMS system located in Chattanooga, TN.

With few exceptions, the UCA IEDs provide all data and control functions needed by the UCA Client/Server to supervise the entire switchyard and surrounding transmission system. These include power system data, breaker control and status, recloser control and status, and various other operational statuses and analog quantities for the real-time operation and control of TVA transmission system.

An additional feature provided via the UCA network enables supervisory breaker commands sent from the UCA Client/Server to be completed through an alternate IED if the primary IED doesn't manage to complete the desired TRIP or CLOSE action within a prescribed time interval. This capability is managed by a PLC program that runs in the UCA Client/Server platform.

GOMSFE models (a.k.a. "bricks") used jointly by the UCA Client/Server and station IEDs for supervisory control include the following:

XCBR

The XCBR brick is focused on functionality and data associated with switchyard breakers. At Tiptonville these bricks are incorporated into the Cooper EdisonPro and GE D60 line relays to manage breaker control, breaker status, and other relevant information associated with the four 161kV power circuit breakers at the station.

RREC

The RREC brick is focused on functionality and data associated with switchyard breaker reclosers. At Tiptonville these bricks are incorporated into the Cooper EdisonPro line relays to manage recloser enable/disable control, recloser status, and other relevant information associated with the 161kV breaker reclosers at the station.

GLOBE

The GLOBE brick is focused on data related to the station equipment environment. It provides the status of local/remote switches associated with areas of the switchyard, active equipment modes, common equipment (e.g. station batteries), and so on.

GIND

GIND is a generic, "RTU"-type of brick that facilitates the acquisition of multiple status points. But unlike the other bricks in this list, it doesn't actually model any specific utility functionality. GIND status points may be anything that a utility and IED supplier agree for them to be. So GIND is extremely convenient for representing non-standard status in IEDs. This non-standard status may originate from external contacts or programmable logic, for example.

This is very important, because many IEDs are manufactured as commodity products, with no tolerance for project customization (i.e. extensions) of the standardized bricks (e.g. GLOBE, XCBR, RREC). The price of this arrangement, however, is that GIND data is effectively anonymous if browsed; status objects within the GIND brick show up as "status point #1, status point #2, etc. But once this data is acquired by the UCA Client/Server, it is mapped to appropriate GLOBE, XCBR, or RREC bricks in the repository, which have been customized with extensions to accept the additional data. Here anonymous data acquired from IEDs receive real names and structural locations within the information hierarchy, making it readily understandable to system users. Naturally, no GIND bricks appear in the repository. The same technique is applied to legacy data acquired from non-UCA sources. As another aspect of system interoperability, we believe this accommodation of legacy and extended data is technically and economically essential for the support of continual system migration over time. Utilities must have the latitude to displace legacy system components as a management decision, not as the fiat of technological incompatibilities. Otherwise, the barriers confronting adoption of new system technologies and products will be much steeper.

DIAG

The Siemens StationManager, in its role as UCA Client/Server, generates pseudo status points to indicate device health for each IED on the network. This information is packaged into DIAG (diagnostic) bricks and provided to the TVA SCADA/EMS system via DNP.

MMXU

The MMXU brick is focused on real-time acquisition of power system data (i.e. analog values). The data is acquired as 32-bit floating point values from UCA IEDs. In the UCA Client/Server they are rescaled and mapped to DNP 32-bit 'Analog Input' values for transmittal back to the TVA SCADA/EMS system.

The vast majority of Tiptonville's power system data is provided by the Alstom/Bitronics Network Transducers. The remaining data comes from the Cooper EdisonPro line relays.

Altogether, the equivalent of several hundred points of analog data, status, events, control, and data quality are implemented for the site.

Figure 5 – Siemens Stationmanager, Station PC, and Network Components

Relay Protection Applications

Along with supervisory control functionality, three protection applications have also been implemented: line protection, bus differential protection, and breaker failure protection. The nine relays coordinate this protection activity using a combination of GOOSE messages and traditional contact closures. All protection algorithms and coordination were implemented using the devices' native programmable relay logic capabilities. The nine GE and Cooper relays interact by generating multicast GOOSE messages to transmit discrete state changes such as the 'bus differential' condition and 'protective trip' / 'breaker failure initiate'. Breaker failure lockout conditions are detected and managed internally by the Cooper EdisonPro relay, eliminating need for a standalone HEA lockout relay. Lockout reset and breaker failure enable/disable functions are accomplished via front panel pushbuttons on the EdisonPro, also eliminating external components used in conventional installations.

The relays are able to determine when peer devices are operationally unavailable using heartbeat GOOSE messages issued periodically by each relay and the UCA Client/Server. In certain cases, the devices are able to take advantage of this information by taking an alternative path to complete a required action if abnormal network conditions are detected.

To provide network isolation, externally powered media converters have been installed for all nine relays so that network connections can be interrupted during individual relay testing. Power to the media converters (and thus network connection of the relay) is interrupted by opening blades on FT test switches already installed with each relay for isolation of conventional trip outputs. This prevents a relay under test, generating a GOOSE message, from initiating a breaker operation. This approach was used in lieu of software interlocks, so that all tripping functions (both hardwired outputs of the relay as well as GOOSE outputs) can be isolated using conventional procedures.

Figure 6 – Cooper EdisonPro and SEL-321 Relays

Figure 7 – GE D60 Relay located in cabinet at Siemens 161kV Circuit Breaker

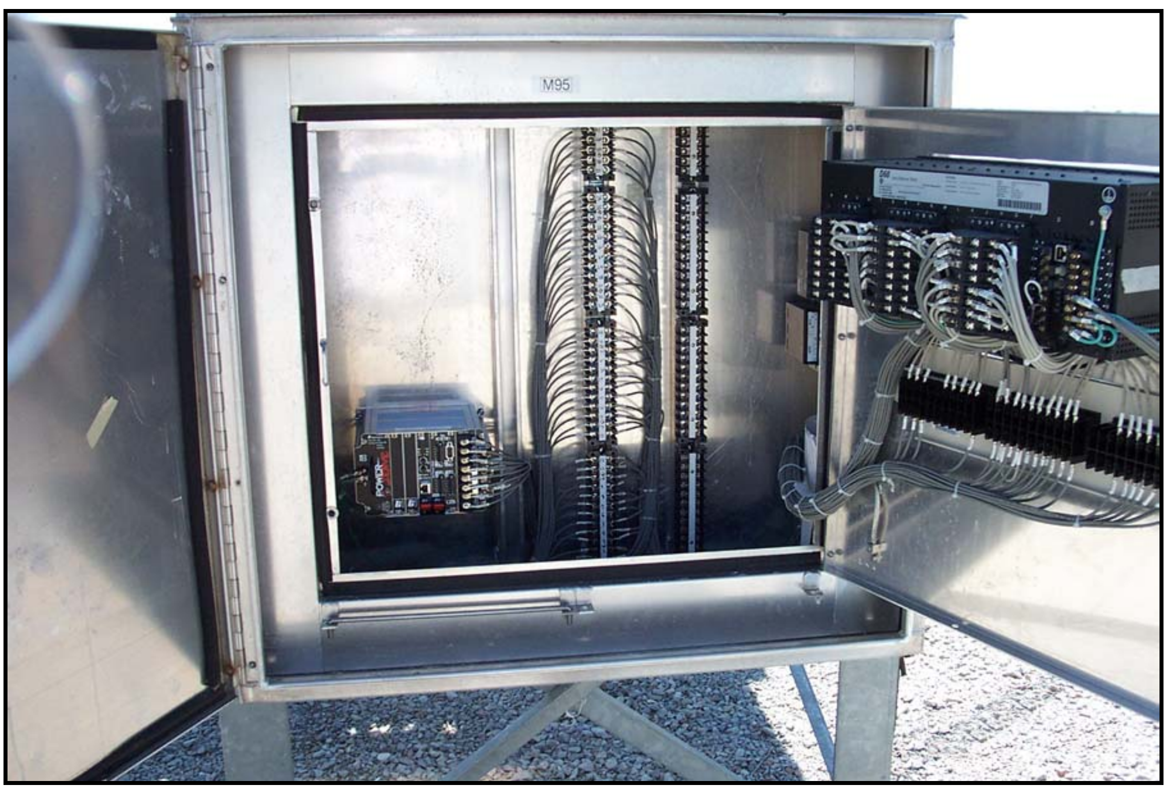

Figure 8 – Alstom/Bitronics PowerServe and rear of GE D60 Relay

LESSONS LEARNED AND AREAS FOR IMPROVEMENT

As with any new technology, unexpected circumstances cause adjustments to the project plans. The Tiptonville demonstration project was no exception. Last minute firmware changes, functional testing deficiencies, organizational boundaries, knowledge of the technology, and design changes challenged TVA as well as its consultant and vender partners.

Training

Given the demands of the project, training for personnel turned out to be critically important. Successful rollout of the technology depended heavily on the skill level of the personnel involved in all aspects of the project, as well as long-term O&M support for the Tiptonville system after project completion. Vender training for IEDs, exposure to UCA basics, and networking fundamentals were at the core of this training. It proved essential for those involved in the project to have an understanding of the technology and products involved, and how they were to be used within the system.

Testing and Commissioning

Plans for the project included testing all schemes in a lab environment, and freezing firmware revisions following that activity. Additional problems, however, were encountered during the final commissioning phase at the Tiptonville site. These problems were not visible until the fully integrated system was available with all components present on the network. While increased testing in a lab environment could have alleviated this problem, it still remains a difficult issue to simulate the behavior of a fully loaded network and system with only a representative sample of the total number of devices.

It was not unexpected that commissioning at site would present some challenges, since it was the first opportunity to validate the fully integrated system in its real-world environment. TVA needed to validate the operation of IEDs in support of SCADA and protection applications, to test the client and server capabilities of the UCA Client/Server platform, to test and validate the customized PLC programs and relay logic, and to validate the operation of the protection applications. Beyond all this, TVA also needed to gain confidence that all these capabilities, including related interlocks, operated reliably under the various anticipated scenarios. This was not always straightforwardly simple; a couple of examples follow:

- A network failure can obviously complicate the operation of interlocks between relays when GOOSE messages are involved. Provisions for these contingencies must be made just as they undoubtedly are for failed contact closures between relays. Tiptonville went a step further: Every relay, as well as the UCA Client/Server, issues heartbeat GOOSE messages every ten seconds. Each relay keeps track of the heartbeats of its peers and assumes that a lost heartbeat means either that the sender is off-line or that the network connection is inoperative. There is also logic that enables a relay to discern network problems from individual device problems. Overall, this allows each relay to initiate an alternate course of action, if relay engineers deem it appropriate, which represents another degree of flexibility with this type of approach.

- Protection interlocks required adjustment to conventional thinking, a result of the interplay between GOOSE messages and conventional contact closures sent among relays. Because GOOSE messages are sent repeatedly over time, receiving IEDs have to be carefully programmed as to how they process and latch new event information. The point is that contact closures are maintained as long as a condition persists while GOOSE messages are broadcast continually.

Addition of the media converters to the network connection of the relays turns out to be an interesting area to pursue in more detail. During discussions within TVA, it became obvious during the commissioning of the system that the issue of "software" isolation versus traditional "air gap" isolation of relay trip outputs is still a hotly debated subject within this company, and likely the industry. Conventional wisdom has trained personnel to isolate any protection device's trip outputs by either opening test switches or removing test blocks, thereby creating an "air gap" in the trip path. GOOSE messaging created a hole in this practice, since any relay remaining connected to the network could still interact with one of its peers, even though the physical trip outputs of the device were isolated. The adopted approach, which added media converters to the network connection of the relays, appears to resolve the issue very satisfactorily.

As is no doubt evident, problems were encountered during the course of the project that had to be individually dissected and solved as they were discovered. Part of the problem involved mental accommodation to the new approaches and as was gained experience with the system, the experience lead to smarter decision making and better anticipation. In the end, all the functional objectives were accomplished by the completion of commissioning, and there has been no operational problems encountered since. This experience, however, leads to the inescapable conclusion that improved test plans that address network contingencies, validate GOOSE performance, enable safe and acceptable test modes, and enable state-manipulation of data during testing are needed.

Organizational Issues

There is also another issue that is gaining visibility. In conventional substations, protection and SCADA are fairly segregated and testing activities in the two areas rarely affect each other. At Tiptonville, however, this is no longer true. Devices on the network are now so interrelated through the network that testing on one device, for example, may require that many other devices be placed off-line as well, for the operational safety of the local system. In another instance, the problem may simply be that multiple departments share functionality in the same device, and so need to coordinate test scheduling. These examples highlight the potential organizational problems that can arise when multiple departments share functionality in the same device or even on the same network, and it raises a question for each utility about how to deal with this issue.

Documentation

Project documents are critically important during the course of a project, particularly when there are several companies involved. The documents provide a common roadmap for all participants and show all the detail necessary for communications interoperability. The Tiptonville Project used the following documents, which were updated as necessary and distributed to responsible parties:

- Functional Specification
- Tiptonville Data Objects
- Resolution of GOMSFE Issues
- Tiptonville Station Point List

After commissioning was completed, a final update of these documents was performed to create an "as installed" set. Other documents were also created to describe the system configuration, applications, and other technical aspects of the project. It is important to note that this project was based on the EPRI specifications that preceded IEC 61850. As such, there were some unpolished areas that the project had to navigate to realize interoperability among the project partners. With the advent of the IEC 61850 communications standard, it's anticipated that future projects will have less difficulty with "bumps in the road".

CONCLUSIONS

The UCA experience gained by TVA through the Paradise and Tiptonville installations has provided the practical knowledge and understanding necessary to move forward. TVA is now beginning the effort to incorporate IEC-61850 not only for mainstream substation design, but also enterprise access to substation data and functionality. Key to the success of this effort will be the enhancement of IED procurement specifications to require IEC-61850 support and acceptance of UCA and other advanced technologies into the daily business throughout TVA. This flexibility of using a common network provides TVA latitude in approaching problems, providing back up, and migrating standard solutions as technology evolves and functional requirements increase.