



IEDs exchange signals using numerous GOOSE messages

"I am very proud of the effort by all concerned on the project. I believe the industry is about to see a transformation that will improve operation, maintenance, and reliability, while at the same time reducing the cost for design, construction and maintenance.
Jim Kurtz, Manager of Protection & Control at Tennessee Valley Authority (TVA)



Bradley



First IEC 61850 Multivendor Project in the USA

An excellent group of TVA and vendor personnel made this Bradley project a success. Jim Kurtz, Manager of Protection and Control at TVA, had the following comments on the project: "I cannot stress how important collaboration like this is to the industry. For vendors and suppliers to work together to resolve issues will help not only them to provide a better product, but also to develop products that will meet the long term needs of the industry. While this effort has leaped TVA forward in technology, we still have work to complete."

THE IEC 61850 SUBSTATION communication standard is almost two years old. Worldwide, there are already over one hundred substations that have been commissioned and running with this new standard.

Several projects in North America have been implemented with IEC 61850 by using products from a single manufacturer. This article reports on the status of a 500KV project - the first multivendor project in the United States to use this new standard. (Fig. 5)

The goal of the project is to utilize the new IEC 61850 standard to its fullest (as practically possible) therefore confirming that the standard is much more than just a communication protocol. Interoperability, one of the major advantages of IEC 61850, will be demonstrated. Our focus is not to describe or explain the theoretical background of the standard itself, but rather to show and demonstrate the practical use of an actual multivendor project and how the standard applies to protection engineers.

Substation Design & Layout

Another goal of this project is to eliminate or significantly reduce wiring between the relays, the control house and the breakers.

The wires are replaced with the communication infrastructure fulfilling the requirements of the protection and control applications by exchanging IEC 61850 GOOSE messages over Ethernet.

Protection & Control Scheme

Redundant protection, a TVA core protection requirement, is applied on all 500kV and 161kV transmission lines breakers and three single-phase 500/161/13kV power transformers within substation.

Transformer Protection

Two complete, comprehensive and independent transformer protection systems are implemented. Set "A" protection provides transformer differential protection, overcurrent protection, transformer sudden pressure protection, hot spot protection, LTC sudden pressure protection and restricted ground fault (RGF) protection for both neutral CT's. Every transformer status and alarms, such as fan status, liquid levels, etc. are collected by the devices, which are located in cabinets mounted on each of the four single-phase 500/161/13kV transformers. Analog and digital data from the IEDs are available in IEC 61850 format to the substation automation system.

Line Protection

Line protection relays provide distance/pilot protection, directional ground overcurrent, synchrocheck, breaker failure and reclosing. Additional pilot teleprotection devices are used for the Sequoyah 500 kV line (individual POTT schemes for both line protection relays) and the Conasauga 500 kV line (individual unblocking schemes for both line protection relays). Both line protection systems on each of the 161 kV lines will share a single communications device for their POTT schemes. Each line relay is operating in a breaker & 1/2 topology. (Fig. 2, Fig. 3)

Breaker Control

The substation contains redundant breaker control devices. The idea behind dual breaker control IEDs is to meet the same redundancy requirement as for line protection. The breaker control IED within the substation yard sends information to and receives information from the line relays using IEC 61850 GOOSE messaging. (Fig. 4)

The only hardwire status input to each line relay is the breaker position statuses and this is only used if a digital IEC 61850 state from either 52BCA or 52BCB devices are not available. A hardwire trip output

Dr. Juergen Holbach is manager of operation at Siemens Power and Distribution in Wendell, NC. He was born in Germany and graduated from the University of Berlin with a PhD in Electrical Engineering. He joined the Siemens AG in 1992 as a development engineer in Berlin Germany. In 1994 he joined the product management group for protection relays in Nuremberg Germany. From 2000 he works at Siemens Power and Distribution in Wendell, NC as a product manager for transmission relays Raleigh, NC USA.



This project was a tremendous learning experience

from the line IED is wired directly to the breaker 1 and breaker 2 trip coils (for risk management purposes). With experience, future designs may provide the substation engineer the option to eliminate these hardwire inputs and outputs and to strictly use the GOOSE functionality.

Network Connections

All IEC61850 IEDs are connected via 100 MBps multi-mode fiber cables to substation hardened Ethernet switches located in the control house. VLANs are used within the IEC61850 GOOSE message configuration of each IEC61850 device to provide security within the network. Figure 9 shows a conceptual layout of the network.

Customer /Project Expectations

Since one of the goals of this multi-vendor project was to utilize the new IEC61850 standard to its

fullest, it is clear that the customer had some key project expectations:

- Open system for protection, control and data collection from any IED.

- Interoperability between IEDs for protection and control functions. Ability to configure IEC61850 system with available manufacturer tools without need for on-site manufacturer support.

- Comparable functionality with streamlined design. Eliminate panel control switches and lockout relays and incorporate functionality into IEC61850 IEDs. This dramatically reduces the panel layout design and allows for a smaller control house (about 1/2 the size vs. traditional design). For example, consider that just one set of protection, up to 12 breakers, can be protected and controlled using one single 19" wide panel versus older designs with 1 breaker per panel with both Set A and Set B protection systems. Standard panel designs for any application can be created.

- Accommodate multiple vendor IEDs

- Comparable performance time

- Secure & dependable overall system. Timely, secure flexible information transfers.

- Flexible management/operation

- Economically viable solution

- Common technology infrastructure

- Reusable practices. Project established foundation of new substation practices oriented around IEC61850 and new procedures. Business case can be made for wholesale refurbishment with these new practices.

- Effective data management system

- Reduced wiring and installation costs. Besides the CT and PT wiring from switchyard breakers and motor operated disconnects, only breaker status and breaker trip wiring has been

implemented. No inter-wiring exists between any of the IEC61850 IEDs.

- High-speed local and remote downloads to IEDs over network

- Improved Operations and Maintenance from remote and local monitoring and diagnostics via network to reduce service time

- System health/status monitoring

- Status communications between IEDs

- Testing methodology. New test plan, tools and methodology needed to match systems new capabilities and plan to implement test cases. Ability to individually test any IED without the concern of operating other IEDs via the network.

On-Site LAB Workout Sessions & Configuration Tools Used

In August 2005, the TVA IEC61850 "project team" met for the first time (Fig. 6) to begin the process of designing the first IEC61850 based high voltage substation in the US. The team consisted of four major relay vendors and representatives from TVA's relay and communication engineering departments. Besides all interoperability demonstrations organized previously by the UCA International Users Group or by CIGRE, the team's objective for this project was to show that each relay vendor can demonstrate interoperability of the protection and automation devices from design to implementation in real life.

During the IEC61850 integration process the four relay vendors participated in three primary tests at the TVA "test lab" substation. The goal was to demonstrate that TVA could take the primary lead of configuring their substation with the available IEC61850 configuration tools using the manufacturers in a support role. This would be the first IEC61850 project where the customer would do the system engineering and

Craig Wester, is southeast US regional sales/application manager for GE Multilin in Norcross, Georgia.

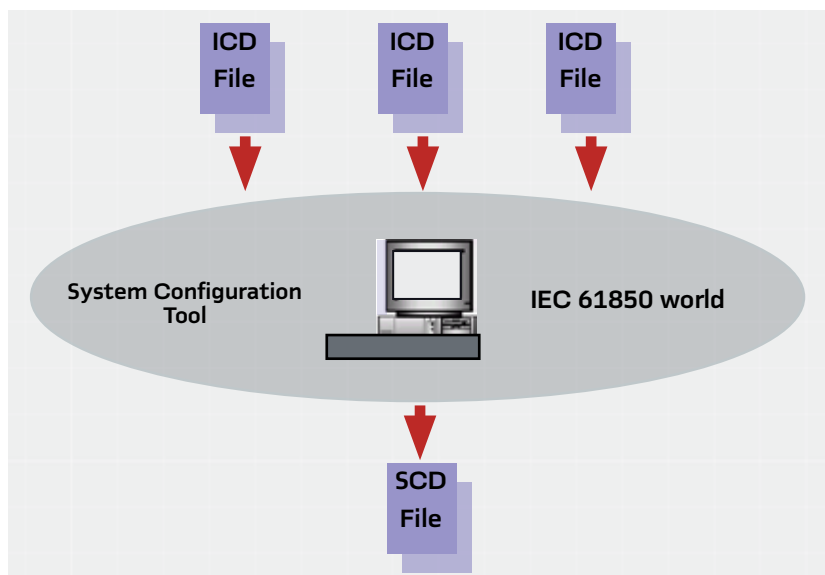
He was born in Belgium, Wisconsin, and received a B.S. in Electrical Engineering with a strong emphasis on power systems from the University of Wisconsin-Madison in 1989. Craig joined General Electric in 1989 as a utility transmission & distribution application engineer. He is a member of the IEEE.

Luc Hossenlopp, is working at AREVA T&D as Substation Automation Product Line manager. He is member of IEC TC 57 WG 10 and has been involved with the design of the IEC 61850 standard since its beginning.

Drew Baigent, is a senior design engineer with GE Multilin in Markham, Ontario, Canada. He has over twenty years experience in the design and implementation of test systems, motor protection & control products, power system protection & control products, and communication protocols & systems. He was involved in the design of the IEC61850 implementation in the GE Multilin Universal Relay family of products.



1 IEC 61850 File Standards



IED integration. The integration during previous interoperability tests on other projects throughout the world had been implemented by members of the relay vendor's development department using tools and programming language that were not always accessible or available for use by the customer. All participating vendors had previous experience with commissioning several IEC61850 based substation worldwide, but in almost all cases one of the vendors was the integrator and mainly used their own products, engineering tools and integration procedure to configure a substation. The integration of these previous projects was simpler because interpretation of the IEC61850 standard was uniquely confined to that vendor's system architecture and product implementation. It is also important to note that trade show interoperability testing only covers a small portion of the functionality required for a complete substation solution. So, the TVA project in this respect was completely different from previous projects and the trade show interoperability tests. TVA was the system designer and system

integrator and they would use the available tools from each vendor while at the same time deal with the unique interpretations of the new IEC61850 standard by each vendor.

Configuration Tools, ICD and SCD Files

The primary goal during the first test meeting (August 2005) of the "project team" was to configure all GOOSE links between the relays from the different manufacturers and to reach a minimal level of device interoperability. The procedure to achieve this is shown in Figure 1. All manufacturers had to supply an ICD file (IED Capability Description) that described the ability of the relays in a standard IEC61850 format. This ICD file is the interface between the relay manufacturers IEC61850 tools and the IEC61850 world. With the ICD files available, the customer can use any independent IEC61850 System Configuration tool to import the ICD files from each relay vendor and configure the system. (Fig. 7) Once the IEC61850 station is configured, a SCD file (Substation Configuration Description) can be created and

exported describing the station in a standard IEC61850 format. The relay vendors must be able to use their proprietary tools to extract the information inside the SCD file and use it to configure the individual relays. TVA decided to use the only commercially available at the time IEC61850 station configuration tool with all the required functionality

Lessons Learned & Testing Tools Used

During the first test meeting a significant amount of discussion was centered around the question of whether TVA wanted to use the GOOSE message implemented in UCA – called GSSE in IEC61850 to provide compatibility with UCA 2.0 implemented substations, or to use the real IEC61850 GOOSE message. After evaluation of all pros and cons, the decision was made to use the IEC61850 GOOSE message because of the advantages this new implementation has to offer.

Some discussions made it apparent that all relay vendors did not fully understand the power of the new standard. For example, it was thought that it was necessary to manually configure which information in a GOOSE message was to be sent first, the data information or the quality information. It was discovered that different manufacturers and, sometimes, different relays from the same manufacturer did it differently, so there was a fear that the information may get misinterpreted.

After a lot of discussions and phone calls, the team determined that the order of the information and quality data did not matter as long as it was declared in the ICD file. The receiving relay will get the information because it is defined via the SCD file and it knows how to process the information correctly.

During that meeting most relay vendors also did not have their tools ready to automatically export and import from their proprietary

Another goal of this project is to eliminate or significantly reduce wiring between the relays, the control house and the breakers

programming tools to the IEC61850 world via ICD and SCD files. This resulted in a significant amount of manual programming work. To validate the correctness of the ICD file, the team used the System Configurator as well as the IEC61850 Validator tool. It was determined initially that some of the ICD files had some format errors and during the import of the files, an IEC61850 Validator tool produced error reports.

These errors were the first hurdle that had to be resolved.

Even though the validation of the ICD files could verify the correct syntax of the file, it could not check for the semantics. Once we were able to import the ICD files and use the System Configurator tool to configure the required system, in some cases, we were not able to receive the programmed GOOSE message because the GOOSE message description was different than what was actually described in the ICD file. To analyze problems where one relay vendor claimed that they were sending a GOOSE message that the receiving vendor did not receive, the team used the network protocol analyzer tool Ethereal® with the MMS decoder

functionality. Ethereal® allowed for the entire GOOSE structure to be displayed, so that a view of the specific relay IED including the value of the data and quality information could be analyzed.

By using Ethereal®, we were able to see where adjustments were necessary and finally all GOOSE messages were sent and received correctly between IEDs of the different manufacturers. The goal for the test week was achieved and the concept of IEC61850 was proven powerful. Even with this accomplished, configuration of the TVA system was not simple. However, the tools available would allow the customer to configure the system by themselves. During the design process, there were several firmware updates, patches and discussions between the development departments of each of the relay manufacturers. Without the great teamwork between all the manufacturers and the deep knowledge of the implementation details of IEC 61850, the interoperability goal could not have been achieved. But it was clear that this was not a practical procedure that a utility could use to configure their IEC 61850 substations.

The configuration of the IED communications was achieved using SCL files only

The second test week was conducted in January 2006. The goal was to have TVA be the system designer/ integrator and configure the system with as little as possible support from the relay manufacturers. We have to admit that this goal was not achieved, because some of the manufacturers' tools were still not mature enough. A lot of manual work was still required and detailed knowledge of IEC 61850 was also necessary in order for the correct ICD files to be extracted out of the SCD file for configuring each IED. With support of the relay manufacturers, the system was successfully configured and working at the end of the week, but the actual goal was not achieved. At the end of the meeting TVA requested that each relay vendor

2 A Set Protection 3 B Set Protection



4 Breaker Control IED

Relays from several manufacturers are used for all line and transformer protection requirements





finish their tools, so that they can have the capability of configuring an IEC61850 system independent of the relay manufacturers.

All manufacturers met again in the TVA “test lab” substation in the third test week (March 2006). Focus was now on the tools of the manufacturers and if they were able to support TVA in configuring their IEC 61850 substation without any major support from the relay vendors and a need to have deep knowledge of the IEC 61850 implementation details.

The tools from ABB, GE Multilin and Siemens were found mature enough to fulfill the customer requirements. However, a new problem was discovered regarding different tools supporting different optional features of the IEC 61850 standard. For example, some IEDs need to know some hierarchical data like “voltage level”, “feeder name” in each IED. This data can be submitted to the IEC 61850 system configurator via the SSD files (System Specification Description). This file format is optional in IEC 61850 and doesn't have to be implemented. The used system configurator in this case did not support this feature at this

time. This made it necessary that after the SCD file was created by the system configurator that the file was edited by another tool to add this hierarchical data and then re-imported in the system configurator.

At the end, TVA was able to develop a procedure that allowed them to configure and design the system independently, without on-site support from the different relay manufacturers. This was demonstrated by TVA during the preparation for the May 2006 IEEE T&D show in Dallas, TX where the Bradley project configuration proved interoperability in the UCA International Users Group IEC 61850 demonstration.

TVA built the demonstration panels and configured the system that was placed on display at the show using the IEC 61850 tools provided by each vendor.

Overall, the process involved a number of hurdles, but demonstrated that by having a strong and determined team of relay manufacturers and excellent group of TVA engineers, future IEC 61850 project implementations can be successful and economically advantageous.

Lessons Learned Throughout the Project

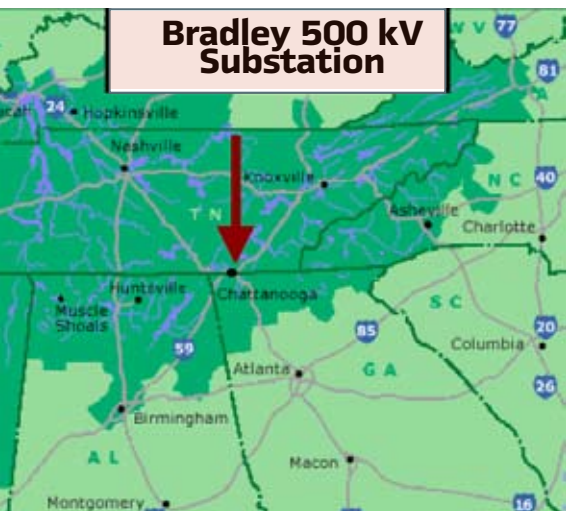
This project was a tremendous learning experience for the participating vendors and TVA. In addition to those described in the on-site lab workout, the following are some of the additional lessons learned throughout the project.

VLAN issue with Ethernet switch - The Virtual LAN (VLAN), an advanced layer 2 function defined in IEEE 802.1Q, provides high priority tagging of a message and efficient means for data exchange in applications using the IEC61850 station bus and process bus profiles. In the IEC61850 standard, a VLAN tag was defined as part of a valid GOOSE message. Some vendors' IED implementation required the VLAN tag in a received GOOSE messages to validate the information. The Ethernet switches used in the Bradley project initially did not pass the VLAN priority tag through the switch. This issue was identified early in the project and a firmware update was provided for the Ethernet switches.

Logical device names - Logical Device (LD) naming syntax is defined in IEC 61850 part 7-2. The logical device names in this system

Steven Kunsman joined ABB Inc. in 1984 and has B.S. in Electrical Engineering from Lafayette College and an MBA from Lehigh University. He is the Head of Global Product Management responsible for ABB Substation Automation Products portfolio worldwide. He is an active member of the IEEE Power Engineering Society PSRC and Substations Committees, an IEC TC57 US delegate in the development of the IEC61850 standard and UCA International Users Group Executive Committee co-chairperson.

5 Substation Location



6 Project Kick-off Meeting



The success of the project is the result of multi-vendor team work

were to be named according to the customer's standard practice for devices associated with breakers. The "99A" and "99B" breaker identification labels were preferred since this was TVA's standard for naming multifunction microprocessor based relays. The naming syntax restrictions defined in the IEC 61850 standard does not allow these type of LD names (those starting with a number) due to constraints in MMS (Manufacturing Message Specification).

The solution for this issue was to name the breaker IEDs (Logical Device names) "LA99A" and "LA99B" respectively.

GOOSE ID naming - GOOSE ID naming is an attribute that is contained in the GOOSE message. One IED vendor uses this GOOSE attribute to display status of received GOOSE messages. In the Bradley project's system engineering tool, the GOOSE ID was automatically assigned as a number, although the standard is not restrictive to numbers and allows strings.

The issue on utilization of IEC 61850 data is that one vendor usage or extension of the data may not be possible with another vendor's implementation.

The GOOSE ID strings in the SCD file were renamed using a separate tool capable of manual modification of GOOSE ID names.

Status vs. quality order - It was thought that it was necessary to specify which information in a GOOSE message was to be sent first, the data information or the quality information. It was discovered that different manufacturers and sometimes different relays from the same manufacturer did it differently, so there was a fear that the information may get misinterpreted. After a lot of discussions and phone calls, the team determined that the order of the information and quality data did not matter, as long as it is declared in the ICD file. The receiving relay will get the information because it is defined via the SCD file and it knows how to process the information correctly.

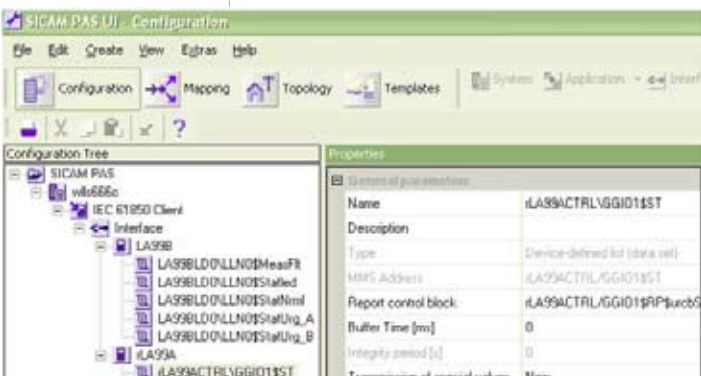
The effect of the quality state on the status state - Conventional hard wiring states are either on or off without an indication of signal quality. The IEC 61850 standard does not provide rules for the interaction between quality and status bits. The question posed is should the loss of the quality state effect the state of the status value, thus a quality state of 0 results in a force of status state of 0 (even if the status is actually true or 1)? Or should a quality state of 0 result in staying at the last known status state (which is 1 in this example)?

Both vendors meet standard, but do not interoperate - Device

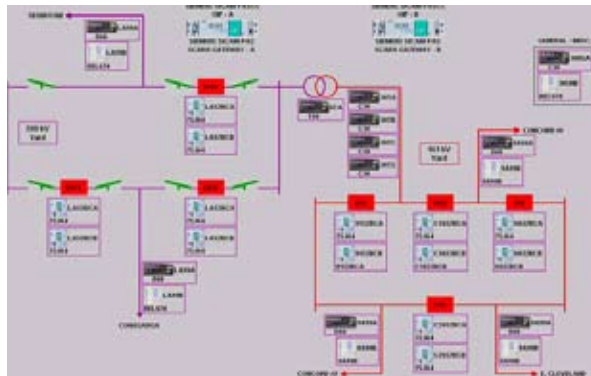
(IED) conformance to the standard is accomplished by validating an IED at an accredited IEC 61850 test facility in accordance to the IEC 61850 Part 10 and the UCA International test procedures. It is important to note that the conformance testing does not validate conformity but only validates the IED testing has identified no "non-conformities". An IEC 61850 device certificate is then issued by the accredited test facility providing the vendor a statement that no non-conformities were identified during the IED testing. The testing is limited to a single device in a test system and does not cover multi-device system level testing or interoperability in a multi-vendor system, i.e. the IEC 61850 certificate does not guarantee that a certified device will interoperate with another device. Device and client interoperability has been left to the vendors to validate. In the Bradley project, all vendors had IEC 61850 certified IEDs, but several issues as previously mentioned resulted from wrong interpretation or ambiguity in the IEC 61850 standard. Below are some examples of issues encountered during the Bradley project that impacted GOOSE interoperability between different vendor devices:

Supporting optional attributes in GOOSE - One example of the interoperability issues encountered

7 Configuration Tool



8 Bradley - Final Configuration



Collaboration between vendors is extremely important for the acceptance of IEC 61850

was that one vendor could include both mandatory and optional attributes in the IED using GOOSE messaging. Then another vendor's IED (GOOSE receiver) could only understand mandatory attributes and was not able to support the optional attributes; thus preventing interoperability. The resolution was to not use the vendor specific attributes in the GOOSE communication between these IEDs.

Adherence to name case sensitivity - Another issue encountered was in the adherence lower and upper case sensitivity. One vendor was more liberal and did not strictly adhere to the case sensitivity as defined in the standard. The other vendor's engineering tool was rejecting the names when the case was opposite to that as defined in the IEC61850 Part 7. This was resolved by using a newer version of the SCL XML schema.

Quality in GOOSE versus no quality - The support of data item quality flags in GOOSE datasets was a major obstacle in the beginning of the Bradley project. Different vendors provided different levels of support for quality flag data. In this case, one vendor required quality information in their application to confirm validity of the data for each value received via GOOSE. At the same time, another vendor was not able to send quality information in the GOOSE message. This resulted in the inability to exchange GOOSE message between IEDs and thus, a major interoperability issue. It

was decided to use both status and quality within the Bradley project for consistency. Both quality and status are now available in each vendor's device and successful GOOSE interoperability between multiple vendors has been accomplished.

Length of names of GOOSE Control Blocks - The length of GOOSE control block names supported in the different vendor IEDs was an issue. The Bradley project's system engineering tool automatically generates names for DataSets and GOOSE Control Blocks. The string length of these automatically generated names was too long for one vendor's IED. The GOOSE Control blocks in the SCD file were renamed using a separate tool capable of manually modifying the GOOSE control block names.

Substation section - The substation section of a SCL file contains information about the substation layout, logical node references and device configuration and association information. One vendor's IED tool required this substation section along with the Logical Node references to be imported from SCD file generated by the system engineering tool. The system engineering tool was not able to produce the needed information so manual manipulation of the SCD files was required to complete the IED engineering. The resolution was manual configuration of the SCD file adding the necessary information.

What vendors have to improve to make it easier? - Better preparation of the product and system technology is needed. IEC 61850 is a very comprehensive and complex standard that has the potential to revolutionize substation automation systems if the necessary tools and product functionality is available. The vendors involved in this project needed to collaborate to assure that the substation automation system functionality and interoperability capabilities

were validated prior to the execution of the customer engineering and system build up.

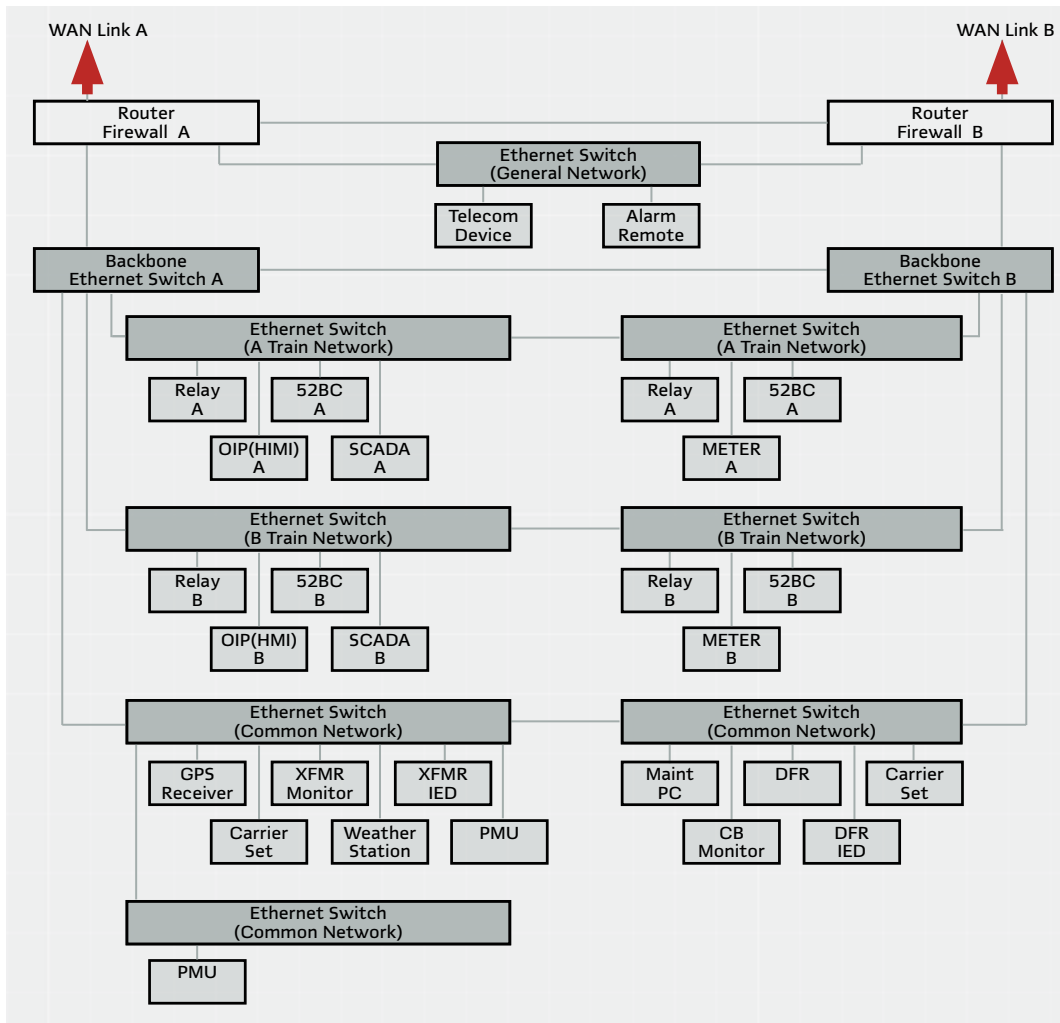
What could have been done differently? - Clearly, the lessons learned in the multi-vendor TVA Bradley IEC 61850 substation project have been extremely valuable for the entire industry pushing for this new standard. The extent of the Bradley project provides complete functionality, with a goal to move into the digital substation. We can state that the Bradley project has explored all benefits made possible through the new standard that prior to this project has not been done in a multi-vendor environment. Most of the executed IEC 61850 projects have been turnkey homogenous vendor solutions where interoperability between one vendor's products is much easier. In the other projects where multi-vendor projects have been executed, the foreign device has typically been a main 2 or backup protection terminal where the system functionality only required limited exposure of the IED functionality via the IEC 61850 system. On the other hand, industry expositions demonstrating multi-vendor IEC 61850 interoperability have set expectations that the complete IEC 61850 benefits are readily available. This is not the case since these demonstrations focus on

Lars Frisk, joined ABB in 1998 and has since then been working with IED and Tool development in Västerås, Sweden. Lars is currently working as Engineering Architect with focus on IEC61850 in tools and IED development. He has 15 years of experience within hydropower plants, power distribution and substation automation.

Julio Rodriguez, works for Siemens PT&D in Wendell, North Carolina. He was born in Colombia and graduated from La Salle University in Bogotá as Electrical Engineer. He joined Siemens in 1996 as design engineer for substation automation in Bogotá, Colombia. In 2000 he moved to Nuremberg in Germany to the configuration and project management group for substation automation, developing projects all around the world. In 2006 he joined Siemens PT&D in Wendell as Sr. Application engineer focused on automation for substations and the implementation of the IEC61850 protocol.

IEC61850 based system must be considered an integral part of the protection and control system and not just another protocol application for substation automation.

9 TVA Bradley - Conceptual Network Layout



simplistic applications and minimal functionality to prove vendor A can interoperate with vendor B.

What could have been done in this project is to set up an interoperability project to validate product and system functionality before starting the Bradley project. In this case, the project was conducting the interoperability validation. System engineering is the critical step in the Bradley project where an open discussion regarding system engineering tool to know the limitation in the integration of other vendor's IEDs.

The system engineering process is one area that multi-vendor exchange of IED and engineering data needs improvements. Today, a vendor's system engineering tool works perfectly with their own devices but creates limitation when exposed to other vendor's devices.

What needs to be done in the industry is a higher level of interoperability functionality and standard test cases that can assure a minimum level of interoperability. Here the recommendation is that the UCA International Users Group set up performance and functionality

criteria for levels of interoperability. Device level conformance certification only validates a fraction of the overall substation automation capability. Figure 8 shows the final design deployed for the TVA Bradley Substation.

The industry should consider Ethernet switches as "protective devices" when it comes to implementations of critical protection schemes using IEC61850 standard and whether they are configured and maintained by protection/test engineer or IT department.