Case Study: IEC 61850 as Automation Standard for New Substations at CFE, Practical Experiences

Néstor Moreno and Maycol Flores
Comisión Federal de Electricidad

Luis Torres, Jorge Juárez, and David González
Schweitzer Engineering Laboratories, Inc.

Revised edition released April 2010

Originally presented at the
12th Annual Western Power Delivery Automation Conference, April 2010

Case Study: IEC 61850 as Automation Standard for New Substations at CFE, Practical Experiences

Néstor Moreno and Maycol Flores, *Comisión Federal de Electricidad*
Luis Torres, Jorge Juárez, and David González, *Schweitzer Engineering Laboratories, Inc.*

***Abstract*—This paper presents a set of projects developed by Comisión Federal de Electricidad (CFE) using IEC 61850 in an extensive way to optimize the use of intelligent electronic devices (IEDs) and integrate all the information for their new transmission and distribution substations. It also covers the efforts that CFE is making to establish IEC 61850 as the preferred option for substation automation.**

This paper discusses best practices and lessons learned during the execution of several projects developed for new substations using IEC 61850 as a communications suite.

CFE is reducing their substation automation system project costs by applying the IEC 61850 protocol and by transmitting most of their field inputs/outputs through fiber-optic links via GOOSE (Generic Object-Oriented Substation Event) messages.

This paper discusses CFE documented experiences and advantages while developing their IEC 61850 projects.

I. Background

Comisión Federal de Electricidad (CFE) is the Mexican government-owned utility that generates, transmits, and distributes energy to over 100 million people. CFE is one of the electric giants of Latin America with 177 power generation plants (58,238 MW, 147.1 GVA), over 49,250 km of transmission lines (161 kV and higher), and 8 to 9 percent annual growth, which means more than a million new customers per year [1].

CFE creates electric power using various technologies and multiple primary energy sources, including thermoelectric, hydroelectric, coal-fired, geothermal, and wind-powered plants and facilities, as well as one nuclear power plant.

CFE is committed to offering excellent service. CFE guarantees high quality standards in all its processes and rivals the best electrical companies in the world [2].

II. Introduction

In 2005, as part of a continuous effort to stay ahead of technological advances, CFE started to design local specifications because they had requirements for substation automation systems (based on their present best design practices) that were not addressed by the IEC 61850 standard. The CFE customized specifications, along with the IEC 61850 requirements, were applied in the substation automation system projects for transmission-level substations (400 kV, 230 kV, 138 kV, and 115 kV). Presently, CFE is also working on developing specifications for applying IEC 61850 at distribution substations to increase standardization at all voltage levels.

CFE is the first electric utility with an IEC 61850-based system, which has been in operation since 2008. The first project (La Venta II) taught CFE many lessons about designing IEC 61850 systems. The goal for CFE since that first project is to incorporate the interoperability and interchangeability of different vendor equipment for use in substation automation systems [3].

The processes of specifying, bidding, and appropriating IEC 61850 projects helped CFE to set the path for development of the latest IEC 61850 projects. The learning process has not always been easy, but CFE is now applying most of the lessons learned to their new project development.

III. Technological Justification

CFE historically has made a substantial effort to develop state-of-the-art solutions for protecting, supervising, controlling, and monitoring their electrical substations. For IEC 61850 projects, CFE created a set of requirements that provide solutions to address most of their concerns related to safe operation and high availability of the power system. Their goal is to have less power interruption for CFE customers.

Table I summarizes the most important concepts for CFE when developing IEC 61850 projects.

TABLE I
KEY CONCEPTS FOR IEC 61850 PROJECTS AT CFE

Concept	CFE Definition
Interoperability	The ability of the system components to function effectively with other components, including communication among multiple vendor components using a common protocol, (i.e., GOOSE [Generic Object-Oriented Substation Event] messages). Interfaces, protocols, and data models must be compatible to reach this goal.
Interchangeability	The ability of the system components to be replaced by another manufacturer's device that fulfills the same protection functions. This means the ability to replace intelligent electronic device (IED) Brand A with IED Brand B without any disruption of the substation automation system.
Open protocol	The use of a standard protocol, free of charge (no royalties) for CFE with well-defined and managed information for clear understanding of its scope.
Vendor independent	Selection of system components (protection and control IEDs, networking equipment, etc.) not dependent on a single supplier.
System information quantity and speed	The ability to specify information to share, as well as the selection of communications speed and frequency for data sharing.
Substation system network architecture	Optimal architecture for integrating all the substation components in a local-area network (LAN) (i.e., self-healing, fiber-optic ring for panel IED interconnection).
Networking equipment features	Networking equipment that fulfills standards for safe application in a substation environment (IEEE 1613 and IEC 61850 certified) and provides a standardized way to set up and manage such equipment or almost any other component of the substation automation system.

IV. ECONOMICAL JUSTIFICATION

CFE has learned many lessons during IEC 61850 project implementation. Some of the most important justifications for this solution are related to the following economic benefits:

- Cost reduction by replacing many copper control cables with fiber-optic links for alarm and control signals. Fig. 1 shows control cables that will be replaced by fiber-optic links. The economical benefit is mainly to reduce commissioning labor.
- Reduced construction for trenches and cable raceways for new substations. Because the need for copper cables is reduced, the trenches or ducts required for taking field equipment signals into control buildings are reduced. The number of signals from the field is limited to potential transformer, current transformer, and sometimes tripping signals. The remaining signals are communicated through the new fiber-optic links.
- Maintenance cost reduction. CFE takes advantage of multifunctional relays and equipment to reduce the number of IEDs required for protection, control, metering, and monitoring. Fewer pieces of equipment mean fewer maintenance hours.
- Panel-to-panel cabling reduction. Using an extensive communications network infrastructure and GOOSE messaging, a minimal number of cables are interconnected among panels.
- Reduced control building and associated construction costs by using fewer panels. By grouping protection and control functions in multifunctional IEDs, CFE will update their technical specifications to allow grouping of multiple functions in the same IED; present technical specifications require an independent IED for almost every protection function.
- Promotion of CFE specifications to reduce or eliminate the auxiliary relays. Adopting the new specifications will help to avoid failure points and reduce panel size and internal wiring.
- Pre-tested system. As part of the quality assurance requirements for the reception and acceptance of goods, CFE requires that every system delivered to any electrical substation pass a factory acceptance test before delivery. Pre-testing ensures that commissioning will be conducted smoothly and site acceptance testing time will be reduced. CFE has experienced up to a 50 percent commissioning time reduction.
- CFE promotion to reduce protection, control, and measurement panel accessories to reduce failure points and panel size. CFE is eliminating elements such as panel pushbuttons, switch selectors, and mechanical relays (e.g., 86).

Fig. 1. Copper cable replacement

V. PROJECT CHALLENGES

While developing IEC 61850 projects, CFE and their suppliers faced many challenges and problems. Some of these issues are discussed in this section.

An integrated team of multidisciplinary protection and control and/or automation engineers worked to discover the best automation system solution. This synergetic work involved multiple discussions and created important conclusions, including a better understanding of the requirements and needs of each discipline. Working in this way, each group needed to clearly communicate their scope and responsibilities and, of course, to learn the other participant's scope in order to share responsibilities for project development.

Using state-of-the-art technology involved learning about new applications, finding equipment limitations, designing workarounds, and, in some cases, changing equipment to fulfill technical requirements. Some of this new knowledge led to discovering "holes" in the technical specifications that needed to be fixed to improve project development.

It was necessary to quickly learn about many communications topics, including virtual local-area network (VLAN) configuration, Ethernet switch management, spanning protocols, and many other topics.

It was also necessary to understand new configuration and testing tools. CFE invested resources to develop an application to validate IED configuration files, including IED capability description (ICD), Configured IED Description (CID), and Substation Configuration Description (SCD) files. Fig. 2 shows the user interface for the OpenSCLConfigurator tool ported and developed by CFE as an open-source application [4].

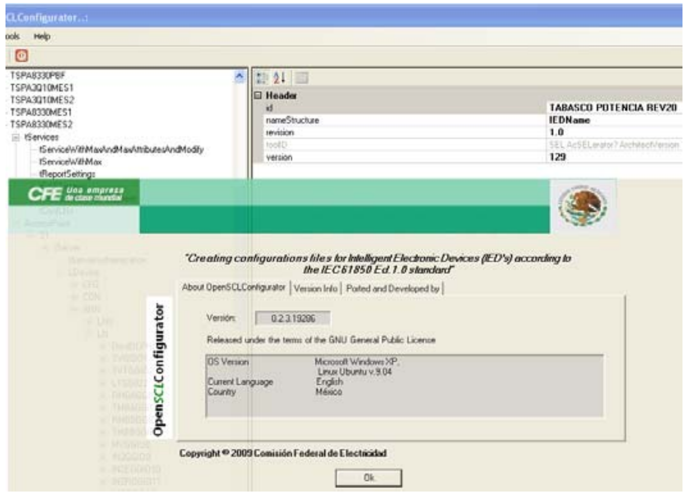

Fig. 2. OpenSCLConfigurator tool

One key to successful IEC 61850 project development and implementation is to properly document the programming and settings for every device. Logic diagrams, as well as documentation that explains how the GOOSE messages travel among the equipment, are essential to understanding an IEC 61850-based project. Without such information, it is impossible to understand and efficiently troubleshoot the system in case of failure or improper operation.

Fig. 3 shows part of a table that documents the GOOSE messaging transmissions. When developing the engineering and documentation set, it is critical to design a master list of Internet Protocol (IP) addresses for every single IED that will integrate the system, including relays, meters, communications data concentrators, and Ethernet switches.

DEVICE	DATASET	MULTICAST MAC ADRESS	APP ID	VLAN ID	VLAN PRIORITY	SIGNAL	DESCRIPTION
TSA3Q00MES1	GOOSE016	01-0C-CD-01-00-12	1	0	1	ESTADO 52a FASE A INTERRUPTOR A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind01.stVal bit 0
						ESTADO 52b FASE A INTERRUPTOR A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind02.stVal bit 0
						ESTADO 52a FASE B INTERRUPTOR A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind03.stVal bit 0
						ESTADO 52b FASE B INTERRUPTOR A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind04.stVal bit 0
						ESTADO 52a FASE C INTERRUPTOR A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind05.stVal bit 0
						ESTADO 52b FASE C INTERRUPTOR A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind06.stVal bit 0
						PERDIDA SF6 INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind07.stVal bit 0
						RESORTE DE CIERRE DESCARGADO INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind08.stVal bit 0
						BLOQUEO DE RECIERRE INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind09.stVal bit 0
						BLOQUEO FUNCIONAL DE SF6 INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind10.stVal bit 0
						DISCORDANCIA DE POLOS INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind11.stVal bit 0
						FALTA VCD CTO CIERRE Y CONTROL INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind12.stVal bit 0
						FALTA VCD CTO APERTURA 1 INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind13.stVal bit 0
						FALTA VCD CTO APERTURA 2 INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind14.stVal bit 0
						FALTA VCA INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind15.stVal bit 0
						SELECTOR L/R EN LOCAL INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO9.Ind16.stVal bit 0
						MONITOR BOBINA DE DISPARO 1 FASE A INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind01.stVal bit 0
						MONITOR BOBINA DE DISPARO 1 FASE A INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind02.stVal bit 0
						MONITOR BOBINA DE DISPARO 1 FASE B INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind03.stVal bit 0
						MONITOR BOBINA DE DISPARO 1 FASE B INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind04.stVal bit 0
						MONITOR BOBINA DE DISPARO 1 FASE C INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind05.stVal bit 0
						MONITOR BOBINA DE DISPARO 1 FASE C INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind06.stVal bit 0
						FALTA VCD CTO CONTROL DE CUCHILLAS INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind07.stVal bit 0
						SUPERVISION CIERRE ACCIDENTAL INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind08.stVal bit 0
						FALTA VCD CTO DISPARO 1 INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind09.stVal bit 0
						SUPERVISION APERTURA 1 ACCIDENTAL FASE A INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind10.stVal bit 0
						SUPERVISION APERTURA 1 ACCIDENTAL FASE B INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind11.stVal bit 0
						SUPERVISION APERTURA 1 ACCIDENTAL FASE C INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind12.stVal bit 0
						SUPERVISION APERTURA 2 ACCIDENTAL FASE A INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind13.stVal bit 0
						SUPERVISION APERTURA 2 ACCIDENTAL FASE B INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind14.stVal bit 0
						SUPERVISION APERTURA 2 ACCIDENTAL FASE C INT A3Q00	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind15.stVal bit 0
						ANORMALIDAD MES A3Q002	TSPA3Q00MES1.GOOSE016.ANN.IN2GGIO12.Ind16.stVal bit 0

Fig. 3. Portion of table used to document the IED transmission of GOOSE messages

Fig. 4 shows a sample spreadsheet that documents IP addressing information for the project.

One major challenge arose because there were no standard tools to generate a complete set of substation automation system documentation. In this case, the use of tools like OpenSCLConfigurator helped to mitigate the lack of such tools, but it did not cover all the required IEC 61850 documentation. Most of the vendors provided flexible tools for setting their own equipment, but many of these tools did not help when applied to a multiple vendor system, so creating a whole SCD file for a substation was a challenging and demanding activity. In some cases, this required changing XML (Extensible Markup Language) configuration files by using XML text editors.

Some of these tools are shown in the following figures. Fig. 5 shows the SCD file content using Notepad++ Editor; Fig. 6 shows an analyzer screen for a control function; Fig. 7 shows the same control information using an MMS (manufacturing message specification) client.

DEVICE	IDENTIFICATION	IP ADDRESS	SUBNET MASK	MULTICAST MAC ADRESS	APP ID	VLAN ID	VLAN PRIORITY	GOOSE DATASET
LOCAL CONTROL CONSOLE	CCL	192.168.1.2	255.255.255.0	----------------------	---------	---------	---------------	----------------------
EVENT PRINTER	EVENT PRINTER	192.168.1.168	255.255.255.0	----------------------	---------	---------	---------------	----------------------
ENGINEERING CONSOLE	CI	192.168.1.3	255.255.255.0	----------------------	---------	---------	---------------	----------------------
SCADA PRINCIPAL	SCADA SERVER MAIN	192.168.1.4	255.255.255.0	----------------------	---------	---------	---------------	----------------------
SCADA RESPALDO	SCADA SERVER BACKUP	192.168.1.5	255.255.255.0	----------------------	---------	---------	---------------	----------------------
MR1MCADSP	TSPMR1MCAD	192.168.1.6	255.255.255.0	01-0C-CD-01-00-03	1	0	1	GOOSE001
MCAD SERVICIOS PROPIOS	TSPSSPP1MCA	192.168.1.7	255.255.255.0	01-0C-CD-01-00-04	1	0	1	GOOSE002
METER 93840	MM 93840	192.168.1.18	255.255.255.0	----------------------	---------	---------	---------------	----------------------
DISTURBANCE RECORDER A3Q00 Y A3Q10	RD A3Q00-A3Q10	192.168.1.19	255.255.255.0	----------------------	---------	---------	---------------	----------------------
BUSBAR DIFFERENTIAL 87B - AB	TSP230KVPBAB	192.168.1.25	255.255.255.0	01-0C-CD-01-00-05	1	0	1	GOOSE003
PROTECTION 85L LT-A3Q00	TSPA3Q00PP1	192.168.1.31	255.255.255.0	01-0C-CD-01-00-0B	1	0	1	GOOSE009
PROTECTION 21 LT-A3Q00	TSPA3Q00PP2	192.168.1.32	255.255.255.0	01-0C-CD-01-00-0C	1	0	1	GOOSE010
PROTECTION 67N LT-A3Q00	TSPA3Q00PR0	192.168.1.33	255.255.255.0	01-0C-CD-01-00-0D	1	0	1	GOOSE011
MCAD INT A3Q00	TSPA3Q00MCA	192.168.1.34	255.255.255.0	01-0C-CD-01-00-0E	1	0	1	GOOSE012
PROTECTION 50FI LT-A3Q00	TSPA3Q00PBF	192.168.1.35	255.255.255.0	01-0C-CD-01-00-0F	1	0	1	GOOSE013
MCAD INT A8220	TSPA8220MCA	192.168.1.36	255.255.255.0	01-0C-CD-01-00-10	1	0	1	GOOSE014
PROTECTION 50FI LT-A8220	TSPA8220PBF	192.168.1.37	255.255.255.0	01-0C-CD-01-00-11	1	0	1	GOOSE015
DISTRIBUTED CABINET INT A3Q00-1	TSPA3Q00MES1	192.168.1.105	255.255.255.0	01-0C-CD-01-00-12	1	0	1	GOOSE016
DISTRIBUTED CABINET INT A3Q00-2	TSPA3Q00MES2	192.168.1.106	255.255.255.0	01-0C-CD-01-00-13	1	0	1	GOOSE017
ETHERNET SWITCH No 1	SWITCH 1	192.168.1.141	255.255.255.0	----------------------	---------	---------	---------------	----------------------
ETHERNET SWITCH No 2	SWITCH 2	192.168.1.142	255.255.255.0	----------------------	---------	---------	---------------	----------------------
ETHERNET SWITCH No 26	SWITCH 26	192.168.1.166	255.255.255.0	----------------------	---------	---------	---------------	----------------------
ETHERNET SWITCH No 27	SWITCH 27	192.168.1.168	255.255.255.0	----------------------	---------	---------	---------------	----------------------

Fig. 4. Project IP addressing spreadsheet

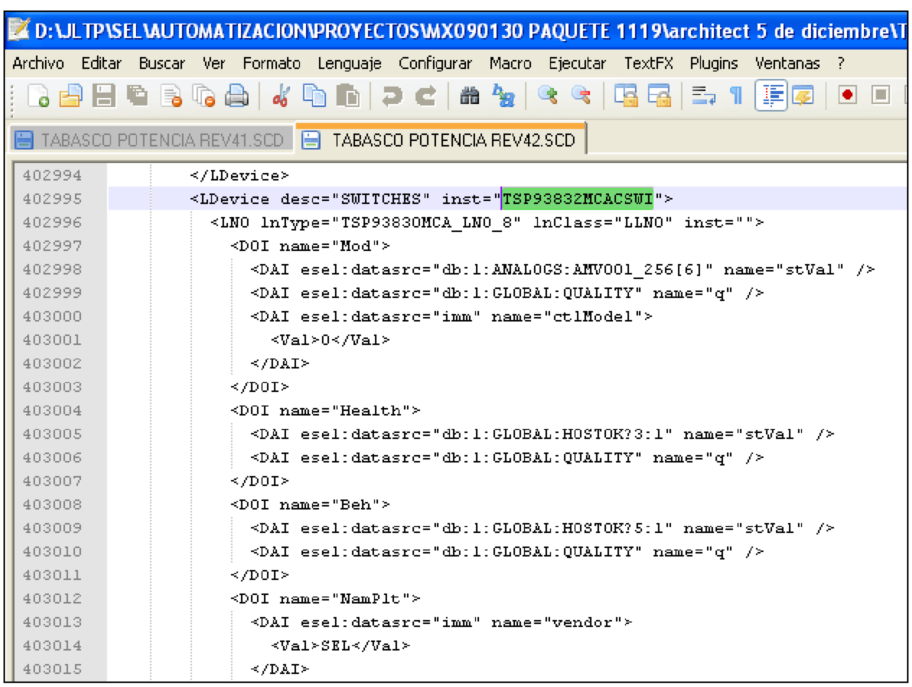

Fig. 5. SCD file edition via Notepad++

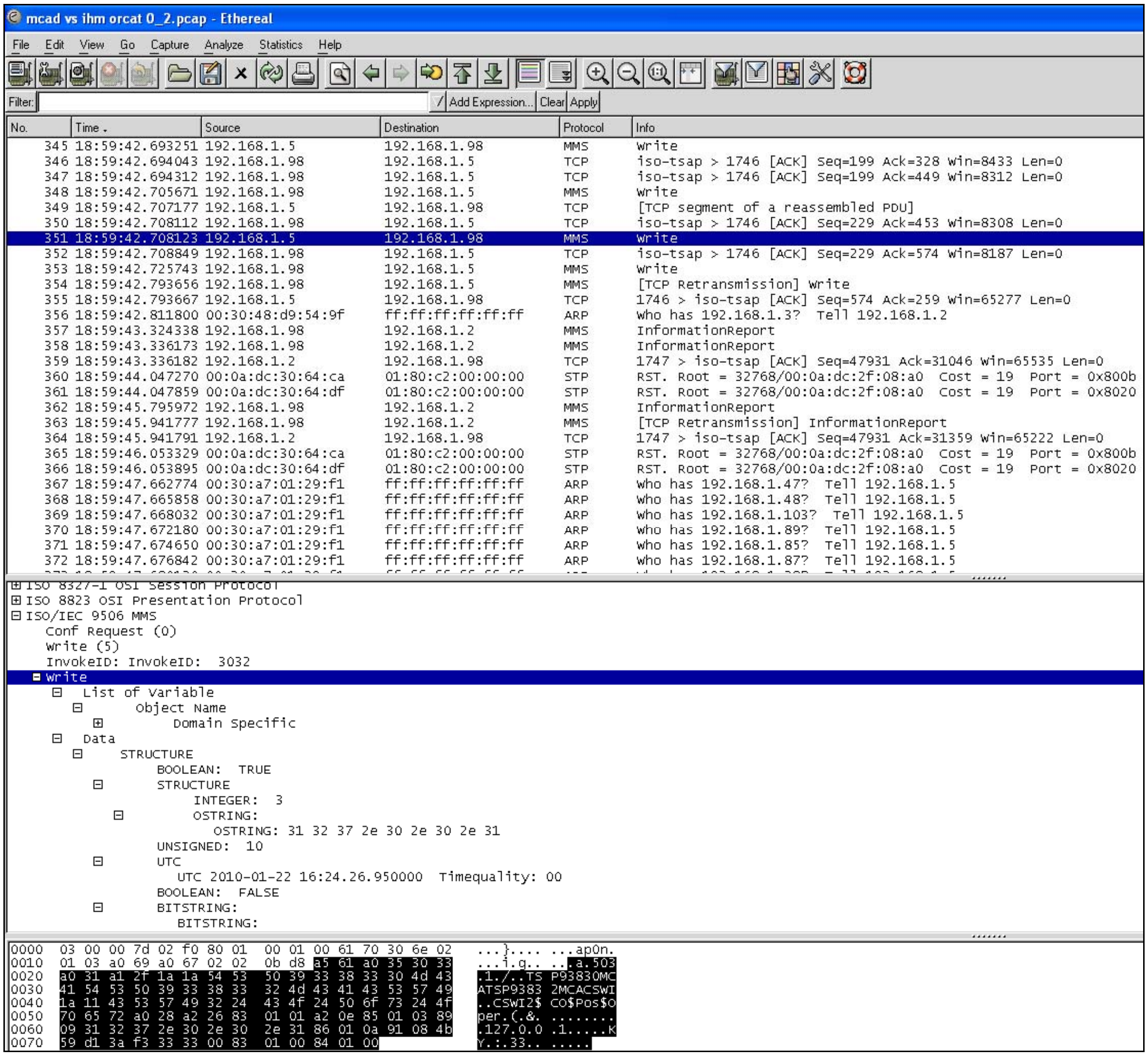

Fig. 6. Control operation sniffering through Ethernet analyzer

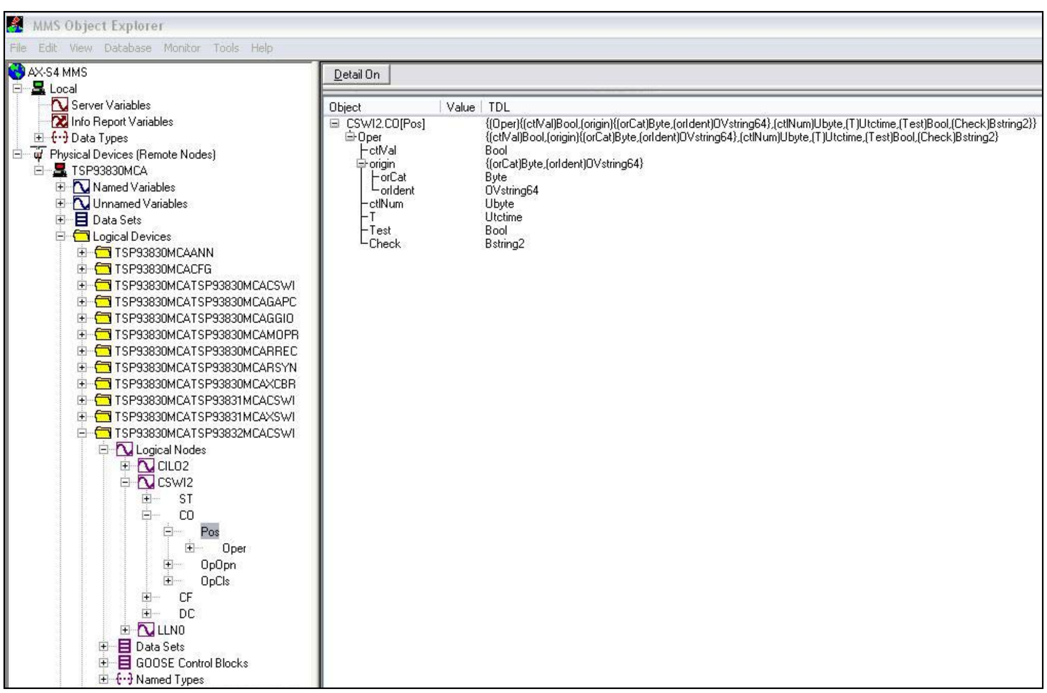

Fig. 7. Control operation sniffering through MMS client

Another important task was to develop projects without intuitive tools for extensive testing of the substation system behavior, performance, and response time. Using commercial and freeware tools like AX-S4 MMS, Ethereal®, and Wireshark, CFE developed and specified a test set for system acceptance, as described in Part 6 of [5].

Having full interoperability of the system components working as a single unit was another major challenge. Not all vendors supported the technical requirements of CFE, which created some problems at project implementation time. Most of the problems were addressed and solved by the vendors. Each vendor had its own strengths and weaknesses when implementing the IEC 61850 project and meeting required CFE specifications.

Another very important issue included achieving IED interchangeability for CFE systems. By having an interchangeability feature on the substation systems, CFE was not tied to a single manufacturer, and IEDs could be changed without disrupting system operation or with minimal impact to the system. Presently, one manufacturer has configuration flexible enough to match any other compliant IED configuration from any vendor. These IEDs actually accept and store the SCL file internally. When these files are modified to match another vendor's product, these IEDs expose data in the same way as the other vendor's products. Of course, protection and automation performance remain at the same quality level as the IED vendor. IEC 61850 communication is standardized, but the application performance is not.

Part 2 and Part 3 of [5] cover this interchangeability requirement for IEC 61850-based projects. These sections also cover CFE requirements for system component adaptability; as mentioned previously, this adaptability was achieved by defining local specifications for project development.

The human factor was one of the most important challenges that CFE encountered during implementation. CFE faced some conservative users who preferred to continue with some of the proven and historical solutions for substation automation instead of moving to new and innovative solutions. Fortunately, most CFE personnel were willing to apply this new technology, learn about new equipment, and adopt a new automation philosophy.

With their extensive experience in power system operation and specification development, CFE found that the IEC 61850 standard does not include some alarms and data points that are important for CFE system operation; thus, the customized substation automation system specification included new requirements.

Table II shows a logical device definition that includes some alarms, such as Blocked Mechanism (MecBlk) and Trip Coil Monitor (TripCoilSup1, TripCoilSup2), that are not included in the IEC 61850 standard but are required by CFE for their system.

The same IEDs that were reconfigured to match other vendor IEDs for interchangeability were changed to incorporate these new values. IEC 61850 allows for the extension of standardized data models with new data such as these.

TABLE II
LOGICAL DEVICE DEFINITION FOR LOGICAL NODE XCBR [5]

Mandatory Data Required		Comments
Name	**Type**	
SumSwArs	BCR	Current (A) accumulated (I^2t).
CBOpCap	INS	Operating capacity. The value generally used in operation is **4** (open-close-close).
MaxOpCap	INS	Operating capacity when mechanism is fully loaded.
MecBlk	SPS	Mechanism locked (spring uncharged).*
DisPol	SPS	Discrepancy of poles.*
LosVacBrk	SPS	Breaker ac loss.*
LosVdcClCi	SPS	Breaker closing circuit dc loss.*
LosVdcTrC1	SPS	Tripping Circuit 1 dc loss.*
LosVdcTrC2	SPS	Tripping Circuit 2 dc loss.*
TrCoiSup1	SPS	Trip Coil 1 monitor.*
TrCoiSup2	SPS	Trip Coil 2 monitor.*

* Value is not defined in the IEC 61850 standard.

VI. LESSONS LEARNED

By developing IEC 61850 projects, CFE gained experience and learned many practical lessons that helped to develop better technical specifications. The following examples are some of the important lessons learned.

A. *Network Architecture Configuration*

During the initial projects, one of the first proposals was to improve efficiency on the Ethernet LAN. The proposal created different and independent LAN connections according to the different voltage levels in the substations. However, interconnecting different Ethernet rings causes increased reconfiguration times during a fault and puts at risk the safe operation and availability of the power system. Fig. 8 illustrates an early network architecture specification for the IEC 61850 project.

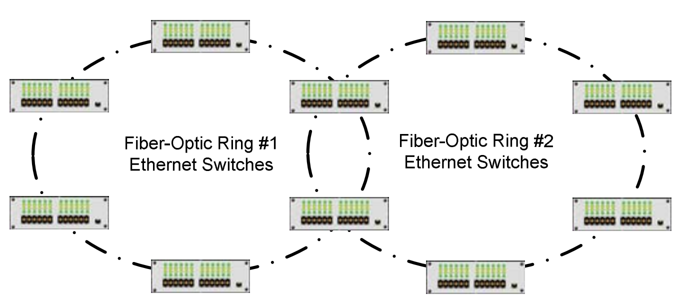

Fig. 8. Initial project network configuration

One of the first lessons learned was that when all the IEDs are connected to a single redundant Ethernet ring, the reconfiguration time on a faulted system decreases significantly. Reconfiguration time varies depending mainly on the number of Ethernet switches that integrate the LAN ring. For this configuration, fiber-optic 1000BASE-SX connections are used for communication among Ethernet switches. As defined in [5], the communication from the Ethernet switches to the protective relays, meters, I/O modules, and bay control units uses 10/100BASE-T copper cable links. Fig. 9 shows the required network architecture for new IEC 61850-based projects at CFE. One advantage of this solution relates to the self-healing of the fiber-optic ring, achieved by the use of a Spanning Tree Protocol among the Ethernet switches. Based on the SICLE (*Sistema de Información y Control Local de Estacion*, Substation Local Control and Information System) specification [6], CFE specified that a redundant set of switches (main and backup configuration) must integrate all the IEDs at the substation LAN, as shown in Fig. 10.

From that configuration, CFE learned to improve system performance; system administration is now specified using one Ethernet switch per panel. Based on the CFE substation automation system specification in [5], the use of copper connections inside the panel and IED connections to adjacent panels is allowed. By implementing the network configuration shown in Fig. 11, the system meets the specified CFE redundancy requirement. The substation LAN uses the self-healing 1000BASE-SX fiber-optic ring for communicating among all the components of the system.

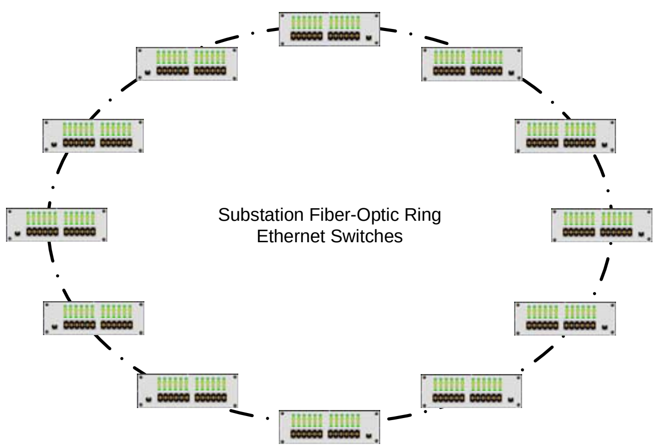

Fig. 9. The use of Ethernet switches by panel

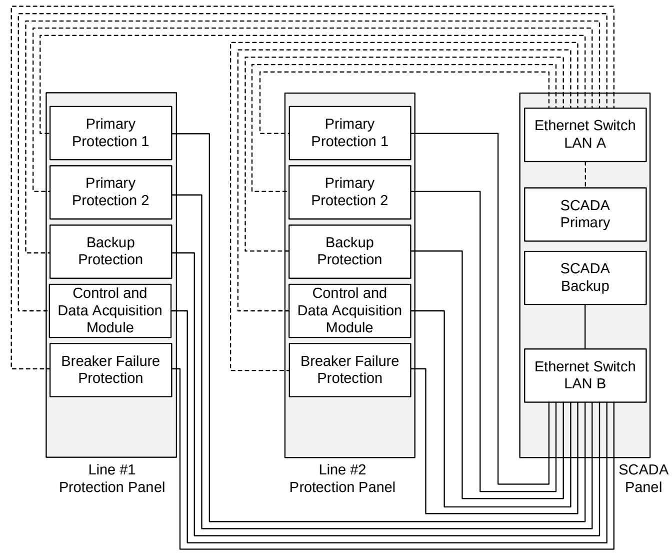

Fig. 10. System network architecture based on SICLE specification

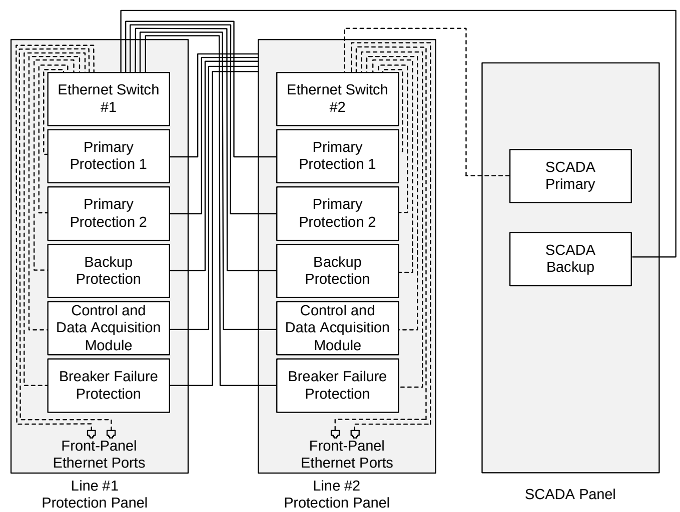

Fig. 11. System network architecture based on substation automation system specification

B. Ethernet Ports on the Front Panel

In most of their Ethernet-based projects, CFE must open the panels to have access to Ethernet connections for maintenance, testing, and configuration of the system. Based on recent experience, CFE now requires two Ethernet ports on the front of each panel [5]. Fig. 12 shows the panel layout with the front-panel Ethernet ports. Some see this feature as unnecessary, but it provides several benefits, including the following:

- An accessible connection point to the substation automation system.
- No need to open the panels to use the Ethernet connections.
- Multiple points of access to system components provided by the port connection available at almost every panel.
- An accessible monitoring connection point, which helps to troubleshoot the system if needed.

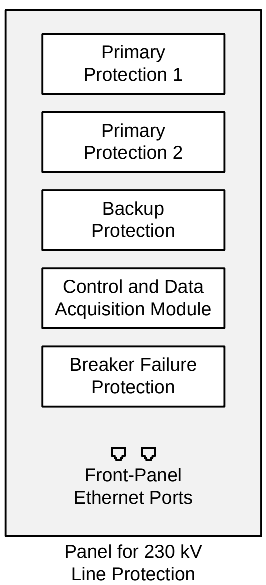

Fig. 12. Ethernet connection points on the front panel

C. Extensive Interaction Between CFE and Suppliers During Design Stages

The communication between CFE and their suppliers is very important, especially during system engineering, communications architecture development, and definition of logical devices and logical nodes. It is almost mandatory that all involved parties agree and set requirements and concepts for a better performing system. All agreements must be well documented. Participation by the end users responsible for operations is critical to improve the commissioning of the substation automation system.

D. Use of Managed Ethernet Technology

The use of managed Ethernet switches as part of the system is highly recommended because the system gains the following advantages:

- A rapid reconfiguration speed on the Ethernet LAN during a fault on the system with the use of Spanning Tree Protocol and other features.
- A choice to monitor a particular device from any point in the LAN.
- Better performance and data distribution by using VLANs, prioritization, and data routing administration.
- Manageability and supervision capability for the Ethernet communications devices.

E. Use of I/O Modules in Extreme Conditions

In addition to all the other project innovations, CFE wanted to install the I/O module cabinet in the switchyard, which exposed devices to extreme weather conditions, including temperatures exceeding 100°F, rain, electrostatic discharges, and electromagnetic interference. To prevent damage to the I/O devices, CFE specified an application of a special paint coating to prevent rust and an outdoor cabinet design with additional shading elements to prevent direct sun-ray heating. Reference [5] specifies that the internal temperature of outdoor cabinets must not exceed 113°F. Fig. 13 shows a cabinet with shading elements that meet the new CFE specification.

Fig. 13. New outdoor I/O module cabinet

VII. Conclusions

Many lessons have been learned by CFE since the first IEC 61850-based project. Many improvements are now reflected in the CFE substation automation system specifications. These specifications address the requirements for new substation automation projects, including defining a way to test the system before delivery and on-site commissioning. Automation projects based on IEC 61850 are the path for present and future projects, including new installations and substation retrofits.

The initial IEC 61850 projects were more costly than a traditional solution mainly because of the networking functionality; however, they provide greater flexibility to manage the system, along with requiring less maintenance and providing better monitoring and system performance. New IEC 61850 projects offer a simpler way to expand systems in the future. They increase system reliability by having IEDs close to switchyard equipment connected via fiber-optic cables, which reduces commissioning tasks and construction-related work. Important savings were realized in subsequent projects from engineering design reuse and system cloning.

CFE is sharing their experience with others who are considering IEC 61850-based projects on their systems. Others can learn from the CFE implementations as they begin their initial project design and specification.

VIII. References

[1] Comisión Federal de Electricidad, "The Company." Available: http://www.cfe.gob.mx/lang/en/Pages/thecompany.aspx.

[2] Comisión Federal de Electricidad, "Transmission and Distribution." Available: http://www.cfe.gob.mx/lang/en/Pages/thecompany.aspx.

[3] V. Flores, D. Espinosa, J. Alzate, and D. Dolezilek, "Case Study: Design and Implementation of IEC 61850 From Multiple Vendors at CFE La Venta II," proceedings of the 9th Annual Western Power Delivery Automation Conference, Spokane, WA, April 2007.

[4] Source Forge, "SCL Manipulation and Configuration Tools." Available: http://sourceforge.net/projects/opensclconfig/.

[5] *Características Generales Aplicables a Sistemas de Automatización de Subestaciones Basados en la Norma IEC 61850*, Revisión 2, Comisión Federal de Electricidad, January 2009.

[6] *Sistema de Información y Control Local de Estacion* (SICLE), Comisión Federal de Electricidad, December 2006.

IX. Biographies

Néstor Moreno García received his BS in Electronics and Communications Engineering from Universidad Autónoma de Baja California, Facultad de Ingeniería in 2002; an MBA from Universidad Anahuac del Sur in 2005; and an MS in Electrical Engineering from Instituto Politécnico Nacional in 2008. After graduation, he worked for Comisión Federal de Electricidad as power line communication project leader, analyzing programmable logic controller (PLC) technologies and developing two pilot projects with different PLC technologies. In 2004, he was promoted to be responsible for the automation department, coordinating project Sistema Integral de Información (SIME), elaboration and normalization of procedures and specifications of automation specialty. In 2005, Mr. Moreno was promoted to be responsible for the regulation department and currently is responsible for control specialty in transmission process.

Maycol Flores Leon received his BS degree in Automation Control Engineering from Instituto Politecnico Nacional, Escuela Superior Mecánica y Eléctrica in 2001. After graduation, he worked for Comisión Federal de Electricidad on automation project development for medium- and high-voltage substations. In 2008, he was promoted to be responsible for automation projects for electrical substations. He currently is responsible for protection, control, and communications in CFE substations. Mr. Flores has presented at the Master Conference at Reunion de Verano de Potencia (RVP-IEEE) and Reunion de Otoño de Comunicaciones (ROCC-IEEE). He is a member of ANCE (Asociación Nacional de Normalización y Certificación del Sector Eléctrico), working on revisions and proposals for the IEC 61850 standard.

José Luis Torres Pérez received his BS in Electronic Engineering from Instituto Tecnológico de la Laguna in 2005. After his graduation, he worked for SENSA Control Digital as a commissioning engineer. In December 2006, he joined Schweitzer Engineering Laboratories, Inc. as a testing and quality assurance engineer, responsible for internal and customer testing for protection, control, and metering systems. In 2009, he was promoted to senior automation engineer. Since then, he has been an automation project leader, and his duties include management, engineering design, and commissioning of integration projects.

Jorge Juárez Mejía received his BS in Electrical Engineering from Oaxaca Technological Institute in 1996. From 1996 until 1999, he worked for SEIPE as a protection technician. In 1999, he was the head of the protection, control, and metering department in the southeastern distribution division (SDD) at Comisión Federal de Electricidad (CFE) in Palenque, Mexico. From 2000 to 2004, he was head of the protection, control, and metering department in the SDD of CFE in Tapachula, Mexico. During this time, he was engaged in supervision, maintenance, improvement, and commissioning of protection, control, and metering system activities. In October 2004, Mr. Juárez joined Schweitzer Engineering Laboratories, Inc. (SEL). He is currently a senior protection engineer in San Luis Potosí, Mexico. His activities include protection, control, and metering system design and commissioning of SEL products for power utilities and industrial plants.

Rey David González Barrios received his BS in Electronic Systems Engineering from Instituto Tecnólogico y de Estudios Superiores de Monterrey in 1993. After graduation, he worked for Video y Computación Nacional as a SCADA software development and commissioning engineer. In 1998, he joined INELAP-PQE as an integration engineer, responsible for technical support and integration and automation market development. In 2000, he joined Schweitzer Engineering Laboratories, Inc. as an integration and automation department manager to manage, engineer, and commission integration projects for electric utilities and industrial customers. He currently works as head automation engineer and has been project leader for many innovative systems. He has presented several papers at Reunion de Verano de Potencia (RVP-IEEE) and Congreso Iberoamericano de Protecciones in México (CIP-UANL).

20100419 • TP6431-01