Case Study: Introduction of New Technologies in Unattended Substations in Panama

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***Abstract*—The Panamanian transmission company Empresa de Transmisión Eléctrica, S.A. (ETESA) is implementing new technologies related to substation automation and control. They are making a breakthrough in the way they are controlling and monitoring their unattended substations. In an effort to standardize their operations, ETESA partnered with an engineering firm to design an integrated solution that protects, controls, and automates the Boquerón 3 substation in Panama.**

This paper presents the integrated system design challenges. It also presents the technologies and solutions applied to successfully integrate intelligent electronic devices (IEDs) via IEC 61850 with a local human-machine interface (HMI) serving as a local control without IEC 61850. Data acquisition is sent to and remote control is received from the supervisory control and data acquisition (SCADA) center via IEC 60870-5-101 without any additional hardware needed for protocol translation. The status of Boquerón 3 can be monitored via web browsers from any point in the country by engineers or technicians who require this information.

I. Introduction

The IEC 61850 standard is focused on substation automation, integration, and control. Utilities from around the world are looking to this standard as a way to standardize the interoperability and expansion capability of their substations and avoid the future obsolescence of their protection, control, and monitoring (PCM) systems.

Looking for the interoperability and interchangeability that IEC 61850 offers, Mexico and Central America have adopted IEC 61850 as a standard for some recently built substations. For instance, the Central American Electrical Interconnection System, or SIEPAC (Sistema de Interconexión Eléctrica de los Países de América Central) project, a transmission link that connects southern Mexico with Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama, uses the IEC 61850 standard in all of its substations. Some of the utilities that participate in this project are as follows: in Mexico, the government-owned Comisión Federal de Electricidad (CFE); in Costa Rica, the Instituto Costarricense de Electricidad (ICE); in Honduras, the Empresa Nacional de Energía Eléctrica (ENEE); in Nicaragua, the Empresa Nicaragüense de Electricidad (ENEL); and in Panama, the Empresa de Transmisión Eléctrica (ETESA).

II. Project Background

The management of the electric power system in Panama is divided between transmission, which is controlled by government-owned ETESA, and generation and distribution, which are controlled by private utilities. ETESA is the only entity in the country allowed to operate the transmission power system.

The interconnected system in Panama has a double circuit with four 230 kV transmission lines, two secondary lines, and two main lines. The two main 230 kV transmission lines cross the country (see Fig. 1). The Changuinola line (shown as a dashed line) goes from the Caribbean Sea to the Panama province. The second line, Progreso (shown as a solid black line), starts at the border with Costa Rica and ends near Panama City. The Progreso line is connected to the SIEPAC transmission line (gray), as shown in Fig. 1.

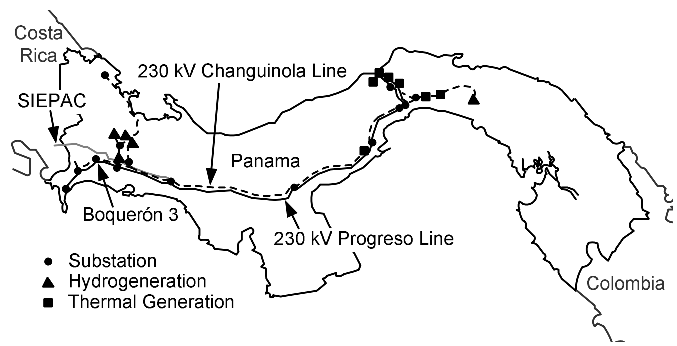

Fig. 1. The interconnected power system in Panama. The two main transmission lines, Changuinola and Progreso, are shown. The latter line is part of the SIEPAC transmission link.

In 2009, ETESA bid on a very important project for the construction of a new 230 kV substation called Boquerón 3. This substation would serve as one of multiple anchor points for the several hydroelectric projects that would feed energy to Panama.

Four hydroelectric plants located in the Chiriquí province of Panama would be connected to the 34.5 kV bus of the Boquerón 3 substation. The energy generation of these hydroelectric plants would provide electrical energy for the country of Panama and also increase the amount of energy that Panama could sell to any of the countries that are part of the SIEPAC project, especially to Costa Rica because it is adjacent to Panama in the SIEPAC transmission line route. Although Costa Rica and Panama are interconnected via the SIEPAC line, the energy exchange is not made directly from ETESA to ICE. Instead, the energy exchange is regulated and made through the regional electric market, Mercado Eléctrico Regional (MER). MER is an agency responsible for the purchase, sale, and management of energy between countries that belong to the market. At this time, MER is formed by the countries that participate in the SIEPAC project.

The Boquerón 3 substation project required designing a PCM system that met the standards for Panamanian transmission substations. In an effort to standardize the philosophy, design, and interoperability of future substations and also facilitate their future expansion, ETESA decided to entirely design the system using the IEC 61850 standard.

III. Substation Arrangement

The Boquerón 3 230 kV substation (see Fig. 2) includes the following:

- Two 230 kV transmission lines, which connect the Boquerón 3 substation with the Progreso and Mata de Nance substations.
- A 230 kV bus with a breaker-and-a-half arrangement.
- One 83.33 MVA, 230/34.5 kV transformer.
- One 34.5 kV bus with four hydroelectric generators connected.

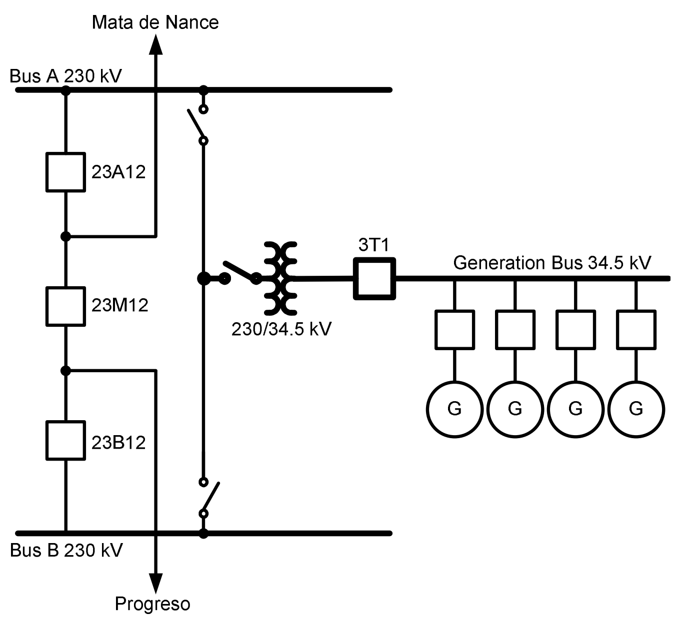

Fig. 2. One-line diagram of the 230 kV Boquerón 3 substation.

IV. System Design Scope

ETESA defined how the substation PCM system must be designed in order to comply with its current specifications and how the new equipment must be integrated into the existing supervisory control and data acquisition (SCADA) system.

A. Protection Design Scope

The protection system design for Boquerón 3 complies with ETESA protection schemes needed for the breaker-and-a-half arrangement present in the substation. These protection schemes include the following:

- Main and backup protection for the 230 kV Progreso and Mata de Nance lines.
- Directional comparison protection system for the two 230 kV lines.
- Reclosing function for the breaker-and-a-half scheme.
- Synchronism-check function for the two 230 kV lines.
- Main and backup protection for the 230/34.5 kV transformer.
- Protection for the 230 kV and 34.5 kV buses.
- Digital fault recording for the two 230 kV lines.

B. Control and Automation Design Scope

The control and automation requirements for Boquerón 3 are based on the operative philosophy of similar substations and on other new requirements due to the new technology used for this substation (i.e., IEC 61850). These requirements are as follows:

- Control and measurement using IEC 61850.
- Control, automation, and interlocking using IEC 61850.
- Human-machine interface (HMI) redundancy.
- SCADA redundancy.
- Local tagging at the HMI.
- Substation status monitoring via a web browser.
- Integration of the Boquerón 3 substation to the National Dispatch Center (CND) with IEC 60870-5-101.
- Local event printer configuration.

V. Protection Schemes

The protection system designed for the Boquerón 3 substation includes the protection functions contained in the ETESA protection specifications listed in Table I, Table II, and Table III.

Table I
230/34.5 kV Transformer Protection Schemes

Description	Function
Main transformer differential	87T1P
Backup transformer differential	87T1S
Breaker failure	50BF
Control and data acquisition module (CDAM)	CDAM

Table II
230 kV Bus Protection Schemes

Description	Function
Bus A differential	87B-A
Bus B differential	87B-B

TABLE III
230 KV LINE PROTECTION SCHEMES

Description	Function
Main line differential	87L
Main directional comparison	85L
Main line distance	21/21N – Zone 1 (ground) 21/21N – Zone 1 (phase) 21/21N – Zone 2, 4
Backup line distance	21/21N – Zone 1 (ground) 21/21N – Zone 1 (phase) 21/21N – Zone 2, 4
Backup directional overcurrent	67N
Breaker failure (breaker-and-a-half scheme)	50BF
Synchronism check	25
Reclosing	79
CDAM	CDAM

Two digital fault recorders (DFRs) are part of the ETESA requirements as complementary equipment. These DFRs are not integrated via IEC 61850. Instead, they are polled in their proprietary protocol from the protection offices in Panama City.

Two aspects that were considered when selecting protective relays for the project were compliance with the ETESA protection scheme specifications and IEC 61850 capability.

VI. PROTECTION SYSTEM DESIGN

Fig. 3 shows details of the protection system at the Boquerón 3 substation. The protection design engineers faced challenges due to the complexity of a breaker-and-a-half scheme. One major challenge was a 230/34.5 kV transformer with no breaker on the 230 kV side. The transformer was connected via disconnect switches to Buses A and B. This atypical arrangement required the careful selection of the protection system to ensure the availability of this substation in the interconnected system.

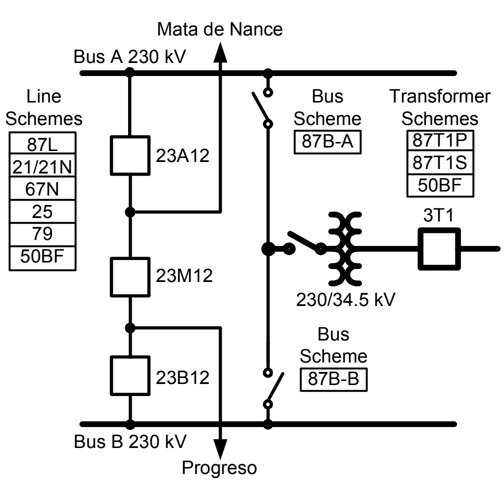

Fig. 3. Protection schemes for the Boquerón 3 substation.

Generic Object-Oriented Substation Event (GOOSE) messages are used to maximize the functionality of the protection equipment. GOOSE messages are used in the protection system to transmit and communicate the following signals between the line and the transformer protection relays:

- The control, interlocking, and status of the line reclosing scheme.
- The breaker pole status.
- Teleprotection alarms.
- Breaker failure scheme alarms.
- Trip coil failure alarms.

Fig. 4 shows the GOOSE message subscription for the reclosing relay of the Mata de Nance line. The GOOSE messages shown are reporting tripping information from the relays (CCIN001 to CCIN003) and the reclosing function state of the Progreso line (CCIN004).

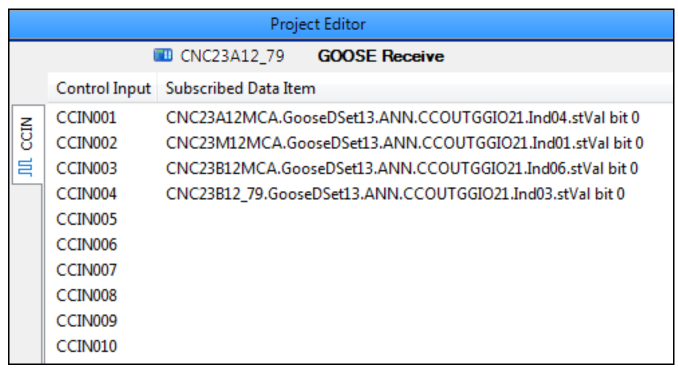

Fig. 4. GOOSE subscription for the 23A12 breaker reclosing function.

Taking advantage of IEC 61850 features, GOOSE messages are used for protection logic and interlocking. When a relay operates, its tripping signal is published to the subscriber relays. Subscriber relays use the published tripping signal to make interlocking or tripping decisions.

The reclosing function for the breaker-and-a-half scheme follows the same principle as the relays. The control command is issued either from the local HMI or from the CND and received by the relay associated with one of the breakers.

Once the state of the reclosing function changes in the relay, it is published via a GOOSE message so that the subscribing relays change their reclosing function states and reconfigure the protection functions associated with them.

A synchroscope is mounted on the SCADA panel, facing the control desk where the main and backup HMIs are placed. The synchroscope is positioned in a way that the operator can use it and the HMI to perform synchronization. The synchronism-check function is implemented in both distance protective relays. The synchronization is started with a control command that is only issued by the local HMI. The operator opens the synchronization window programmed in the HMI for one of the two lines, looks at the synchroscope, and waits for the right conditions to issue the synchronize command from the HMI. Then the relay closes the associated breaker at the right time.

Table IV, Table V, and Table VI summarize the system protection tripping logic.

TABLE IV
MATA DE NANCE (230-9A) 230 KV LINE TRIPPING LOGIC

Protection Function	Protection Group		230 kV Breakers			34.5 kV Breakers	Breaker Lockout			
	Main	Backup	23A12 Breaker	23B12 Breaker	23M12 Breaker	3T1 Breaker	23A12 Breaker	23B12 Breaker	23M12 Breaker	3T1 Breaker
			Tripping	Tripping	Tripping	Tripping	Lockout	Lockout	Lockout	Lockout
21/21N Zone 1 (ground)		*	*		*					
21/21N Zone 1 (phase)		*	*		*					
21/21N Zone 2		*	*		*					
21/21N Zone 4		*	*		*					
67N		*	*		*					
87L	*		*		*					
21/21N Zone 1 (ground)	*		*		*					
21/21N Zone 1 (phase)	*		*		*					
21/21N Zone 2	*		*		*					
21/21N Zone 4	*		*		*					
50BF – 23B12		*	*	*	*	*	*	*	*	*
50BF – 23M12		*	*	*	*	*	*	*	*	*

TABLE V
PROGRESO (230-9B) 230 KV LINE TRIPPING LOGIC

Protection Function	Protection Group		230 kV Breakers			34.5 kV Breakers	Breaker Lockout			
	Main	Backup	23B12 Breaker	23A12 Breaker	23M12 Breaker	3T1 Breaker	23B12 Breaker	23A12 Breaker	23M12 Breaker	3T1 Breaker
			Tripping	Tripping	Tripping	Tripping	Lockout	Lockout	Lockout	Lockout
21/21N Zone 1 (ground)		*	*		*					
21/21N Zone 1 (phase)		*	*		*					
21/21N Zone 2		*	*		*					
21/21N Zone 4		*	*		*					
67N		*	*		*					
87L	*		*		*					
21/21N Zone 1 (ground)	*		*		*					
21/21N Zone 1 (phase)	*		*		*					
21/21N Zone 2	*		*		*					
21/21N Zone 4	*		*		*					
50BF – 23B12		*	*	*	*	*	*	*	*	*
50BF – 23M12		*	*	*	*	*	*	*	*	*

TABLE VI
230/34.5 KV TRANSFORMER TRIPPING LOGIC

Protection Function	Protection Group		230 kV Breakers			34.5 kV Breakers	Breaker Lockout			
	Main	Backup	23A12 Breaker	23B12 Breaker	23M12 Breaker	3T1 Breaker	23A12 Breaker	23B12 Breaker	23M12 Breaker	3T1 Breaker
			Tripping	Tripping	Tripping	Tripping	Lockout	Lockout	Lockout	Lockout
87T1P	*		*	*		*				
87T1S		*	*	*		*				
50BF – 3T1		*	*	*		*	*	*		*
86T1P	*		*	*		*	*	*		*
86T1S		*	*	*		*	*	*		*

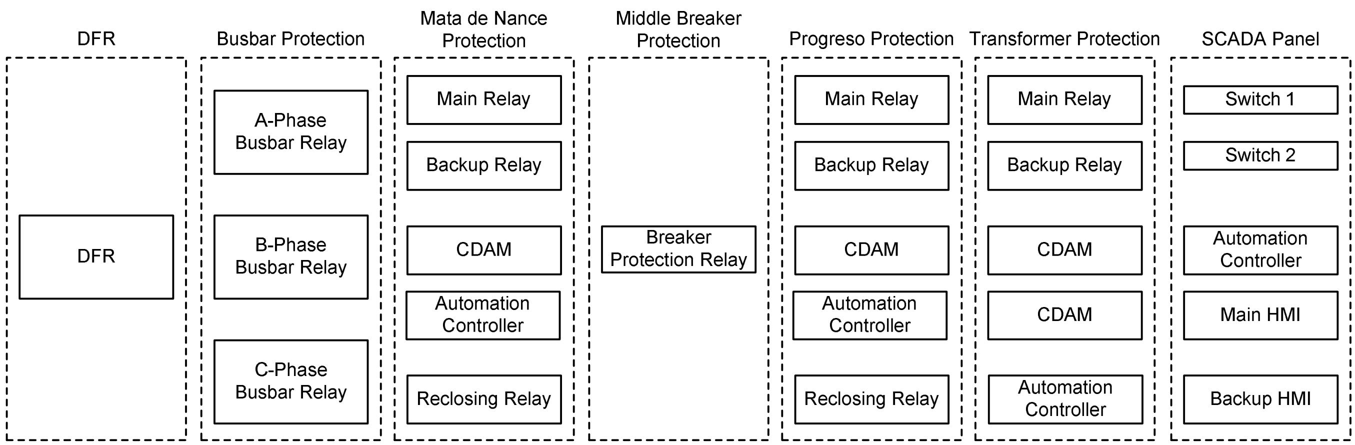

Fig. 5. Layout of the Boquerón 3 PCM panels.

VII. PCM PANELS AND COMMUNICATIONS ARRAY

Fig. 5 shows the Boquerón 3 PCM panel layout, which comprises seven panels with the following functions:

- Disturbance recording.
- Bus differential protection.
- Mata de Nance line protection.
- Middle-breaker CDAM protection.
- Progreso line protection.
- 230/34.5 kV transformer protection and 34.5 kV breaker protection.
- SCADA system implementation.

All the protective relays and other intelligent electronic devices (IEDs) have fiber-optic Ethernet ports that are connected to two managed switches located on the SCADA panel. Optical fiber was chosen instead of copper connections mainly to avoid electrical interference and to save panel space. The switches also are connected to devices that are part of the substation management system, such as printers, routers, HMIs, disturbance recorders, and revenue meters.

VIII. CONTROL SYSTEM DESIGN

The first design proposal made to ETESA was based on a control scheme where the CDAM located on the bay panel could be used as a bay controller with the possibility of serving as a breaker control device. ETESA best practices for substation control and operation do not allow performing primary apparatus control from the PCM panels. This restriction is to avoid incorrect or accidental operations of the apparatus that could cause harm to personnel or equipment. Hence, apparatus control must be achieved only from two places: the local HMI or the CND.

To comply with ETESA specifications and to ensure the system interoperability required by the functions of the Boquerón 3 substation, an independent redundant (local and remote) SCADA system was included in the second design proposal. In case of a hardware and/or software malfunction in the primary system, this SCADA system ensures local and remote control and data acquisition by means of the backup system. Fig. 6 shows the redundant SCADA system architecture.

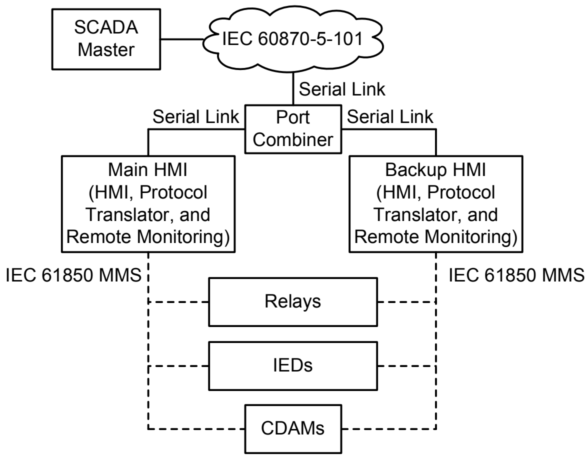

Fig. 6. Redundant SCADA system architecture.

ETESA specifications require an integrated system using the newest technology in substation automation, (i.e., IEC 61850). This requirement implies that the control and monitoring functions of the substation disconnect switches, circuit breakers, and protection logic must be in the local HMI. Also, the data acquisition, control of the system, and integration of the substation with the CND must be provided by the same IED where the HMI is located. This means that the solution must contain no additional hardware in the communications path between the relays, HMI, and CND to minimize possible points of failure.

Automation engineers faced several challenges in the Boquerón 3 control system design. The main challenges were as follows:

- Integrating the IEC 61850 standard with the IEC 60870-5-101 protocol.
- Integrating the IEC 61850 standard with the ETESA-requested HMI software, which lacked native IEC 61850 communication.
- Programming the HMI to achieve a fully redundant system.
- Programming the local tagging, which is controlled through the HMIs.
- Using newly released software that would serve as a protocol gateway between the IEC 61850 system local HMI, and CND SCADA master.
- Achieving local HMI redundancy.
- Providing redundant SCADA reporting.
- Controlling the alarm printing services in both HMIs.

IX. Solution Implementation

Several design activities were performed to comply with the ETESA requirements and specifications. An important aspect of the entire solution was the use of an industrial-oriented HMI and its programming, which allowed automation engineers to develop the solutions required for implementing local tagging, redundant control services for both Microsoft® Windows® and the HMI, sharing data between the two independent HMIs, and event printer control.

In order to ensure system availability and minimize common points of failure in the integration paths, automation engineers decided that all the protocol gateways, the local control (HMI), and the web server should reside in the same hardware. Two rugged computers (the main HMI system and the backup HMI system) were used as the SCADA server, local HMI, and web server. The rugged computers have identical hardware and software configurations. The following subsections describe the automation system challenges and the way they were addressed.

A. CND Master Integration

Substation data obtained in IEC 61850 must be sent to the CND for remote control and monitoring. The CND SCADA master concentrates data from all the remote ETESA substations. The SCADA master communicates using the IEC 60870-5-101 protocol. A software protocol gateway is used to poll data directly from the relays in IEC 61850 with the manufacturing message specification (MMS) protocol. The data are concentrated in the protocol gateway and then transmitted to the CND SCADA master via IEC 60870-5-101.

Even though the protocol conversion is performed transparently by the software, the complexity and features offered by IEC 61850 are not compatible with other protocols, such as IEC 60870-5-101. For example, the way the command controls are issued and how the control commands are allowed or not, depending on the point of origin, are not compatible. Therefore, it is difficult to convert simple IEC 60870-5-101 messages to perform actions that are more elaborate in the IEC 61850 protocol [1]. For instance, within the command control message that is issued from an HMI or SCADA master, a property called origin category (orCat) is included. This orCat is an analog value from 0 to 8 that is unique for each control in the substation (e.g., the HMI, remote control station, or SCADA master). Based on this value, the relay knows the origin of the command control. Inside the relay, a command control can be allowed or disabled, depending on the value of this originator property.

Instead of using IEC 61850 control attributes like orCat to allow and perform control commands and directly operate breakers or disconnect switches by using the internal bits of the relay, a manual configuration had to be made in the relay and in the protocol gateway.

In common IEC 61850 systems, control commands are executed by activating a specific bit inside the relay. This bit is linked to a set/reset instruction in the relay that can be used to open or close breakers and motor-operated disconnect (MOD) switches or to enable or disable protection logic. In the Boquerón 3 control and automation design, the control command properties used by IEC 61850, like activating a specific action bit inside the relay or the use of orCat, were disregarded. To design the system control, remote bits linked to a particular action inside the relay are used instead of the internal relay bits.

In the protocol gateway, calculation logic was developed to determine, based on the actual state of the apparatus interlocking or tagging, if the received control commands from the CND should be issued to the apparatus or not.

Fig. 7 shows the interlocking logic implemented for one of the circuit breakers in the substation. This logic allows the trip or close commands sent by the CND to be issued if several conditions are met, such as tagging not being present in the circuit breaker.

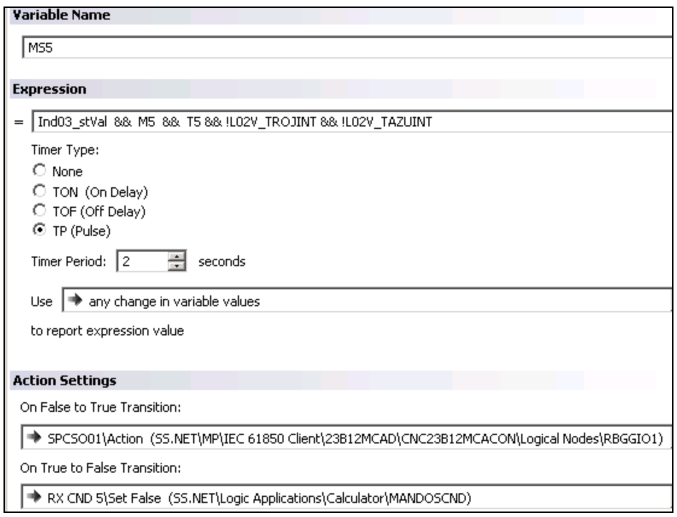

Fig. 7. Interlocking calculations in the protocol gateway.

B. HMI Integration

The use of an industrial HMI that lacks IEC 61850 native communication was one of the main challenges of the project for the following reasons:

- Difficulty integrating the IEC 61850 data with the HMI in any of its supported protocols to ensure full interoperability
- Difficulty keeping the project within budget while acquiring the right software tools.

As previously mentioned, all the SCADA solutions were included in the same hardware to minimize single points of failure. The same decision was made in the selection of the protocol gateway. This protocol gateway must be able to handle the conversion from IEC 61850 to IEC 60870-5-101 and also publish the IEC 61850 data into a communications protocol that the industrial HMI can understand. The protocol gateway must be as robust and reliable as the HMI. This protocol gateway must allow fast data interchange and protocol translation to support an avalanche of events (caused by a critical failure in the transmission system) without losing any of these events. The selected protocol gateway obtains data from the field using IEC 61850 and then translates the data for an OPC server to which the HMI connects. The native HMI OPC driver takes the data published by the protocol gateway OPC server and then uses the data in its own language.

In this design, the HMI becomes the central point of the entire solution. It serves as the local control for the substation and allows the enabling or disabling of protection functions as well as logical tagging of breakers and disconnect switches. The only way to interact with the substation devices in the control house (e.g., disconnect switches and breakers) and perform logical tagging is through the HMI, as required by ETESA. The HMI displays power system measurements to help ETESA make decisions on energy management and control.

C. Local Redundant HMI

ETESA needed the substation to be equipped with two HMIs: a primary HMI and a backup HMI. In this scheme, the normal local operation can be done with the main HMI, and in case of failure, the local operation can still be achieved with the backup HMI. Because of the functions of the substation, automation engineers decided to implement a system with two independent HMIs, where each HMI can be used to independently issue control commands, poll data from the relays, send data to the CND, work as a web server to show the substation status, and perform logical tagging and interlocking. A complex scripting program was needed to monitor the services for both Microsoft Windows and the protocol gateway. Another complex scripting program was developed in order to monitor services and exchange data between the HMIs. These scripts located in each IED allowed the construction of a truly independent redundant system.

D. SCADA Redundancy

A unique serial communications channel is used by the CND master. Data are transmitted to the Boquerón 3 substation via fiber-optic multiplexers, and the change from optical fiber to a serial interface is made in the substation system. It was determined that the switching time from the main system to the backup system and vice versa must be as fast as possible to provide maximum data availability to the CND.

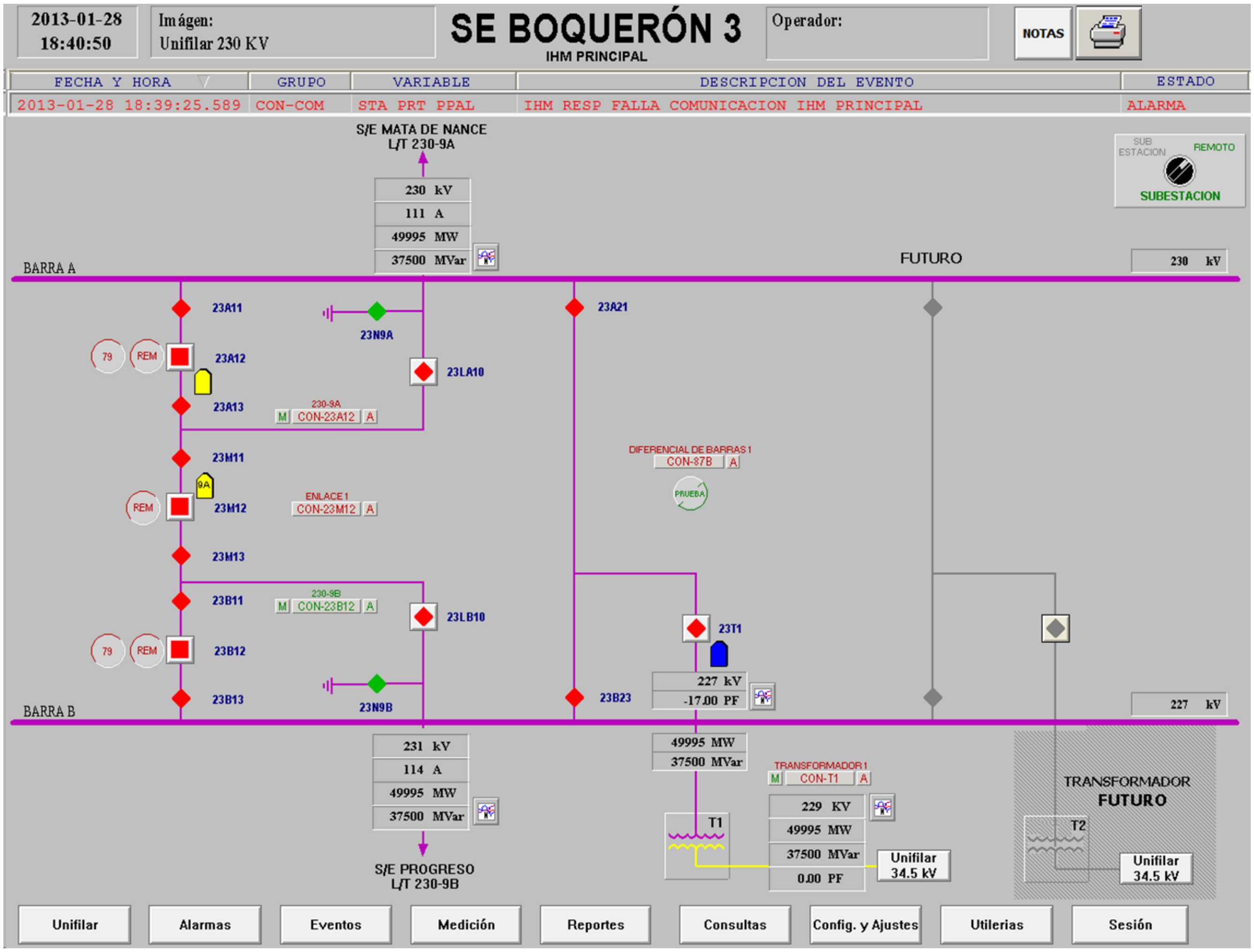

Fig. 8. General view window of the Boquerón 3 substation HMI.

Fig. 8 depicts the one-line diagram that is visible on the HMI of the Boquerón 3 substation. Tags placed on the breakers (yellow tags) and on one MOD switch (a blue tag) can be seen.

A challenge to achieving SCADA redundancy was that only one serial channel connection was used to transmit data from the substation to the CND. Even though the protocol gateway has a redundancy function, it could not be used because of the way it works. Protocol gateway redundancy works by continuously sending Internet Protocol (IP) packets in a rhythm, like a heartbeat. With the packet exchange between the two HMIs, the protocol gateway ensures that the communication between the HMIs and the redundancy services of the protocol gateway perform correctly. Based on this explanation, the redundancy feature does not monitor the communications health or status of the services for IEC 61850, IEC 60870-5-101, or the OPC server, not even if the Windows system freezes. It is because of this specific behavior in the redundancy operation that the built-in redundancy feature of the protocol gateway could not be used in this project.

The SCADA redundancy method includes implementing a local scripting routine that monitors both the quality of the points polled by IEC 61850 and OPC and manages the service restart if something goes wrong. This caused the need for each HMI to have robust data acquisition to ensure that the correct data are delivered to the CND. The method also includes using a serial port combiner between the two serial channels of the HMIs and the SCADA connection, as shown in Fig. 6. The HMIs are continuously transmitting data to the CND, but the port combiner is in charge of transmitting only the data of the first HMI that answers CND requests.

E. Local Tagging

ETESA operational best practices use logic tagging (placed on the HMIs locally and at the CND) and hardware tagging (placed directly on the equipment) to perform clearance procedures in the substations. As a part of the project requirements, the control and automation solution must include the logic tagging on the HMIs in order to keep personnel safe when clearance procedures are performed. ETESA requires that the logic tagging programming for the Boquerón 3 substation be based on the switching, tagging, and clearance procedures used by Matanuska Electric Association [2].

The tags are located only on equipment that can be remotely operated by either the HMI or the CND, such as MOD switches or circuit breakers. Red, yellow, blue, and white tags can be applied to breakers, and red, blue, and white tags can be applied to MOD switches. As mentioned before, a logic script programmed within the HMI was the solution to perform the tagging requested by ETESA. Based on the type of tag present on the equipment, control or protection functions are enabled or disabled. Implementing logical tagging requires advanced programming skills to create the scripts to make the tags work. The complexity in the logical tagging implementation increased dramatically because of the two independent HMIs. The following challenges had to be addressed:

- In the redundant HMI system, a tag placed or removed in one of the HMIs must be visualized automatically in the other HMI. This requirement involves the interchange and monitoring of the tag status between the two HMI computers. To achieve this, complex scripting methods were written, where each HMI monitors the tag status of the other HMI. A script runs every time the status of a tag changes in order for each HMI to update its tag status to match that of the other HMI.
- As a clearance procedure tool, the tags placed on the HMI need to be integrated in some way to block or allow the control commands from the CND. To meet this requirement, HMI tag status is included in the calculation performed in the protocol gateway. This inhibits or allows the control commands to the substation equipment. This was achieved by taking the HMI tag statuses, publishing them into the protocol gateway OPC server, and then including them in the calculation logic for every breaker or MOD. In this way, interlocking from the CND or from the HMI was successfully fulfilled.

F. *Event Printing*

An event printer was also part of the design requirements. The function of this printer is to print the alarms that originate in the substation. Each HMI is programmed to configure a printer to capture alarms. The event printers are configured identically on both HMIs. As mentioned before, both HMIs run independently; hence, when an event occurs in the substation, each HMI sends the same alarm to the same configured printer. The complexity of complying with this aspect of the project was not in printing the substation alarms, because event printing capability is included in the HMI features. Rather, the complexity was in controlling which HMI would send the alarm or event to the configured printer. If the HMIs printing services are not controlled, the printer captures each alarm twice (sent by the main and backup HMIs). To solve this, overlapping scripts were written to control the printing services on both HMIs.

Both printing services are disabled until the right conditions are present. The default printing service is located in the main HMI and starts only when the quality of specific points monitored by the HMI is good. The same data interchange and monitoring philosophy used in the logical tagging was used for the printing service controller. Each HMI monitors certain points of the other HMI. By checking the quality, communication, and status of these monitored points, the main or backup HMI can determine when to start or stop its printing services.

When the quality and status of the main HMI do not satisfy the conditions previously discussed, then the backup HMI starts its printing services. This way, only one alarm is sent to the printer, and the system maintains the redundancy features requested by ETESA.

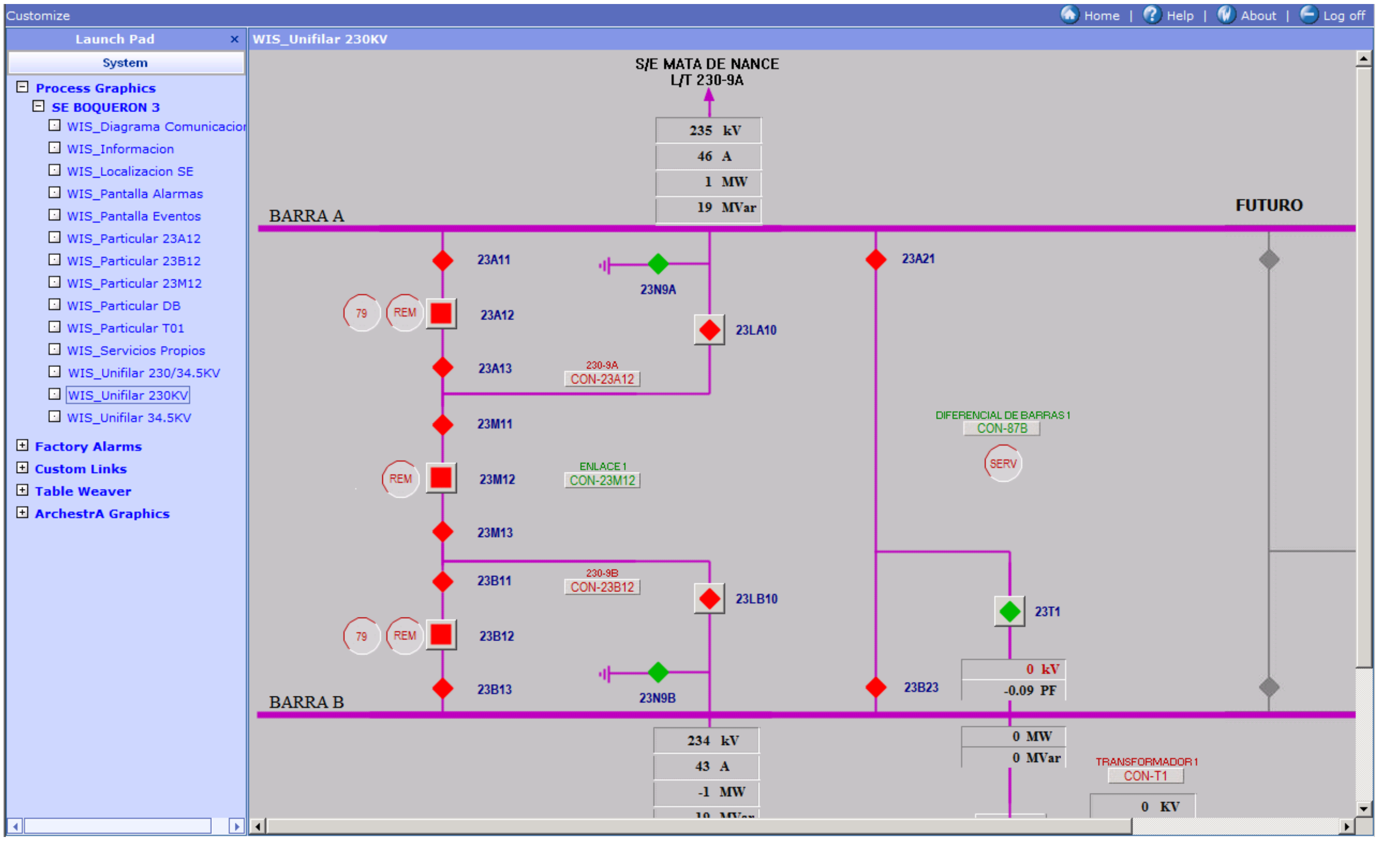

Fig. 9. HMI web server screen showing the Boquerón 3 230/34.5 kV one-line diagram.

G. Substation Monitoring Via Web Browsers

Another ETESA requirement was the possibility of remote visualization of the Boquerón 3 substation status. ETESA wanted to be able to monitor measurements, circuit breaker and disconnect switch statuses, alarms, and substation topology on a webpage accessible from any place inside the ETESA domain and via user-restricted accounts. This feature helps ETESA operations personnel monitor the Boquerón 3 substation status without being in the CND office and make informed decisions to maintain power transmission. Also, a window displaying sequential event records helps ETESA personnel speed up substation restoration during system disturbances. Fig. 9 shows a one-line diagram screenshot from the web browser HMI.

X. Conclusion

The use of the IEC 61850 standard in electrical substations is increasing worldwide, and it is a promising standard, both for the features it offers and for the future possibilities it holds.

Even though this standard is used in many new substations, the SCADA master at the ETESA CND still uses legacy protocols or standards to communicate with the new substations. As discussed in this paper, complex calculations and a great amount of time are required in order to integrate the new technologies with those present in the control centers. Also, the best features of IEC 61850, such as automatic mapping or automatic event reporting, cannot be fully used.

The most time-consuming and demanding part of the Boquerón 3 project was programming the substation control and automation system. It is well known that existing software could meet all the ETESA requirements described in this paper, but factors like the specific software in which the HMI must be designed, the IEC 60870-5-101 protocol used to report data to the CND, and specific compliance requirements forced automation engineers to design the solutions described in this paper.

As the very first ETESA IEC 61850 project, the Boquerón 3 substation has ETESA requirements and specifications that are similar to those in the existing substations and do not necessarily represent the best practices for this type of project. As one of the lessons learned in this project, ETESA specifications now require that relays be connected in a redundant Ethernet star topology. With the star topology, ETESA ensures that, besides the redundancy present in the HMIs, redundancy in the communications path between relays and HMIs can be achieved.

Finally, because of the success of the design solution and the satisfaction of ETESA, the system described in this paper is now the ETESA standard for the control and automation of all new substations.

XI. References

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XII. Biographies

Héctor Pérez receive his B.S. in electrical engineering from the Federal University of Espírito Santo, Brazil, in 1981. In 1986, he received a post-graduate degree in systems control from the Federal University of Rio de Janeiro, Brazil. He has been working in areas related to control and power in the electrical system in Panama, specifically with hydroelectric generators, substations, and power lines. Héctor presently works for Empresa de Transmisión Eléctrica, S.A. (ETESA) as a project manager and protection design engineer. He was an inspector for important projects in Panama, such as the gas turbine combined cycle Bahia las Minas thermal plant in Colón, Panama. Héctor also has worked as maintenance chief at the Bayano Hydroelectric Power Plant in Panama, assisting with the update and improvement of the control system for the governor and excitation systems.

Luis Carlos Herrera Bugarín received an assistant degree in electronic engineering in 1999 and a bachelor’s degree in electronic technology in 2005 from the Technological University of Panama. In 2012, he received a bachelor’s degree in computer system engineering from the Latin University of Panama. In 2007, he began to work for Empresa de Transmisión Eléctrica, S.A. (ETESA) as an operation and maintenance assistant. He was in charge of the automation and control of all the ETESA substations in the province of Chiriquí and worked on several projects related to the integration and testing of all control and automation systems to expand the Changuinola, Guasquita, Veladero, and Boquerón 3 substations. He has professional experience in fields such as automation, integration, SCADA, control, and programmable logic controller (PLC) programming.

Edson Hernández received his B.S. in electronic engineering from the Technological Institute of San Luis Potosí, Mexico, in 2006. After graduation, Edson worked as an associate technician at the Instituto Potosino de Investigación Científica y Tecnológica (IPICyT) in the automation processes of the laboratory as well in the research and development of nanotechnology devices. In 2008, Edson joined Schweitzer Engineering Laboratories, Inc. as an automation engineer, designing automation and control solutions for national and international projects. Edson is experienced in automation, integration, SCADA, and control. He is interested mainly in renewable energies, process automation, and device integration.

Camilo Alzate received his B.S.E.E. in 2007 from the Universidad Pontificia Bolivariana, Medellín, Colombia. In 2009, Camilo moved to San Luis Potosí, Mexico, and started working at Schweitzer Engineering Laboratories, Inc. (SEL) as an automation engineer. He was a design engineer for an automation project in power systems and, six months later, became a services automation engineer. In this position, he worked on an SEL Mexico project, including commissioning the Boquerón 3 substation in Panama. Presently, Camilo works as a project manager.

Alejandro Correa received his control and automation engineering degree in 1997 from the National Polytechnic Institute (IPN), Mexico. In 2001, he worked for the Telvent company, where he developed information technology and industrial automation projects, specializing in SCADA and related integrated systems for Comisión Federal de Electricidad. In October 2006, he joined Schweitzer Engineering Laboratories, Inc. in Mexico, where he is presently an automation engineering manager.

Jesús Gallegos received his B.S. in industrial engineering in 1991 from the Technological Institute of San Luis Potosí, Mexico. From 1992 until 2008, he was head of the protection and metering offices of the Western Transmission Area of Comisión Federal de Electricidad in Colima and San Luis Potosí, Mexico. He served on the faculty of the Marista University of San Luis Potosí in 2007. In September 2008, he joined Schweitzer Engineering Laboratories, Inc., where he has served as a protection system design engineer and as a head of the department for protection services in San Luis Potosí, Mexico.

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