Sending Protection and Automation Data Over PEMEX Ethernet Network: A Case Study

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ABSTRACT

PEMEX *Gas y Petroquímica Básica* (PGPB) is responsible for processing the gas extracted from the oil fields of Mexico. PGPB main facilities are located in the southeastern part of Mexico. Ciudad Pemex is a gas processing complex, which is the first link in the chain processing the gas received from the oil platforms deployed in the Gulf of Mexico.

Reliability and safety of the Ciudad Pemex electrical power system are major concerns for PGPB authorities. Unfortunately, the gas processing facilities, including Ciudad Pemex, do not have protection engineers on site. PGPB protection engineers are located at different regional offices and serve several gas processing plants. There was no system in place to provide these protection engineers with the information required to remotely analyze power system disturbances and to give them remote access to protective relay settings.

This paper describes an automation and integration system, which fulfills these requirements. The system also provides useful information to local operators and maintenance personnel at Ciudad Pemex. The paper is divided into three parts, the first one presents the problem to be solved; the second describes the basic automation and integration system architecture. Finally, the third presents and discusses real system operation cases.

INTRODUCTION

PEMEX *Gas y Petroquímica Básica* (PGPB) is part of *Petróleos Mexicanos* (PEMEX), the state-owned oil company of Mexico. PGPB is responsible for the processing of natural gas and its liquids, as well as the transport, commerce, and storage of related products [1].

During 2001, PGPB processed an average of 3.9 billion cubic feet per day of gas and an average of 443 thousand barrels of liquid gas per day. PGPB has 80% of its activities in the southeastern part of the country, in the states of Veracruz, Tabasco, and Chiapas.

The Gas Processing Complex (GPC) Ciudad Pemex is the oldest complex in the history of PGPB; it first began operations in 1958. In 1981 and 1982, it began operations for the sweetening and sulfur recovery process, and in recent years, there has been extensive revamping in the chemical process of the complex. As part of this initiative, a goal was set to update the power system of the complex.

Gas Processing Complex Ciudad Pemex

The GPC Ciudad Pemex is located 60 km away from Villahermosa, Tabasco, the state capital. Villahermosa also hosts the PGPB Regional Office and is a central point for coordination of PGPB activities in the area. Figure 1 shows the location of the PGPB Regional Office and the GPC Ciudad Pemex [2].

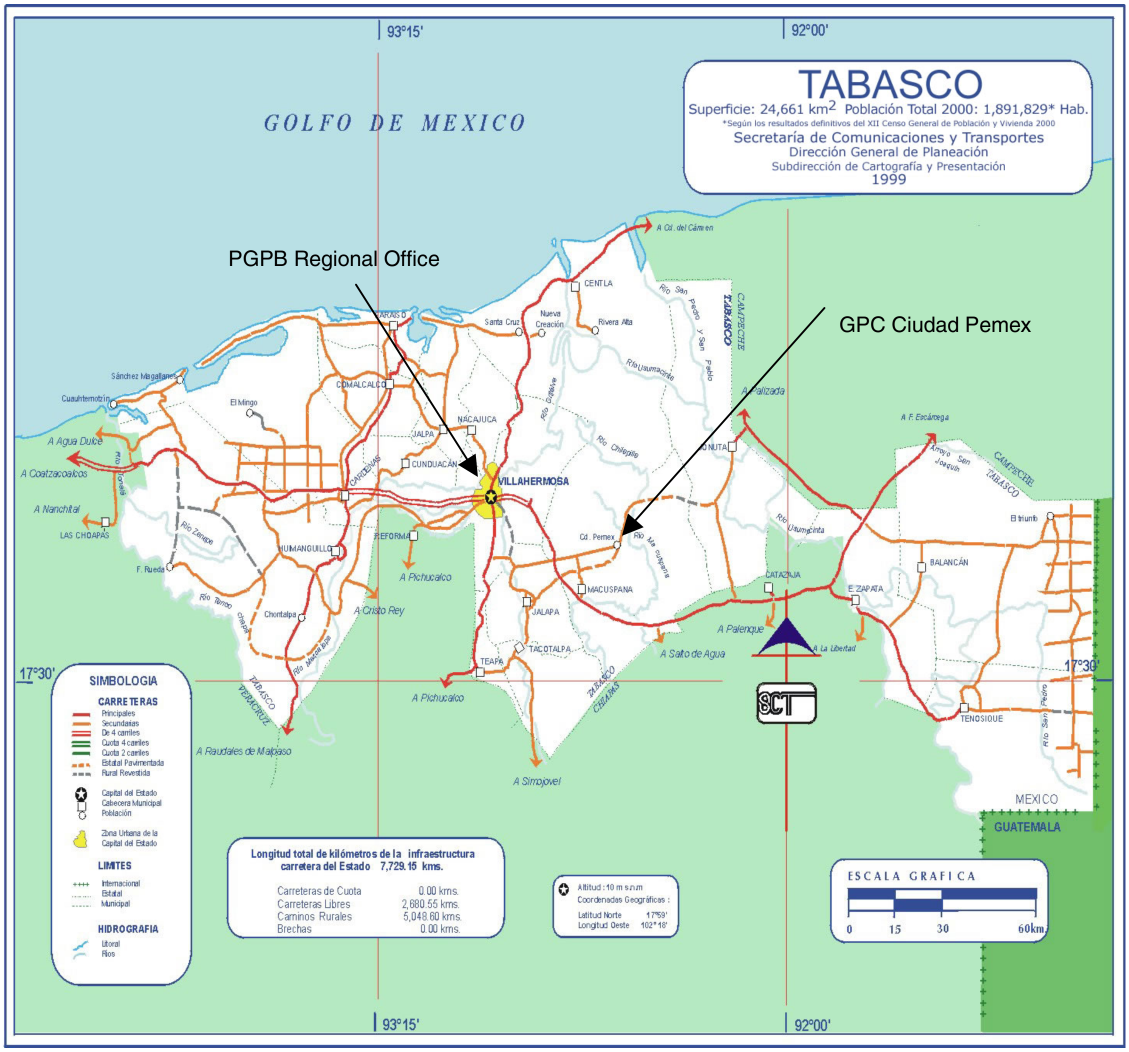

Figure 1 Geographical Location of Ciudad Pemex and the PGPB Regional Office

During emergencies, the gas is sent to external flares where it is burned in the atmosphere. As a result of this, combustion products such as carbon dioxide (CO_2), sulfur dioxide SO_2 (mist), and hydrocarbons are present in the air. The concentration levels are not a threat to human health, but they were taken into account when selecting mechanical and electrical equipment for the GPC.

The state climate is humid, with an average humidity of 72%, temperature of 27°C, and precipitation of 2,000 mm of water per year; the rainy season is during the summer [3].

Over the years, PGPB has invested in a communications infrastructure for the GPC Ciudad Pemex. Now it has nearly 100 telephone subscribers and 50 computer nodes distributed over the complex, which form the GPC Local Area Network (LAN). Inside buildings it uses copper wiring, and between buildings it uses fiber optics. In the substation building there exists one fiber-optic patch panel, but no LAN connection or substation LAN. The GPC Ciudad Pemex is linked to the PGPB Regional Office by means of a 10 Mbps microwave. Figure 2 shows a schematic for the communications network for the GPC Ciudad Pemex and the PGPB Regional Office. All of the communications infrastructure is the property of PGPB, so there are no public links or paths.

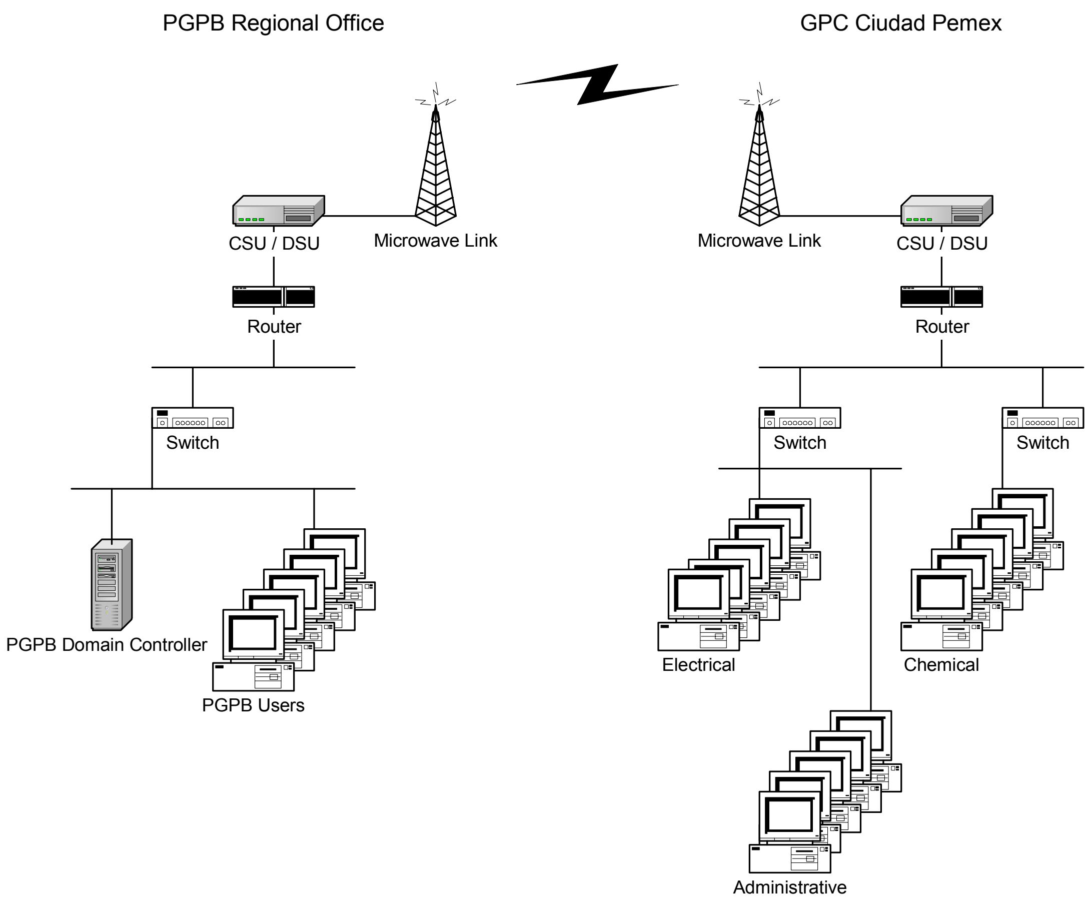

Figure 2 Communications Network

GPC Ciudad Pemex Power System

The GPC Ciudad Pemex has its own power generation; its infrastructure consists of two 30 MVA generators and a 13.8 kV distribution grid. Also, it has two 115 kV links to the *Comisión Federal de Electricidad* (CFE) electrical grid. These links are maintained in cogeneration with CFE because of the importance of the processes carried out in the GPC. CFE is Mexico's national electrical utility.

Figure 3 shows the one-line diagram of *Subestación Principal 115 kV*, the 115 kV/13.8 kV electrical substation. Before the modernization of the protection system, the substation had electromechanical protective relays for the following functions:

- Two 115 kV lines with directional overcurrent 67N.
- Two 115 kV/13.8 kV power transformers with differential protection 87T and overcurrent 51P/51N, underfrequency 81U, and verification and synchronization 25 on the 13.8 kV side.
- Six 13.8 kV feeders with overcurrent protection 50/51P, G.
- Two 13.8 kV links to generators with directional overcurrent protection 67N, underfrequency 81U, and verification and synchronization 25.

The power system had been in operation nearly 20 years, with most of its electromechanical protection equipment near or past its useful life. Also, it had neither a Supervisory Control and Data Acquisition (SCADA) system, nor tools to recover and analyze power system events and faults.

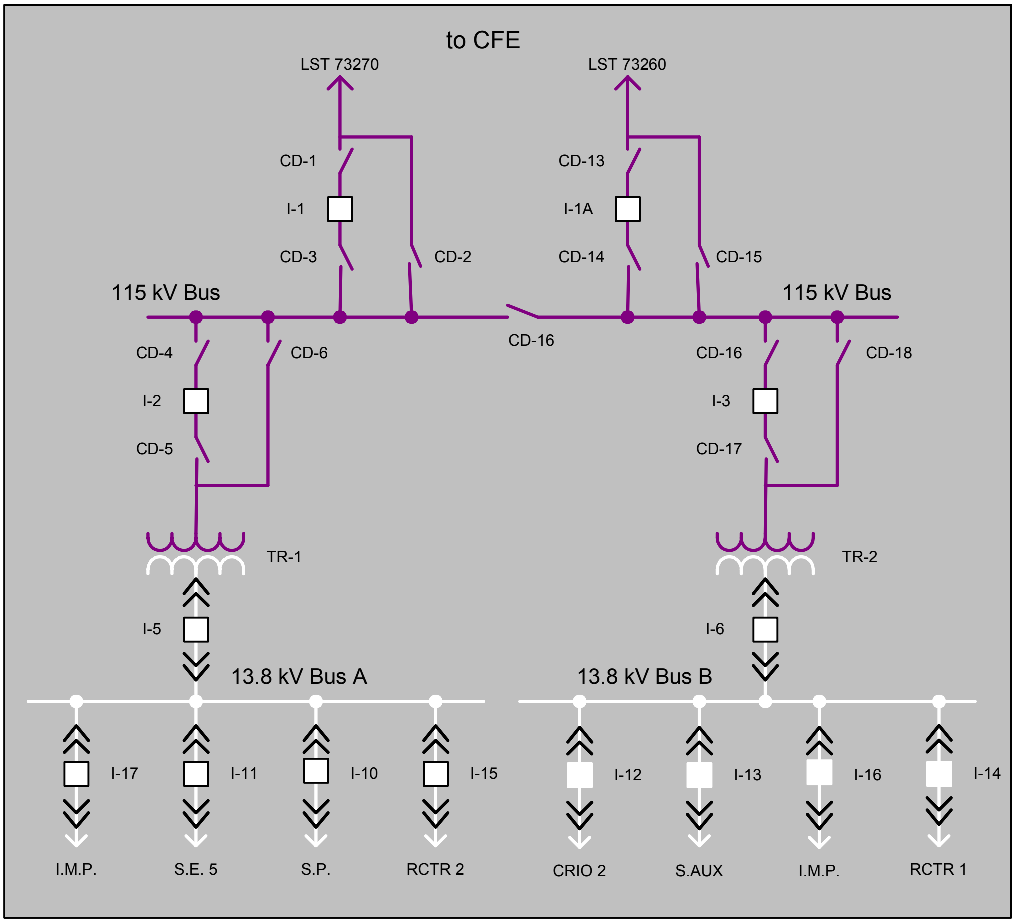

Figure 3 One-Line Diagram of *Subestación Principal 115 kV*

Electrical engineers with the proper technical background and experience for power system disturbance analysis are not available on site. Electrical engineers focus on the operation and maintenance of power system apparatus as well as the other electrical equipment present in the GPC. The lack of well trained personnel is due to the main activity of the GPC Ciudad Pemex. Its personnel includes administrators and chemical, mechanical, and electrical engineers and technicians, who focus on the operation of the GPC.

PROBLEM DESCRIPTION

Several factors caused the GPC Ciudad Pemex power system to have low reliability and to be an expensive and unsafe system to operate. These include the following:

1. Existing electromechanical protection apparatus were in service beyond their useful life, resulting in substation equipment damage every year and high protection system maintenance cost.

2. No event data were recorded from the power system disturbances, and no subsequent analysis was done. It was not until equipment maintenance was performed that the state of electrical apparatus was known.
3. Adjustments in protection settings due to dynamic changes in the operation of the power system were not possible with the existing protection equipment.
4. The interconnection point with the CFE was mission critical; disturbances in the utility could have led to a power system shutdown in the GPC Ciudad Pemex.
5. There was a lack of personnel with experience and knowledge in disturbance analysis at the GPC Ciudad Pemex.

In addition to solving these issues, the following requirements needed to be met:

1. A local HMI was needed for local monitoring and control of *Subestación Principal 115 kV*.
2. Basic substation information needed to be widely available to all personnel, both locally in the GPC Ciudad Pemex and remotely in the PGPB Regional Office.
3. Protection data such as relay settings, Sequential Events Recorder (SER), and oscillography were required to be available to personnel with experience and technical background in disturbance analysis, either on site or at the PGPB Regional Office.

SYSTEM DESCRIPTION

The design in the system took into account engineering best practices to assure a reliable and secure system. Protective relays were chosen based on the protective functions needed, but also on the approval list published by *Laboratorio de Pruebas de Equipos y Materiales* (LAPEM) [4], part of the CFE-recognized test laboratory.

The information provided by protective relays was integrated based on the use of the communications processor. This solution provided a simple, secure, and reliable communications scheme as shown in [5] and other successfully integrated systems.

The integration approach taken was to use an Ethernet network, based on the conclusions shown in [6], particularly: "Ethernet networks provide a good connection for engineering data collection from IEDs to the engineering workstation at remote sites." The use of an Ethernet network in the substation brings a whole different set of protocols and tools, especially those conforming to the Transfer Control Protocol / Internet Protocol (TCP/IP) suite.

When transferring protective data over the Ethernet, several electronic vulnerabilities arise, as mentioned in [7]. The vulnerabilities are those related to SCADA via a private network. Every effort was taken to mitigate the risks of these vulnerabilities, including access restriction, user authentication, and log audit.

Fault tree analysis helped in the design of the system architecture. As shown in [8], the techniques are fairly simple to use and provide useful information for establishing maintenance programs for substation apparatus and improving reliability in communications infrastructure and computer systems.

Protection Overview

Digital relays were selected to provide the protection functions for each equipment in *Subestación Principal 115 kV*. The selection process took into account the following guidelines:

- Digital relays must be tested and approved by LAPEM.
- Digital relays must work under substation conditions and also under the environment found on the oil and gas facilities.
- Digital relays must provide communications ports to be easily integrated into the SCADA system in a simple design.

Panels of protective relays were supplied and installed to provide protection, control, and monitoring functions as follows:

- In order to protect the two 115 kV lines, protective relays were installed as primary protection 21/21N and backup protection 67N, 59N.
- To protect the two 30 MVA power transformers, protective relays were installed as primary protection 87T and backup protection on the high voltage side and low voltage side 67/67N; on the low voltage side, a relay is verifying the synchronization 25/27 to monitor and protect underfrequency 81U.
- To protect the six 13.8 kV feeders, protective relays were installed with overcurrent protection functions, 50/51 and low frequency 81U.
- To protect the two links between *Subestación Principal 115 kV* and the GPC Ciudad Pemex generation, two protective relays were installed at each end with the teleprotection application with directional comparison POTT (MIRRORED BITS™ communications). The links are also protected by an inverse power protection function 32.

Integration Overview

The Integrated System is based on a proven solution, a substation-hardened communications processor. The protective relays are connected to the communications processor via a serial communications link in a star configuration. The communications processor uses a technique called "Interleaved Communications" in which several communications use the same serial link, in this case:

- Solicited ASCII
- Solicited Binary
- Unsolicited Binary
- Binary Commands (used for control)

The Integrated System architecture is shown in Figure 4. As can be seen, the communications processor hosts an Ethernet processor card, which provides connectivity to the substation LAN. The Ethernet processor card supports File Transfer Protocol (FTP) and Telnet from the TCP/IP protocol suite.

The LAN link to the communications processor serves three objectives:

1. Oscillographic data retrieval to the remote PGPB Regional Office for event analysis.
2. Remote digital relay settings, visualization, and adjustments.

3. SCADA system backup. The information visualized in the local HMI is present in the communications processor database and is available to the remote user via a LAN connection.

Security access via LAN is enforced in the communications processors via “hard” passwords.

Even though Figure 4 shows the substation Ethernet LAN as a single bus, it is actually a set of point-to-point connections between the switch and every device on the LAN (switch, NICs, and Ethernet processors).

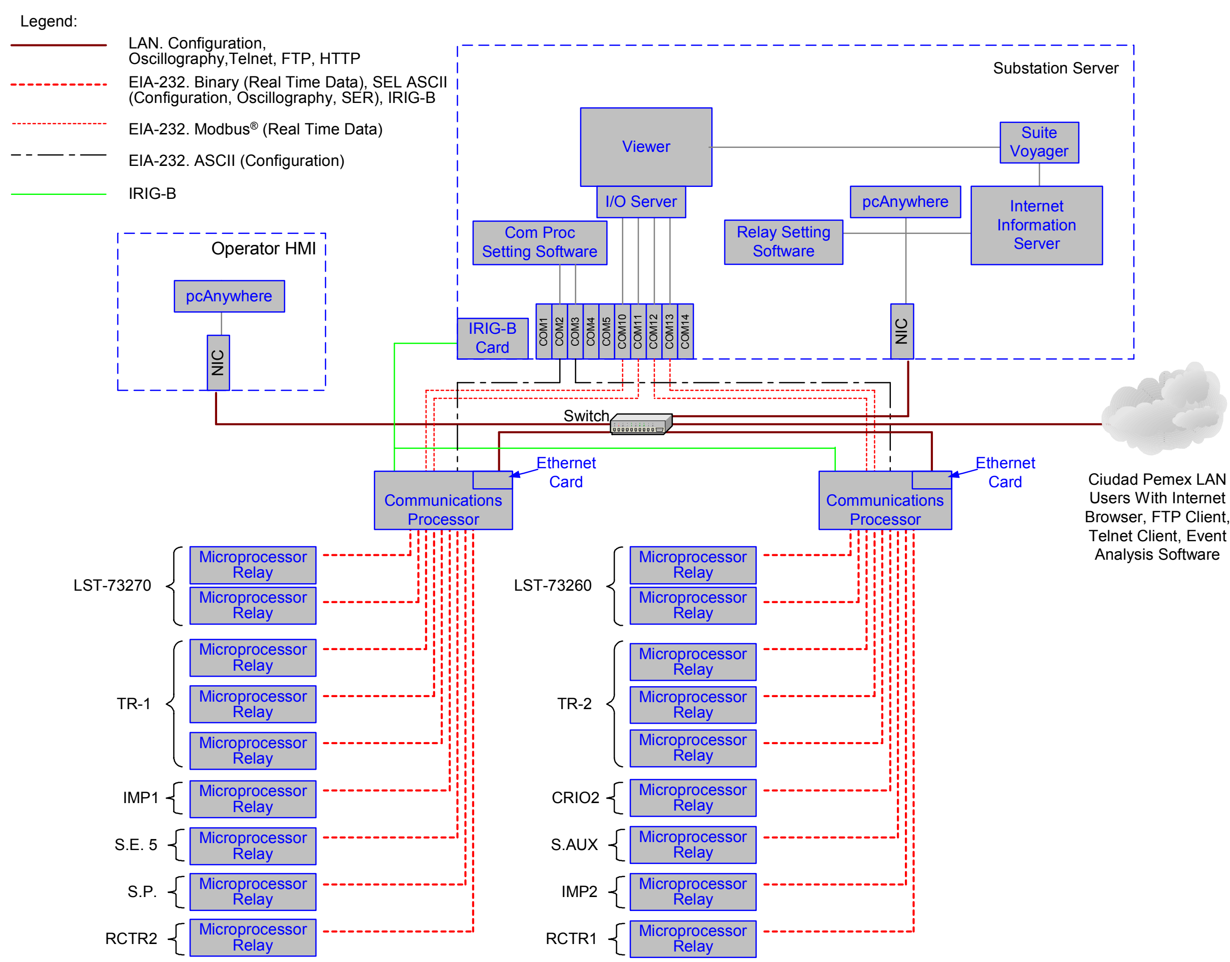

Figure 4 System Architecture

Substation Integration Software Overview

The Integrated System server applications run on an industrial PC with hardware capabilities to run server applications. These server applications include a Windows® 2000 server, an I/O server, a local HMI, and an Internet information server (IIS). The PC also runs protection software programs that assist with such tasks as managing event reports, establishing relay settings, and system analysis.

The Windows 2000 server is configured as a domain controller for the substation. This means that it maintains a security system for the users of the substation integrated system.

The HMI application was developed using an off-the-shelf product with a set of screens that include the following:

- One-line diagram
- Specific equipment screen
- Alarms screen
- Specific equipment alarms screen
- Communications screen
- Real-time trends

An example screen for the HMI application is shown in Figure 5. As can be seen from Figure 5, this screen has been customized for this particular application. In essence, however, it is the same as other substation integrated systems.

As an add-on to the off-the-shelf HMI product, there is a "visual translator" that transforms selected operator screens to a format that can be published by a web server. The web server selected for this integrated system is IIS; IIS "serves" web pages to the user on the LAN or WAN. It is the same product found on government web sites, e-commerce web sites, etc., over the Internet, but it can also be found running on Intranets over private LANs or WANs to publish information to users with access to the LANs or WANs.

In this project, the pages served are eXtensible Markup Language (XML) format with information from the substation integrated system. XML allows the browser to present the information with the same colors, fonts, figures, and drawings as the original HMI. Figure 6 presents an example of a screen taken from one browser client.

One advantage is the ease of training, due to the experience most users have using the web pages on the Internet. Navigating through the substation information web pages is exactly the same as any other web site.

Because the IIS is running over a Windows 2000 domain server, every user who wishes to browse the substation web site is requested to provide a user name and password. This security is enforced using Windows 2000 server security, which means password files are maintained in a single place.

Subestación Principal 115 kV is an unmanned substation. To allow secure remote operation, secure remote access software for the substation server and for the operator HMI was installed. This allows remote HMI operators to take control of the substation server as if they were physically in front of it. Security is configured the same way as the IIS; it requires users to log on to the substation domain and then grants access to the substation server.

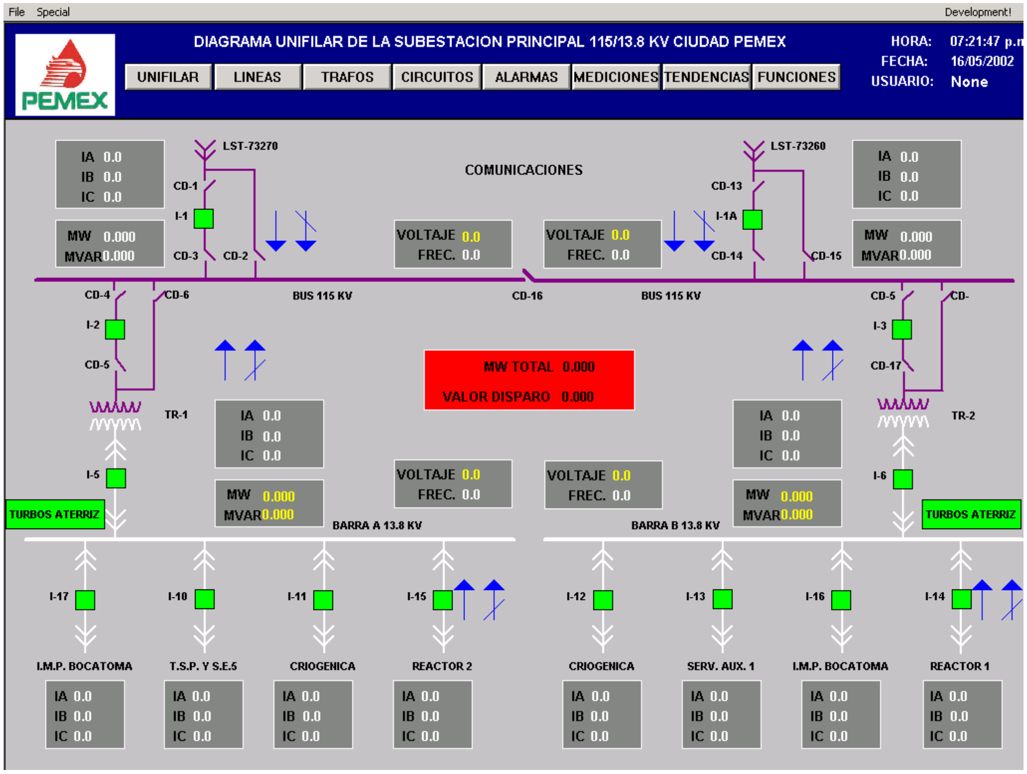

Figure 5 Local HMI One-Line Screen

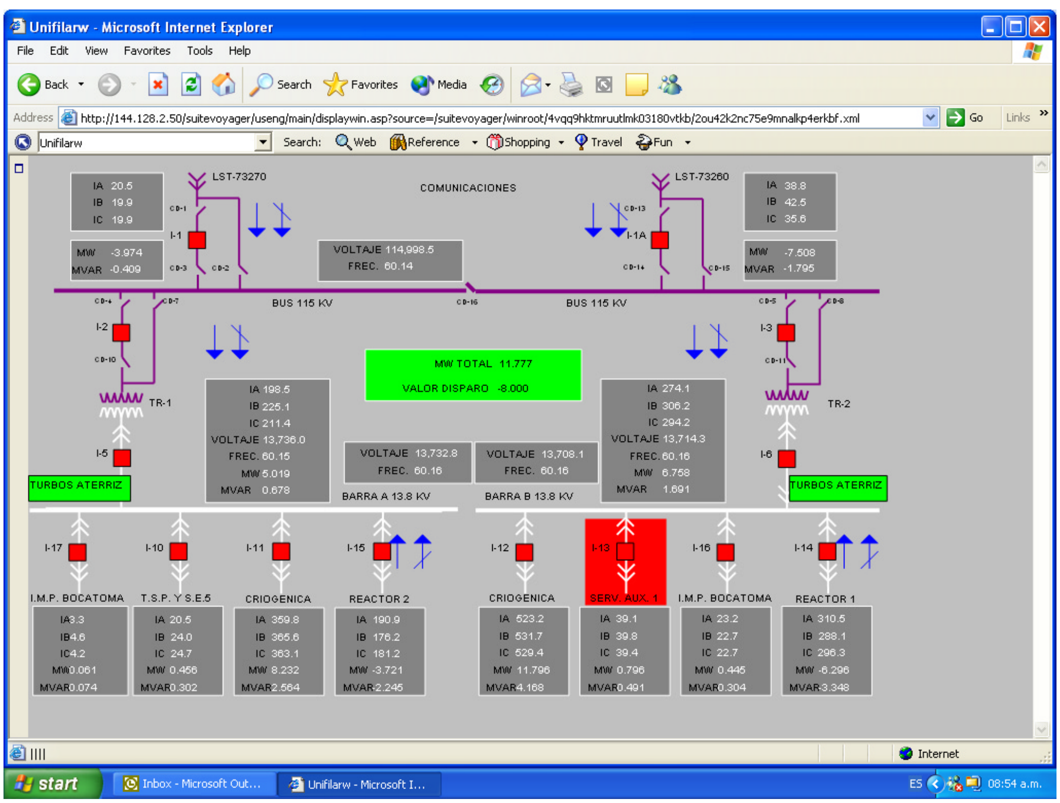

Figure 6 Intranet Web Page One-Line Screen

System Operation Experience

The protection panels were installed and commissioned during the first quarter 2002. The Integrated System was installed and tested during March 2002. Training was conducted to supply operators with the proper understanding of the system, its screens, and functions. Also, training was given to protection engineers in the GPC Ciudad Pemex and the PGPB Regional Office in the use of the Internet tools, especially those of Telnet, FTP, and fault analysis software. It is worthy of mention that little time was given to cover the use of the Internet browser, due to the experience shown by the engineers.

Despite the change of technology, from electromechanical relays to microprocessor relays, from no integrated system to substation data monitoring in an office 60 km away, support to the whole system has not been as time consuming as first thought. In fact, having the information (relay settings and event records) in an electronic format has reduced the response time for support and helped the protection engineers fine-tune the relay settings.

Examples of Operations

In these past months, there have been the following operation examples:

- During the summer, an increase in demand by domestic users, due to the use of air-conditioned equipment, shifted the power flow from the GPC Ciudad Pemex to CFE. Using information provided by the Integrated System, authorities in the GPC disconnected until the demand was covered by other power suppliers to CFE.
- The power system frequency experienced shifts during connection and reconnection to the CFE grid. PGPB protection engineers designed different group settings in the digital relays to accomodate these different circumstances.
- Fault information retrieval has become a simple click and connect process. Access via Telnet to communications processors and microprocessor relays has reduced the number of trips to the GPC Ciudad Pemex for protection engineers, reducing the time to collect the information for event analysis and allowing better relay setting adjustments.

Advantages of the System

The advantages of the Integrated System and the microprocessor protective relays are as follows:

- Operation of microprocessor protective relays has helped the GPC Ciudad Pemex electrical maintenance personnel find wiring problems and, in some cases, erroneous settings on existing protection equipment in different substations.
- Information provided by the Integrated System has helped to coordinate the complete power system of the GPC Ciudad Pemex. It has also helped to fine tune protective relay settings for each different set of operating conditions.
- Microprocessor protective relays have provided information to disconnect and reconnect the GPC Ciudad Pemex power system due to frequency changes and power consumption in the CFE power system.
- Microprocessor protective relays have helped reduce chemical process downtime due to a more reliable electrical power system.
- Time to perform event data retrieval has been reduced from several hours to approximately 30 minutes, without the need for leaving the office.
- More complete data have been made available to determine the root cause of a fault.

- There has been no expense in software or training for users browsing data over the Intranet into the *Subestación Principal 115 kV* web page.

Future Enhancements

As every system evolves, it becomes more robust and useful. The GPC Ciudad Pemex has identified future enhancements to this Integrated System:

- Integrate information from other relays in the GPC. Protective relays in the 13.8 kV distribution grid are located in the plant and can be integrated into the system.
- Improve the robustness of the computer systems. The substation server is the weakest link in the information chain as shown from fault tree analysis. Adding a redundant array of hard disks and a redundant server will increase the system reliability.

CONCLUSIONS

1. Web technology and protocols such as HyperText Transfer Protocol (HTTP) and Telnet sessions are useful tools for substation monitoring, bringing protection data close to the personnel who use the data most often.
2. Monitoring event and fault data registers in the IED contributes enough information to analyze power system faults, and to correct and improve the protection coordination in the GPC Ciudad Pemex.
3. Industrial clients, with the proper infrastructure and security measures in place, can outsource their need for protective data analysis with external consultants or specialized firms. Existing technology and equipment aid to achieve this goal.

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BIOGRAPHIES

Enrique Priego-Franco has a B.S. in Electrical Engineering from *Universidad Juárez Autónoma de Tabasco (UJAT)* in Villahermosa, Mexico. He has 25 years of experience in the oil industry and has been working for PEMEX PGPB since 1977. For the last five years he has been the Installation Coordinator for GPC Ciudad Pemex.

Carlos Alberto Guzman-Carranza has over seven years of experience in systems design, implementation, and project management in the Energy, Steel, Oil, Software, and Environmental industries. He has a very strong technical background with expertise in the design, development, integration, and automation of control systems, as well as strong experience in infrastructure, data management, data mining, and systems integration. Mr. Guzman has demonstrated expertise leading teams in executing systems integration and implementation for private and public sector clients. He obtained his Electronic Systems Engineering degree from the *Instituto Tecnológico y de Estudios Superiores de Monterrey* (ITESM) in Monterrey, Mexico (1993) and his master's degree in Environmental Engineering from the UNAM-DEPFI in Mexico City, Mexico (1998).

Manglio Alejandro López-Aguilar is an Industrial Electrical Engineer from Tuxtla Gutiérrez Technological Institute. He worked for six years in Protection in *Área de Transmisión y Transformación Sureste* (ATTSE) and *División de Distribución Sureste* (DDSE) of CFE. His activities were supervision, preventive and corrective maintenance, design and installation of panels, and commissioning of power substation protection, measuring, and control systems. He has experience in analysis of electrical faults, short circuits, and coordination research protection settings and engine protection. From 1998 to 2000, he worked in INELAP-PQE as a Technical Support Engineer. Since 2000, he has worked for Schweitzer Engineering Laboratories S.A. de C.V., as the leader of the Southeast Technical Support Center in Coatzacoalcos, Veracruz. He has given training courses on different protection relays to CFE and private companies.

Jorge Humberto Díaz-Hernández has a Computer Engineering degree from the *Universidad Autónoma de Aguascalientes* in Aguascalientes, Mexico (1997) and is finishing his master's degree in Power Systems from *Cinvestav IPN* in Guadalajara, Mexico. He has worked for three years in system design, implementation, and project management. He has been working for Schweitzer Engineering Laboratories S.A. de C.V. as an Integration Engineer since September 2000.

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