MODBUS AND ETHERNET COMBINE TO IMPROVE GAS STORAGE FIELD CONTROL SYSYTEM COMMUNICATIONS

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INTRODUCTION

Pacific Gas & Electric's Los Medanos Underground Storage Field is located in the foothills of Mt. Diablo near Concord, California in the heart of the fastest growing industrial region in the San Francisco Bay Area. Put into service in 1980, the facility provides support to PG&E's gas transmission system during peak load periods and is capable of delivering gas from the reservoir at a rate of 320 million cubic feet per day.

The facility is comprised of 20 gas wells bored into a sandstone formation about 4000 ft. below the surface. A 4000 HP natural gas powered reciprocating compressor pumps gas into the underground formation up to a maximum field pressure of 1600 psig,

The wells are grouped into four "well pads" each with two to nine wells that provide the necessary piping to allow both injection and withdrawal from the field. Each well contains downhole and uphole safety valves, a choke valve to control flow during withdrawal, and an orifice meter to measure the flow rate of gas into and out of the well.

In addition to the four well pads and compressor station, there is a pressure limiting station (PLS) which controls the pressure of the gas leaving the station during withdrawal periods.

CONTROL HISTORY

The original control system design was based on the Modicon 484 programmable logic controllers (PLC) using Modicon's 500 series I/O modules. One PLC was installed at well pads A, B and D, two PLCs at Pad C and one PLC at the PLS. Two PLCs were installed in the control building; one to control the compressor and one to provide alarm annunciation and interface. Programmed to compute flow rates, remotely control the choke valves, control the compressor, and monitor various safety systems, these PLCs represented "state-of-the-art" technology when they were installed. There are also hard-wired control systems at each well pad designed to provide manual control and safety systems independent of the PLCs.

STATION	NAME	CONTROL RESPONSIBILITIES
1	Pad A	Wells: 2A, 3A
2	Pad B	Wells: 4B, 5B, 6B
3	Pad C	Wells: 7C, 8C, 9C, 10C, 11C, 15C
4	Pad C1	Wells: 12C, 13C, 14C
5	Pad D	Wells: 16D, 17D, 18D, 19D, 20D, 21D
6	PLS	Station flow rate, main line pressures, temperatures
7	K1	Compressor Unit K1
8	Station	Alarm Interface/Annunciation

Table 1: Los Medanos Controllers

The PLCs were designed to operate independently from one another. Alphanumeric displays and thumbwheel switches installed at each well pad provided a means for operators to enter set points and read data locally.

In 1985 a Hewlett Packard model 9836 computer was installed in the control room to gather data from each PLC and provide a means for remote control of the well pads. The HP also functioned as a data supervisor and alarm generator. If an alarm event occurred at Pad A for example, the HP would detect the event, send a message to the Station PLC to annunciate the alarm horn in the control room, and then also send messages to each of the other PLCs to turn on the Pad A alarm indicators at each of the other well pads. Alarms and hourly flow and pressure data were logged to a printer.

Spare circuits in a 25-pair cable, installed during the original construction as part of the telephone system, were used to establish the data communications network between the PLCs and the HP 9836. A Modicon J474 module was added to each PLC system to connect the PLCs to the network. The J474 modules provided a communications interface for the PLCs, and were configured to use MODBUS ASCII protocol on a 4-wire RS422 circuit at a 9600 baud rate.

Back in the control room, the HP 9836 ran a customized HP-BASIC program specifically designed to poll each of the PLCs and display selected data on the screen. When the operator wanted to change a set point, he would change the screen display which in turn interrupted the polling sequence and allowed a write command to be sent to the desired PLC.

For it’s time in 1985, this supervisory control and data acquisition system was considered quite sophisticated and continued to work well and with good performance for as long as possible – that is, until the system hardware was so old that repair parts were no longer available.

MODERNIZATION PURPOSES

When deregulation of the California natural gas transmission industry caused an increase in the value of underground storage services, the control system upgrade program was more vigorously pursued. The potential for lost revenue caused by operating restrictions due to equipment failure at Los Medanos quickly became a significant economic factor.

In 1992, PG&E became acutely aware of the impending obsolescence problem after receiving a service bulletin from AEG Modicon stating that, after 15 years on the market, component parts for the 500 series I/O were becoming increasingly unavailable, and thus repair support would be discontinued in six years (1998). By 1998, the PLC central processing units were failing at a rate of about 2 per year. As spare parts stocks dwindled, the risk of a non-recoverable failure of the control system increased. At Los Medanos, control system failures would severely limit the ability of personnel to vary the gas flow and the facility cannot be reliably operated at full capacity.

If the control system failed and only manual field operations were possible, the minimum operating inventory of the field would need to be increased due to uncertainties surrounding pure manual operation of the wells. The cost of carrying the added inventory, combined with the lost opportunity costs derived from inability to take maximum advantage of the practice of parks and lends was estimated to be between $250,000 to $500,000.

INCREASED PERFORMANCE EXPECTATIONS

The HP 9836, with it’s two 5-¼” floppy drives and 8” integral monochrome display, proved to be very reliable. While production of these computers stopped in the mid 1980’s with the advent of PCs, HP stated that they would continue to support the unit at their service centers on a time and material basis. It should be noted that the HP 9836 operated virtually trouble free during it’s 13 years of operation.

Despite the high reliability however, the HP 9836 computer based system had some notable deficiencies. For instance, since the HP9836 was integral to the alarm and ESD systems, both of these critical systems were inoperable if the BASIC program stopped running. Furthermore, the scan rate for the 90 analog and 511 discrete data points was approximately 20 seconds and the system had no archiving or trending capability.

LOCATION	DISCRETE INPUT	DISCRETE OUTPUT	ANALOG INPUT	ANALOG OUTPUT
Pad A	30	27	8	0
Pad B	39	32	12	0
Pad C	93	62	36	0
Pad D	66	47	24	0
PLS	13	0	9	0
K1	30	0	0	0
Station	45	27	1	0
TOTAL	316	195	90	0

Table 2: Los Medanos I/O Summary

In general, a 20 second scanning cycle may be adequate for monitoring a slow response process such as is seen with gas pressure and flow control algorithms. But since PG&E has recently adopted condition-based maintenance practices, scanning and archiving at rates of 1 second or better are expected for data associated with rotating machinery (e.g. shaft vibration, bearing temperature, rpm).

The challenge for the design team was to improve the data collection performance while meeting or beating the reliability of the old control system, and of course, delivering the product for the lowest possible price.

SOLUTIONS

From the outset it was apparent that if we were to meet our cost objectives, strict limits had to be set on how much of the existing control system equipment would be replaced. Clearly, the old PLCs and I/O modules would be replaced, but where to stop the upgrade effort was difficult to establish because improvements could have been made in nearly every aspect of the control system.

Much to the chagrin of the project engineers, replacing the communication infrastructure was determined to be too costly to include in the project scope. The new system would have to use the old communication network even as the need for one second scan rates were set for purposes of data logging and archiving.

The cost to upgrade all of the field instrumentation and control elements was also too much to justify, and though old, the equipment was working fine with the exception of a few choke valve motors. Some deferred maintenance would be done, but there would be no enhancements or upgrade to the existing field devices. The new design and construction activity would end at the point where PLC I/O modules meet field wiring.

The manual control panels on the other hand, were an unreliable morass of faulty toggle switches and burned out indicator lights driven by hard-wired relays. Installing panel-mount operator interface terminals in place of the local control panels was never a question.

The design activity then focused on three key elements

- Change control system architecture to optimize communications.
- Add data logging and trending package to the station operator interface system.
- Simplify the manual control panels.

EQUIPMENT

PLC

GE Fanuc's 9030 PLC with rack mounted I/O modules was selected to replace the Modicon 484s.   PG&E had had good experiences with GEF equipment in similar installations over the last 12 years and the 9030 PLC with rack mount I/O significantly reduced the amount of panel space required for wiring. The wide selection of communication modules available for the 9030, including RS-232, RS-422/485 and IEEE 802.3 Ethernet, also made this a good choice for the application. Furthermore, the popularity of the 9030 has led to the development of third party products that can save time and enhance over all system performance.

For example, a problem immediately arose during the design phase when marrying the new smaller controllers with the existing field wiring.   Not surprisingly, the terminals on the rack mounted I/O modules would not accommodate the 16 gauge wiring originally used for the field wiring. Since replacing the field wiring was out of the question, a transition to a smaller gauge wire was required. A significant savings in installation cost was achieved with the use of ENTRELEC pre-formed wiring harnesses which are designed to allow a multi-conductor cable to plug directly onto a rack mounted I/O module. The only wiring labor involved was to land the 20 AWG wire ends at the terminal block where the circuits transition to the field wiring.

The second third party product employed in the new design was SEBRAUN, Inc.'s Modbus MASTER RTU emulator program. This program, which PG&E had previously evaulated on an earlier project, is designed specifically for the GEF 9030 Programmable Coprocessor Module and provides a convenient method for the PLC to function as a Modbus master device without an inordinate amount of programming in the main PLC program. Using PENSAR's proven program saved us the cost of development and testing time which otherwise would have been required.

LOCAL OIT

PanelMate's model 1700 operator interface terminal was selected for installation at the well pads to provide local set point entry and data display. The PanelMate offers a simple, flexible product with ample features at a reasonable cost and includes a GEF communications driver to allow direct connection to the GEF 9030 PLC.

CONTROL ROOM OPERATOR INTERFACE SYSTEM

GE Fanuc's CIMPLICITY HMI product was selected for the main operator interface system located in the control room. This software package, running on Dell Optiplex Gxi personal computers with the Windows NT 4.0 operating system, is used at other PG&E facilities and has proven to be a robust, flexible, powerful and easily supported data acquisition system. The product straight out of the box provides a data archiving and trending package adequate for the application. If necessary in the future, a more extensive data historian module can be added to the base product. Furthermore, by using Windows NT and TCP/IP, the HMI PCs can be easily accessed via PG&E's corporate intranet. Technical support for the system can thus be administered from the technicians office in another part of the control building, or from an engineer's office 20 miles away.

ARCHITECTURE

The architecture of the new system had to accommodate several competing elements; it had improve the data scan rate from the remote locations while using old copper circuits, and it had to allow for future expansion to include a new compressor controller from which data could be polled and logged at rates less than 1 second. Two fundamental changes to the control system architecture allowed each of these desired elements to be fully realized.

The first fundamental change implemented by the new control system architecture was to remove the responsibility for inter-PLC communication from the operator interface computer and place it in the station PLC. The new station PLC is programmed to manage all of the data transactions between the remote sites and the HMI. The HMI uses 10Mbps TCP/IP to poll all of the station data from just one source. Set points entered by an operator at the HMI are written to the station PLC which then interrupts it's ongoing polling task and executes the transaction with the appropriate remote PLC. The station PLC then reports the status of the transaction back to the HMI and resumes it's polling sequence.

The second fundamental change was to the communications network. We abandon the concept of a multi-drop network of PLCs and isolated the communication paths between the station PLC and each of the remote PLCs. The existing 25 pair cable run between each location had a sufficient number of spare wires available to allow separate 3-wire RS-422 circuits between the station PLC and each of the six remote PLCs. Six separate Progammable Coprocessor Modules, equipped with SEBRAUN, Inc.'s Modbus Master RTU PROM chip, are installed in the station PLC to manage the communication transactions with the remote PLCs.

The remote PLCs are now polled simultaneously rather than sequentially and with greater frequency than before, which has dramatically improved the data polling performance. Data that had previously been updated once every 15 to 20 seconds in the old system is now being updated every 1 to 2 seconds. In addition, now when a set point is sent to a remote location, the data polling from the other five sites is no longer interrupted. This structural change to the control system architecture is only possible because of the ability of the GEF 9030 PLC to process all of the required communication requests without interruption. While six coprocessor modules may seem extravagant, it has improved system performance tremendously for a small fraction of the cost of installing new communications circuits.

Removing critical control functions from the operator interface system effectively increased reliability of the control system by reducing the dependency on the HMI as a control element. Normally, once the PLC is programmed and tested, there is little reason for operators or technicians to interact with it. But a PC-based HMI is expected to have a high degree of interaction with operators and technicians alike, and therefore by design is more susceptible than PLCs to external problems. Unusual occurrences can and do happen to PCs such as inadvertent shutdowns, jammed printers, memory leaks, and if attached to a network the potential for damage only increases. With the responsibility for data transactions between PLCs removed, the HMI still plays a critical role in the system architecture but only for set point entry, data display and data management functions such as archiving and report generation and doesn't affect the control of the facility if crashes.

BENEFITS

- Late in the project, operations personnel wanted to replace 2 old pen and paper strip chart recorders with expensive color LCD based recorders. They changed their minds when they saw how the same information could be similarly displayed and archived using the new Cimplicity HMI system. The alternative method resulted in lower equipment cost, and one less item which technicians needed to be trained on and maintain.

- The new system easier to operate and maintain. After only a few short training sessions, technicians are able to troubleshoot the system. Operators as well only required a small amount of training to learn the navigation through the new operator interface displays.

- By using a GEF 9030 PLCs, the system is flexible and ready for the next phase of expansion when the compressor unit K1 controller is upgraded to a 9030. When the new controller is installed, the Cimplicity HMI will poll data directly from the unit controller directly using TCP/IP Ethernet at 10Mbps, thereby providing the high speed data archiving needed for the compressor's condition-based maintenance program.

- The new architecture lowers the risk associated with data communication problems between the station PLC and any of the remote sites. In the previous multi-drop architecture, a single communication problem could cause the data polling from all sites to cease, creating a data black-out. By separating and isolating each of the communication paths, data polling is more reliable and if one circuit goes down, it doesn't take the other paths down with it so only the data from one location is lost.

LESSONS

Because the facility had to remain in operation during construction, the project had to be implemented in phases. This presented us with logistical challenges, but also allowed us to try certain new ideas early in the project and change course if necessary as the project progressed.

Lesson 1

One lesson we learned during initial testing of phase 1. The first phase of the project was to replace the HP 9836 with the Cimplicity HMI, and replace the Modicon 484 at Pad A with a GEF 9030. This meant that the Cimplicity HMI needed to communicate directly with all of the old PLCs within the confines of the old architecture and not just the station PLC as would occur in the new architecture. Theoretically, this posed no problem because GE Fanuc has a Modbus RTU communications driver for Cimplicity. Unfortunately, GE was unaware of an addressing limitation when reading from or writing coils to a Modicon 484. We were able to work around the problem by managing the data addressing within Cimplicity, but only after an extensive search for an expert in legacy products at AEG Modicon, and numerous cross-country phone calls to GE Fanuc.

The lesson: When using old protocols, check implementation within new environment.

Lesson 2

During the first phase of the project, we hired a contractor to program the PLCs and configure the Cimplicity HMI. As is often the case with contractors, they started with the best intentions and plenty of resources. But as time passed and other clients required more of their time, the project suffered from changes in personnel. After starting with a team of three, we were left with one programmer who lacked the skills or experience to properly finish the job. Phase one was completed with unresolved problems and PG&E concluded that the rest of the job should be done with in-house expertise. This decision proved well founded since PG&E's engineers had a deeper involvement with the facility, and in fact, better technical expertise for the application at hand. As a result, the rest of the construction stayed on schedule and within budget, and working relationships improved between operations and engineering personnel.

The lesson: continuity of personnel in a job like this is crucial. Contracted personnel must stay on job from start to finish. Also, make sure contract personnel know not just PLC programming, but also fundamentals of all aspects of the job, i.e. for this case, serial communications, including not only protocols and wiring, but also error checking, message sequencing, time outs, retries, etc. And in some cases, this one in particular, using in-house expertise is more effective than contractors.