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RETROFITTING TURBOCOMPRESSOR UNIT AND STATION CONTROLS

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ABSTRACT

For TransCanada PipeLines, the need to retrofit station and compressor unit controls has been driven by the requirements to improve reliability, availability and cost and difficulties associated with interfacing new digital control systems with existing analog systems. TransCanada's massive four year expansion program has exacerbated this need.

TransCanada's turbo compressor controls are becoming obsolete, they are difficult to troubleshoot and maintain, do not control a unit as effectively as newer digital controls and do not have adequate operator or technician interfaces and diagnostics.

This paper describes TransCanada PipeLines reasons and experiences in retrofitting state-of-the-art digital controls in a cost effective manner while minimizing service interruptions.

CORPORATE PROFILE

TransCanada PipeLines (TCPL) is a major North American natural gas transportation and marketing corporation with 35 years of experience in delivering Western Canadian natural gas to markets in Canada and the United States.

The core activities of the Company revolve around the 13,000 km wholly owned mainline gas transmission system in Canada starting at the Alberta/Saskatchewan border in the West and extending to the Quebec/Vermont border in the East. The system was originally built in the 1950's and has steadily expanded to meet the growing demand for natural gas. The TransCanada system serves distribution utilities and industrial customers in Canada, as well as major U.S. pipelines, distribution utilities and industrial customers in the United States.

TransCanada's mainline system is directed toward three of North America's mega markets: Eastern Canada, the U.S. Midwest and the U.S. Northeast. These market areas represented approximately 32 per cent of North America's total gas market in 1992. TransCanada's market share of North American deliveries was roughly 10 percent in 1992. TransCanada Pipeline's current assets are $CAN 8.2 billion.

The pipeline route and compressor station locations are shown in FIG. B. This map also reflects our interconnected system and ownership in associated pipelines. TCPL Corporate Head Offices are located in Calgary, Alberta, Canada.

The number and type of units in our system are listed in FIG. A. We presently have a total of 201 turbo/recip compressor units distributed across 57 compressor stations with approximately 8,227 miles (13,240 km) of various diameter pipe. The installed horsepower exceeds 2,395,000 hp (1,787,000 kW). The daily average throughput in 1993 is over 6 Bcf/Day (170,000 m^3/day).

Aero Derived Gas Turbine First Generation	38
Aero Derived Gas Turbine Second Generation	44
Industrial Gas Turbine First Generation	24
Industrial Gas Turbine Second Generation	19
Gas Engine (Integral) Compressors	62
Electric Motor Drivers	14
Total Units	201

FIG. A
TECHNICAL HIGHLIGHTS

INTRODUCTION

Current throughput demands necessitate that most of our facilities be on-line year round. The maximum capability on our pipeline in 1993 was approximately 6.5 Bcf/day (184,000 m^3/day) depending on temperature, market conditions and other factors. Referring to FIG. C, which shows the average daily throughput of the pipeline, it can be noted that our system runs virtually at full capacity all year long.

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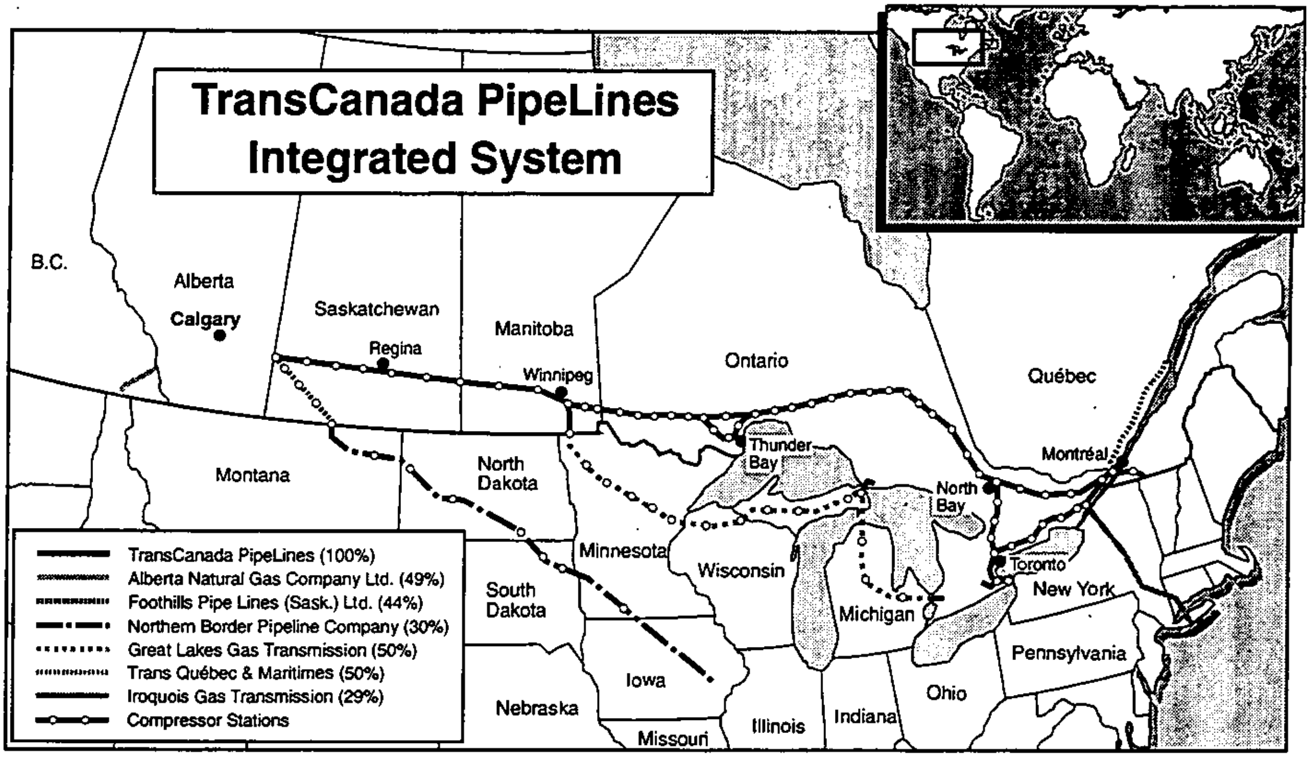

FIG. B
TRANSCANADA PIPELINES SYSTEM

The reduction in throughput during the summer reflects lower system capability due to higher ambient temperatures and necessary maintenance.

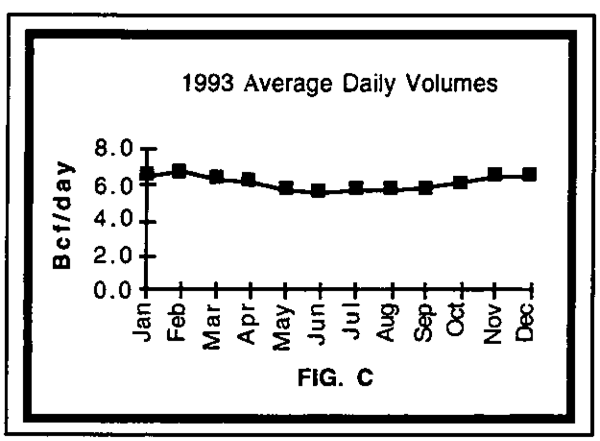

FIG. C

In order to meet our contractual throughput commitments several company objectives were established. These objectives are:

- Increase fleet reliability to 99.1%
- Increase fleet availability to 97%
- Maintain a line pack of 97% of theoretical maximum or better.
- Increase the mean time between failures (MTBF) of a unit to greater than 700 hours. (MTBF accounts for all failures that cause a unit to shutdown.)
- Decrease the mean time to repair (MTTR)

A significant part of the reliability and availability objectives were met by addressing the unit shutdown philosophy. The goal of reducing the number of unit shutdowns was established and a task force was assigned to set up unit alarm and shutdown matrices. A side benefit of this goal was meeting the corporate objective of reduced gas emissions by reducing the number of alarms and shutdowns that caused a compressor to vent.

TCPL has had an ongoing program to retrofit controls components for some time. Some larger retrofits, involving replacement of relays with PLC (Programmable Logic Controller) were completed in the early to mid 1980's. However, due to limited growth in the pipeline at that time these projects were few in number. Over the past four years the number of retrofits have increased substantially, primarily as a result of the Company's large expansion program. FIG. D gives a breakdown of the expansion activities that have been ongoing since 1991.

By November, 1994 TCPL will have installed a total of 38 new turbo compressor units, five new stations, approximately 2,500 km of pipe and completed 41 station and unit retrofits. The cost of the expansion exceeds CAD $ 4.2 billion.

This paper seeks to present our experiences in the retrofitting of existing controls and control equipment against the background of such a major system expansion.

	1991	1992	1993	1994	TOTAL
Compression	105 MW	288 MW	37 MW	166 MW	596 MW
# of Units	5	20	5	8	38
New Stations	2	1	1	1	5
Pipeline	841 km	892 km	580 km	205 km	2518 km
Cap. Cost (C$)	1578	1503	738	477	4288 million
Stn. Retrofits	1	9	3	4	
Maj. Unit Retrofits		0	4	20	

FIG. D
SUMMARY OF EXPANSION FACILITIES

TCPL CONTROL SYSTEM

Before going further into the discussion of retrofits, it would be beneficial to describe our typical system and control. A typical turbocompressor station is shown in FIG. E. Our stations are split into three functional and distinct parts; station, plant and unit.

A unit starts at the unit valves, typically the unit suction and discharge valves, including the discharge check valve and the recycle line. In some cases a cooler would also be included in the recycle line.

The plant contains the unit, this would typically consist of a building housing the turbo compressor unit, a control and utilities building housing controls, Motor Control Center's (MCC's), air compressors, boilers, emergency generators etc.

The station consists of the plants, the main line valves, side valves, crossovers and blowoffs. In some cases the station may also contain a building with services and utilities that serve more than one compressor unit.

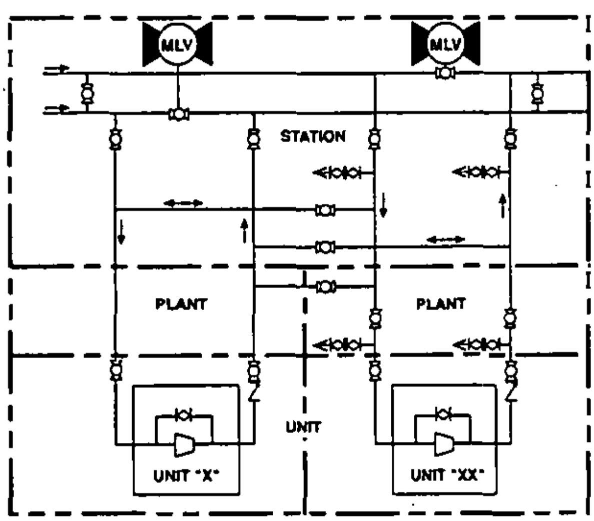

FIG. E
TCPL TYPICAL TURBO COMPRESSOR STATION

As part of the expansion program the existing controls structure was investigated and a number of controls objectives were established:

- Simpler control
- Maximize use of digital control technology
- Minimize "black boxes"
- Minimize and standardize proprietary control software
- Standardize on parts
- Standard station, plant and unit designs
- Increase diagnostics capability
- Improve quality
- Minimize service interruption
  - Keep station downtime for retrofits to zero
  - Complete unit retrofits in three weeks or less
- Flexibility to interface to a variety of older controls
- Simple to troubleshoot
- Minimize cost

It was decided to standardize on a PLC based control system for our stations and units. New PLC models, MMI (Man Machine Interface) display systems and SCADA computers were selected. The control strategy was firmed up and precisely defined.

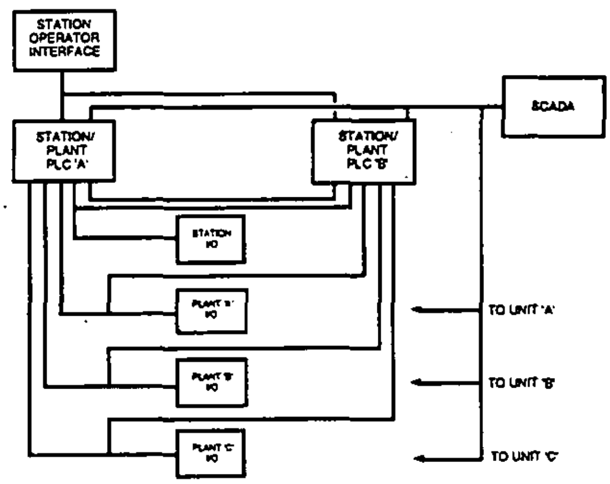

FIG. F
TYPICAL STATION & PLANT CONTROL
(BLOCK DIAGRAM)

The station/plant control system that TCPL adopted as its standard is shown in FIG. F. Each station/plant combination uses two PLC's connected in hot standby. In the event one PLC system or component fails then the other PLC takes over bumplessly. In order to minimize the impact of single point communication failures, the I/O structure is split into different communication channels; one for each plant and one for the station. The station/plant PLC communicates with a SCADA system, a station/plant MMI and with each unit. For very large stations, typically in our western section (refer to FIG. B; from Winnipeg west) four PLC's are used. Two PLC's control pipelines 1, 2, 3 and plants A, B, C and another two PLC's control lines 4, 5, 6 and plants D and up. This minimizes losing an entire station should a catastrophic fault occur. In the Western section we are almost completely looped for six parallel lines.

At the same time that the controls for the stations and plants were being defined the unit controls were also clearly defined. Through the tendering process it became apparent that each turbo compressor vendor would supply us with their standard controls product. This meant a variety of PLC's, MMI displays, panel designs, instruments, drawing formats as well as software. This variety of designs was not consistent with the controls objectives as set out above and therefore did not support our corporate goals. The possibility of having unit controls different in both hardware and operating philosophy would have resulted in difficulties for both the engineering staff and field operating staff.

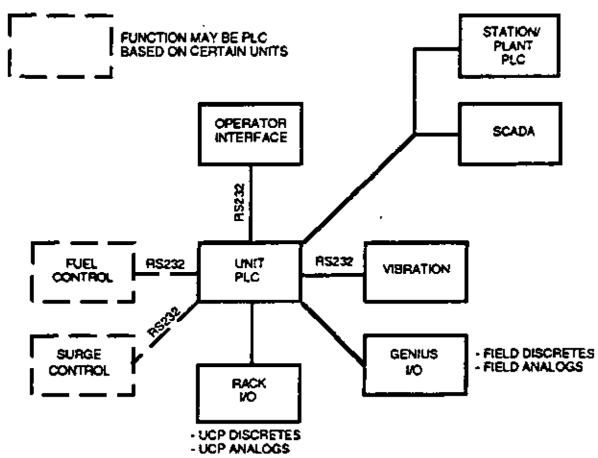

FIG. G
TYPICAL UNIT CONTROL (BLOCK DIAGRAM)

The unit control system that has been adopted as our standard is shown in FIG. G. The unit control is stand alone and operates independent of the station/plant control system. One dedicated PLC is used for the unit controls the same type of PLC that is used for the station/plant. Where possible the fuel control is performed in the PLC. This philosophy is consistent with our requirements to minimize "black boxes" and have quick access to the controls when required for maintenance.

The unit has it's own MMI that performs all the graphics interface to the unit as well as annunciation, trending, logs, performance monitoring.

In order to ensure the controls are as reliable as possible and easier to troubleshoot the number of hardwired internal panel signals and hardware components were reduced by maximizing the use of RS232 communications while still maintaining a simplified hardwired backup. Relay interfaces were and are continuing to be reduced by utilizing more PLC I/O or through redesign.

The PLC performs all the unit sequencing functions including engine, power turbine and compressor protection and as much control as possible to ensure the controls can be easily modified in the future and for ease of troubleshooting. Fuel controllers, which tend to be proprietary "black boxes" with compiled software are difficult to modify and troubleshoot hence the functionality is restricted to fuel control, guide vane control and bleed valve control.

DESIGN STANDARDIZATION

The station, plant and unit controls were developed into standard designs during the course of and as part of our expansion. This included drawings for all layouts, schematics, and wiring diagrams. More than 200 standard drawings have been developed for our stations and plants and more than 50 for our units. These drawings are used as templates each time a new station or plant is built or where unit controls are retrofitted. The standard drawings are copied from a master CADD file and the title block is changed to suit the station or unit. Generally, little else has to change on the drawings except to allow for tie-ins or differences encountered with the various vintages of controls.

Along with the standard drawings, numerous software programming blocks and PLC address and configuration templates have been developed for both station and unit controls. This results in consistent and almost identical programs resulting in familiarity for engineering and operations staff.

Since many station control functions had been connected to a variety of controls systems, both relay and PLC, all the controls end devices, tagging, numbering and addressing had to be defined. All controls have been standardized to the point that it does not matter where in the pipeline a similar device is located it will be designated in an identical manner. As an example, a mainline valve located in a station will have the same tag, I/O point, PLC memory address, wire numbers, PLC logic, drawings etc. at each and every station. This same concept has been applied to the unit design as well. Where signals are common from unit to unit (unit valves, bearing vibration and temperature etc.) the same tag, I/O point etc. is used regardless of the unit. These conventions are detailed in the standard drawings.

In order to prevent a variety of unit control designs the unit control panel, all hardware, design, MMI screen design and the majority of the PLC software is standardized and defined in specifications and drawings. Through standardization all of our units use the same controls and panel designs. This includes all new units ordered from the various turbo compressor vendors. In essence, each and every unit control system is built to the same design and specifications after allowing for the various differences from engine to engine. This standardization also applies to the retrofits that are carried out.

Without these standardized designs we would have had great difficulty in completing the enormous design and retrofit task required.

CONTROLS HARDWARE

Due to the various expansions on the system over the years a variety of controls hardware exists in our system today. Most of this hardware is now obsolete, spares have been exhausted or because of deterioration the controls are unreliable.

A typical station control system would consist of one or more of the following systems:

- Relay Logic/Gate Logic

- PLC Logic using 10-15 year old PLC's
- Graphic Boards
- Hardwired Annunciators
- PDP SCADA Computers with I/O Interfaces
- Analog gas and fire detection
- Pneumatic controls
- Microprocessor "black box" controls

Plant and unit controls are varied and are sometimes integrated into one control system. Certain units have the plant and unit controls integrated into one system, typically the unit controls.

A typical control system for a unit would consist of the following types of controls:

- Analog Fuel Governor
- Analog Anti-Surge Control
- Relay Based Sequencer or Wire Wrap Sequencer or TTL Logic
- Lamps or Hardwired Annunciator
- Analog Vibration Monitor, Gas and Fire Detection

A large station, as can be found west of Winnipeg, refer to FIG. B, will have a variety of the above mentioned types of station, plant and unit controls all on one site.

The unit and plant control data is collected and sent to an existing SCADA system. This is accomplished using hard-wired relay contacts. The interwiring required to send signals to various control systems has become very complex involving several interfacing hardware components.

Control components have a finite life. As control components age and reach the end of their life they begin to fail randomly. Systems employing large numbers of control components, such as relays, can be rendered very unreliable. Relays fail regularly; their coils burn out, contacts seize or they simply fail to respond when commanded. Wire Wrap or TTL type logic are difficult to troubleshoot, repair and modify, as well as requiring experienced personnel.

Over time, additions and modifications have been made to the controls resulting in some control panels becoming over crowded, very difficult to work in, and take much longer to troubleshoot breakdowns. All this has led to decreased MTBF, increased the MTTR as well as poor unit start reliability.

Expanding or retrofitting entailed more than adding to or replacing the controls. Due to age and obsolescence, major electrical equipment also had to be replaced. When expanding switch gear to add new plant and unit loads it was found that breakers for example, were no longer available. Uninterruptable power supplies also had to be replaced, both 120 VAC and 24 VDC. The equipment generally could not handle the increased capacity and were not designed to handle new loads such as switching power supplies. When the uninterruptable power supplies were replaced, their associated chargers and batteries also had to be replaced.

In some cases new cables had to be run to the yard valves. Original wiring was installed in rigid or PVC conduit and buried. Because of frost heaving and moisture, these conduits were broken and wire insulation was damaged. In many cases this caused the wiring to short out. The impact of construction actually worsened the situation since pile drivers and heavy equipment vibrating the ground caused already frail insulation to fail. Adding a new plant required that large portions of the station yard be excavated to expose the high pressure pipe for interconnects. As careful as the construction personnel were, some wiring was affected. Our present design standard uses armored PVC jacketed cable for direct burial. From experience we have found this to be a superior wiring method and virtually eliminates the problems experienced with buried conduit and wire.

The work to tie in a new plant to an existing plant or retrofit affected almost all of the existing control and electrical hardware in one form or another.

RETROFITTING STATION CONTROLS

As noted in FIG. D approximately 2,500 km of new pipeline was added. This included new manifolding at the stations. Manifolding consists of new main line valves, side valves, blowoff's and tie-over valves. Existing older PLC controls could no longer be expanded because the memory was full, parts were no longer available and RS232 communication was not possible. The relay controls could not be expanded because of lack of space, out of date drawings, or because of the reliability issues mentioned previously. Finally, information could not easily be sent to the new PLC and SCADA, and the logic for path to pump for more than two or three plants was becoming complex to do in relay control. Performing partial control in a new PLC for the new manifolding while retaining the old PLC or relay system was tested and was proven unreliable as well as slow to communicate to newer digital controls.

Each station that required modifications typically needed some rewiring of valves, new 24 VDC solenoids, a 24 VDC power supply, installation of a PLC control system as shown in FIG. F, and location of PLC remote I/O to pick up signals in remote buildings. These signals included control and status for all valves, status for the plant functions, status from existing units, ESD functions and remote controls for the existing units. Generally the existing plants or units were not modified during the expansion except as required to tie-in the station controls.

All of this work had to be designed and installed under very tight deadlines. Down time for stations and units had to be minimized. Careful scheduling and coordination during construction were necessary to minimize the down-time. I/O panels were pre-built and pre-cabled according to the standards and conventions previously established. The use of remote I/O was maximized to save programming time, cable and labour. Some control changes were done "hot", valve controls were switched over by manning the station and locking the valves in the correct position so when power was removed the valves would not travel. Controls were tested in place.

Retrofits are now being done to some of the Western stations where our standard drawings and PLC program blocks are being used to retrofit the controls for the entire station consisting of 6 lines including mainline valves and all associated side valves, tie-overs, blowoff valves, etc. Our engineering and drafting time is significantly reduced by using these standards. The quality is also greatly increased and errors are significantly reduced since all designs are based on past tried, proven, checked and tested designs.

RETROFITTING UNIT CONTROLS

For several years there has been an on-going program to replace old analog fuel controls with new digital controls. Engine temperature monitors have also been replaced. Vibration monitor modifications as well as increased bearing temperature monitoring has also been completed on a number of units. These items were added or fitted into existing panel space as best as possible.

There have been very few total control system retrofits over the years since the unit controls had not reached obsolescence or throughput of the pipeline was such that extended down-time could be tolerated in order to fix controls. When a unit was retrofitted the down-time necessary was in the order of four to six weeks. This amount of down-time can no longer be tolerated due to the throughput constraints.

In 1993, TCPL completed four complete unit retrofits. This included entire unit control panels with all components. The retrofitted controls followed the standard designs (see FIG. G) that were established for the new units including the PLC standard program blocks, MMI displays and alarm and shutdown logic. Two of the units required a number of new end devices, a new unit MCC and complete recabling from the new unit panel to the unit.

Two of the units previously had new digital fuel controllers fitted into the panels. For the fuel controller a spare chassis was taken from stock and wired into the panel. All that remained to do at site during the shutdown period was to take the cards out of the fuel controller in the existing panel and move them into the new panel. The chassis left behind could be removed at a later time when the unit was restarted. During the retrofit all SCADA hardwired signals were removed and converted to RS232 communications.

For most of our retrofits we are able to find room to install a new pre-built control panel. This could be in another building or right in front of the old panel. To minimize the downtime we pre-installed the new panel (install, pre-wire to power sources and pre-terminate cables if new cables are used), shutdown the unit and tie in to the unit junction boxes with new cables, start up and commission. The old panel is removed after the unit is running. If the new panel is installed in front of the old panel, it can be moved into the space formerly occupied by the old panel while the unit is running.

In order to meet a three week or less shutdown window, pre-building while the unit is running, pre-planning, shift work and above all a tremendous team effort by Engineering and Operations is required.

Our 1994 retrofit program includes among others, Avons, one RB211 and several LM2500 units. Some units identical to retrofits completed in 1993 will utilize the 1993 designs thereby allowing us to complete them more quickly and keep the fleet designed the same.

CONCLUSION

The standardization of the station, plant and unit controls has provided significant savings in engineering and drafting time, has improved quality of the design and the finished product while reducing check-out time and re-work.

The reduction in time it takes to generate designs has allowed us to take on the increasingly demanding and complex retrofits (as well as new station designs). Due to tight schedules, drawing packages previously issued for bid used to contain approximately 50% of the final construction drawings. Using the standard drawings, the bid packages are now issued with approximately 95% of all control and electrical drawings. This gives the bidders all of the information up front as well as closes the design more quickly. The results are fewer changes and reduced costs.

The mean time between failures (MTBF) is presently being evaluated. As operating experience is gained with the retrofit controls, the new MTBF will be compared with the MTBF prior to the retrofits. Initial observations of our success with control retrofits are as follows:

- Unit starts reliability has increased significantly with new controls. On some units the starts reliability was as low as 60%, this has been increased to approximately 100%.
- Diagnostic capabilities have increased with new PLC/MMI system. Faults, when they do occur can be diagnosed and corrected more quickly; hence the stations, plants or units are down for shorter periods.
- Short circuits in wiring have been totally eliminated where new cables have been installed. Also, when the station yard is excavated, cables being more flexible than rigid conduit and frail wiring, are no longer being damaged (unless struck directly by equipment).
- With standardization, hardware designs and software designs are more consistent, resulting in reduced troubleshooting and commissioning time. All new control panels and designs are virtually identical everywhere in our system including turbo compressor panels provided by the turbo compressor Vendors.
- Controls are much simpler, quicker and easier to modify allowing quicker and more effective response to changes.
- Gas emissions have been reduced by logic changes such as minimizing the alarms and shutdowns on which the compressors vent. Units used to vent on 10-25 shutdowns. This has been reduced to around 5 shutdowns depending on the unit. (fire, high gas, ESD, dry gas seal failure and manual depressure)
- Unit shutdowns have been modified to maximize alarms and trips to idle rather than shutting down if the condition does not jeopardize safety. When a condition exists that requires a shutdown, coolstops have been maximized. Voting logic for certain functions such as bearing RTD's have also been incorporated.
- Station retrofit downtime has successfully been reduced to zero by pre-planning, pre-building and testing in place.
- Unit retrofit downtime of three weeks or less has been met and was exceeded on two units. One unit was down for only 14 days. This was accomplished by pre-building, planning and tremendous team work during the design and construction.
- Engineering time and schedule have been reduced. Retrofits for 1994 March shutdown window started design in December, based on standard designs, these windows are expected to be met.
- We are finding the advantages of standard designs are:
  - Reduced overall life cycle cost;
  - Increased quality;
  - Reduction in errors and rework;
  - Modifications are simpler and less costly to implement;
  - Fast design and project execution (schedule);
  - Familiarity for technical staff hence better trouble-shooting capability.