FUEL CONTROL OF GAS TURBINES BY PROGRAMMABLE LOGIC CONTROLLERS

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ABSTRACT
NOVA Corporation of Alberta has developed a programmable logic controller based gas turbine fuel control system for natural gas compressor set applications. The system carries out all necessary fuel control functions and was integrated into the existing programmable logic controller used for sequencing and shutdown. The system has been successfully implemented on several different aero derivative gas turbines to date. This paper discusses the development of the system, its performance and advantages over standalone hardware-based fuel control systems typically used in the application.

INTRODUCTION
NOVA Corporation's Alberta Gas Transmission Division is a major transporter of Canadian natural gas with over 80% of the marketed Canadian gas production passing through its system. NOVA's system consists over 11,000 miles of pipeline ranging in size from 2" to 48". NOVA operates 93 turbine-powered centrifugal gas compressor sets and 21 reciprocating gas compressor sets totalling over 950,000 (ISO) horsepower. NOVA has an "in house" engineering group responsible for design of the pipeline system and facilities. NOVA supports a wide range of research and development projects with the goal of increasing the cost-effectiveness of the gas transportation service. The fuel control system described in this paper was developed through the Research and Development Program.

NOVA Corporation has been using Programmable Logic Controller (PLC) based control systems for control of our gas turbine-powered natural gas compressor sets extensively since 1980. Originally these PLCs controlled only the unit sequencing functions. As their capability has increased, more of the non-sequencing applications were integrated into the PLC. In 1988 one of the few remaining control functions not performed in the PLC was the gas turbine fuel control. On newer units this function was typically being performed in a separate electronic controller such as those provided by Woodward, Hawker Siddeley or Entronic Controls. An internal research and development project was started that year to research the feasibility of fuel control integration and development of a working system.

BENEFITS OF FUEL CONTROL INTEGRATION
There are several reasons for integration of all unit control functions into a standard PLC. The major reasons are listed below:

Cost
The cost of adding the fuel control to the PLC is minimal and essentially only software is required for the implementation to be complete. The majority of the fuel control related signals are already interfaced to the PLC to support the personal computer-based operator interface system. There is significant savings over the cost of typical standalone fuel control systems which have a purchase cost of approximately $65,000 - $110,000 CAD.

Open Architecture
Most of the current electronic fuel controllers, while allowing access to key parameters, restrict access to the basics of the control system software. The open nature of the PLCs allows access to all fuel control related information and programs in the same fashion as the
other unit functions. This results in less costs for customer interface hardware and software, and less training. Open architecture can allow for user support of hardware and software.

**Standardization**

Integration of the fuel control system into an "off-the-shelf" type of PLC allows for the application of the same base PLC hardware to different unit vendors' control systems and the other PLC systems at compressor stations. This further reduces cost through reduced training, spare parts requirements, and custom interface products. NOVA technical support staff are already in place to maintain the existing PLC systems. As fuel control is simply another function in the same hardware and uses the same software, only minor additional training is required.

**Remote Diagnostics**

Integration of fuel control functions into the PLC allows for remote diagnostics and troubleshooting of much of the fuel control system. For users operating a normally unmanned system where compressor stations are located in remote areas, the possible reduction in outage time is considerable.

**SYSTEM DEVELOPMENT**

At the proposal stage of the project, there was considerable doubt as to the ability of the PLC to perform a function as complex as turbine fuel control. However, because of the potentially high benefit/cost ratio, the project proceeded as an internal research and development project.

NOVA's first application of the PLC based fuel control system was on a Cooper-Rolls Coberra 1533 natural gas compressor set powered by a Rolls Royce AVON 76G gas generator. This compressor set was originally installed in 1970 and is part of NOVA's mainline compression facilities. This unit was not normally required to run except during peak and upset pipeline conditions. The original nonmicroprocessor-based hydraulic/mechanical/electronic fuel control system had become unreliable and was scheduled for replacement. For test purposes a standalone PLC-based fuel system was developed and placed in parallel with the existing fuel control system. A parallel system was used so that the unit would be available using the old system should system demands increase and there was a failure of the PLC-based fuel control system.

Because this unit was required for normal operation of NOVA's pipeline system and to further reduce risks, stringent safeguards were put in place to ensure that the compressor set equipment would not be damaged by an improper operation of the fuel control system. These safeguards included shutdowns for excess exhaust temperature, overacceleration, underacceleration, excessive valve movement, overspeed, underspeed and exhaust thermocouple excessive deviation.

During initial development, fuel schedule information normally necessary for fuel control was not made available. Therefore, the approach to system development, was to develop a system that required only the information already available or that could be obtained by direct measurement and testing of the unit with the existing fuel control system. The system developed does not use any traditional fuel schedules but is purely based on the true gas generator acceleration rate during starts and transients. A method of performing this type of control was achieved using standard PID instructions available in the PLC.

The compressor set was started and extensive testing was carried out on system performance during starts, steady state operation, and during dynamic process conditions. Performance was very good and the system was run on test for 3,100 operating hours. The system was then integrated into the main unit PLC and the original fuel control system removed. As of December 1992, in excess of 14,600 operating hours have been logged. Figure 1 illustrates a block diagram of the PLC fuel control system for the AVON gas generator.

System development was subsequently carried out for other gas generator types. Currently PLC fuel control is operational Rolls Royce RB-211, Rolls Royce AVON, and Allison 570-K powered natural gas compressor sets and under development for GE LM-1600 powered compressor sets. Fuel Schedule information was made available for some unit types, therefore the systems for these did not use the true acceleration-based scheme as developed for the Rolls Royce AVON. Performance for these other systems has also met expectations.

**EQUIPMENT USED**

Standard "off-the-shelf" equipment was used wherever possible to minimize cost and spare part requirements. Some of the major components are described below:

**Fuel Valve**

A standard Fisher valve complete with a pneumatic actuator and positioner was used. The actuator was configured to give a valve stroke time of less than one second in the open and close directions.

**PLC**

A standard "off-the-shelf" PLC was used to perform the fuel control and unit sequencing functions. All the input-output modules used were found in the standard product line. No special modules were developed for gas turbines not requiring variable geometry control by the fuel controller. For gas turbines requiring variable geometry control by the fuel controller, one interface device was developed to interface the linear variable
differential transformer (LVDT) position transmitters to a standard PLC servo positioning module. Fuel control program execution was controlled by a selectable timed interrupt (STI) feature of the PLC processor. This results in execution of the fuel control program at a fixed interval regardless of the other tasks being performed by the PLC.

No redundancy in PLC hardware was used. Operating experience has shown that the field devices are more likely to fail than the PLC components. The PLC system chosen has a low mean time to repair due to the modularity of components.

TESTING

An extensive testing program was carried out to benchmark the performance of the PLC fuel control system against the original hydraulic/electronic fuel control system and manufacturer's specifications during static and dynamic operation. Steady state testing was carried out at various operating conditions and tested all control functions. Each controller was tuned to eliminate any oscillations as well as to meet the dynamic conditions described below. Dynamic testing was carried out by rapidly approaching each of the limiting controllers and ensuring that no excessive overshoot occurred.

A system of adaptive gains was developed for the controllers during the above testing in order to meet performance requirements. An independent gains formula was used for the speed related PID controllers. The proportional gain was set to zero. The integral gain varied with the gain increasing as error increased. Minimum and maximum limits were applied. Derivative gain also varied but inversely with error. A maximum limit was applied and the minimum limit was set to zero.

Dynamic testing was also carried out by changing the unit load as rapidly as possible for a pipeline compressor. This was accomplished by opening the compressor anti-surge (recycle) valve as fast as possible or by starting and stopping parallel compressor units while in compressor speed control mode. Sufficient margin was insured to avoid any other override controllers during the test. In all modes of operation, performance of the system met the manufacturer's requirements and met or exceeded the performance of the old governor system.
Under no circumstances did the compressor speed vary by more than 0.5% (15 rpm) on a compressor with an operating speed range of 3,200 - 5,200 rpm. The system was configured with a 5 rpm deadband in the speed controller. This performance was achieved with the pneumatic valve operator and a fuel control program execution rate of 10 times per second. Even though all performance requirements were met with the above execution rate, the execution rate for some units was raised to 40 times per second for basic fuel control functions and up to 200 times per second for specialized functions. This was done to address gas generator vendor requirements. A jump rate (slew rate) limiter was used in the control system to limit the rate at which the PID controllers could open or close the valve. This type of limiter is necessary to control excessive valve movements just after light off and during large setpoint changes. Although there has been considerable concern with the stroke speed capabilities of the pneumatic valve, the rate finally applied at the jump rate limiter resulted in the control system demanding a valve stroke speed of no less than 31.5 seconds, from fully closed to fully open, and 16.4 seconds from fully open to fully closed. The jump rate limiter is by-passed during fast shutdown conditions.

Figure 2 illustrates the operation during a start sequence, using the original fuel control system. Figure 3 shows the operation during a start using the PLC based system. The PLC based system provided better control during the initial acceleration phase of the start sequence and a more damped response after power turbine breakaway. Under the original fuel control system, the acceleration rate during the initial acceleration phase of the start sequence exceeded the acceleration limit specified by Rolls Royce. Adjustment of this acceleration rate and the system damping were very difficult to change with the original fuel control system.

Figure 4 illustrates the control the PLC based system during dynamic process conditions. At time = 10 seconds the compressor anti-surge valve was moved from the fully closed to the fully open position in one second. A small short term disturbance in power...
turbine speed is observed not exceeding 15 rpms. The gas generator speed is seen to increase initially due to the increased load due to the higher gas compressor flow and then slowly decrease as the natural gas is heated by the compressor thus decreasing the load. A review of the compressor wheel maps illustrated that although the compressor operating point moves significantly, that total power does not change as much as may be expected. The gas turbine speed is seen to increase slightly reflecting this. Similar low level disturbances were observed when starting and stopping parallel compressor units. Although the load changes were relatively small, no greater load change is expected in pipeline service and the dynamic testing was deemed to be sufficient.

Similar testing was carried out for the other unit types implemented to date with similar results.

To date there have been no failures of the PLC hardware on any of the systems. Reliability of the total system has increased rapidly after commissioning of the new systems and there has not been a fuel-control related shutdown on the AVON gas generator in over 11,000 operating hours.

APPLICATION

NOVA currently operates 93 turbine-powered natural gas compressor sets. Approximately 65% of these units are controlled in some part by a PLC, 40% of which are capable of fuel control. As fuel control systems are replaced on units with a PLC capable of fuel control, or when a non-PLC controlled unit requires a control retrofit, a PLC system complete with fuel control will be implemented. Results of this project to date indicate that PLC fuel control is possible on all of NOVA's compressor units regardless of the original type of fuel control system. Cost studies have indicated that a standalone PLC fuel control system is less costly to NOVA as a replacement for an old system even where no other PLC is present. Discussions are currently underway with compressor unit OEMs to have PLC fuel control incorporated into new units. Implementation at several different compressor sites have shown that this system works well in the pipeline compression application. This system has not demonstrated that it is capable of control of a gas turbine in a generator set application where loads change much more rapidly than in the pipeline application, and where exact speed regulations is required.

CONCLUSIONS

A PLC-based fuel control system can be developed capable of controlling gas-turbine-powered natural gas compressor sets used in pipeline applications that meets
the engine control requirements. This system has the advantage of lower capital and maintenance costs, when compared to specialized standalone fuel control systems.

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