

Summary

Invensys Operations Management offers premiere feedwater control systems in Nuclear Power Generation using the Foxboro I/A Series DCS.

Business Value

Recent implementations have offered operation philosophy enhancements, improved startup and runtime performance and significant reduction of unplanned unit trip outages.

Foxboro I/A Series DCS for Feedwater Control Systems

THE COMPETITIVE ADVANTAGE

Invensys Operations Management offers premiere feedwater control systems using the Foxboro® I/A Series® Distributed Control System (DCS). Recent implementations have offered operation philosophy enhancements, improved startup and runtime performance and significant reduction of unplanned unit trip outages.

These advanced control techniques allow for less operator required interaction, more time of automatic control - including during start-up and shut-down when most unit trips are caused - making the entire control system more capable of handling process upset conditions along with normal operation.

BEFORE I/A SERIES AT THE OMAHA PUBLIC POWER DISTRICT

Before the I/A Series DCS was installed on the feedwater controls at the Omaha Public Power District at Fort Calhoun Station, there were many operational challenges. The controls were poorly tuned. Level perturbations were not uncommon during changes in power, with poor low level control.

John Steinke, Senior Nuclear Design Engineer at the facility states that "Having split-range 3-Element control on the bypass feed water valve as well as the main valve allowed for automated controls to handle the switchover from the bypass to the main valve. This reduced operator direct manual interaction, and thereby reduced operator challenges. We also rotate our Steam Generator Feedwater Pumps. The split range 3-element controls greatly reduce the perturbations associated with rotating those pumps. More precise tuning and control have maximized our unit's capability factor (ability to produce electricity) while removing undue burden from the Licensed Operators who are operating the system. To date, we have not tripped based on the DCS or garnered extra down time."

There was a plant transient soon after the controls were installed in which the Hotwell Makeup Valve failed to open. The operators, by that time, overcame their instinct to place the feedwater system in manual, and instead let the controls take action. The feedwater DCS response was called "outstanding." It would have been a much more stressful event for operations using the pre-DCS controls. There have been multiple similar incidents after which Operations commented that the unit would have tripped if the steam generator level control was not on the DCS.

Mr. Steinke also stated how the use of the DCS provided much more system and process information. They are able to use this type of data to ascertain process characteristics (valve and pump non-linearities). The system then had the tools to compensate for these characteristics and provide a better response to control actions.

AFTER I/A SERIES AT TENNESSEE VALLEY AUTHORITY

Scott Gladney, an Electric Engineer at the Tennessee Valley Authority's Sequoyah facility, attributes smoother operations and the reduction of single points-of-failure to installation of the DCS and feedwater controls.

Mr. Gladney states that "We were able to eliminate over 40 single points-of-failure per unit using the DCS feedwater controls. It also simplified the startup of our second feedwater pump. When starting the second pump, speed balancing used to be an operator-intensive manual procedure. The I/A Series block features allow for the controls to completely balance the pumps in automatic. Our swap over from startup valve to main valve was greatly simplified. It used to be an operator manual swap that took about an hour to perform. It is now an automatic event that occurs on they fly with no specific interaction required. I have seen a valve transfer occur as they were starting a turbine online (and in single element) with no significant level perturbations in the steam generators."

Mr. Gladney also stated how the controls were improved to have one set of tuning parameters, and one set of inputs. "If you have narrow range level, steam flow, and feedwater flow, that's all you need to run single element or three element at any power level."

FEEDWATER CONTROL SYSTEM ENHANCEMENTS

The following are brief descriptions of some of the control enhancements delivered for various feedwater control systems throughout the nuclear industry by the nuclear control system engineering team of Invensys Operations Management.

Enhancement #1 – Redundant Sensor Algorithms

Redundant Sensor Algorithms (RSAs) are utilized to eliminate single point of failure vulnerabilities within the control application and improve reliability and robustness of the system and its ability to automatically control the plant over its full power range for the entire fuel cycle. These allow the system to suffer a partial or complete loss of one of the redundant input signals with minimal or no upset to plant operation or loss of vital plant process information. The redundancy starts at the process measurement transmitters. Multiple, mutually exclusive field devices are used to measure the same plant process variable. These measurements are brought into the control system on separate I/O devices (FBMs), further increasing the reliability of these signals. Care is taken to also ensure that the transmitters are on separate process connections, otherwise they are still vulnerable to a single failure, such as plugged piping or failure of the sensing line piping itself.

For all cases, when there is '**No Valid Input.**'

- Control "action" is blocked

- Failsafe action is imposed

- Controls are transferred to **MANUAL** where applicable, holding the plant at a known state.

Additionally, each process measured parameter is evaluated for its specific, proper action to be taken when '**No Valid Input**' exists.

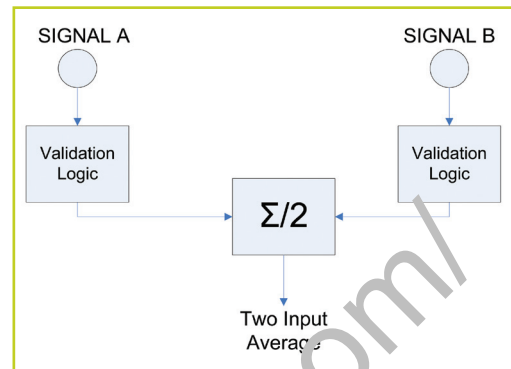
Redundant Sensor Algorithms have been used for feedwater controls for measurements such as Steam Generator Level, Steam Generator Feedwater Flow, Steam Generator Steam Flow, Feedwater Pressure and Steam Pressure.

Enhancement #1.1 –

Dual Transmitter Input Algorithm

Two independent measurements of the same process variable are monitored from separate field devices. When both transmitters are functioning properly, the **Average** of the two is used as the resultant controlling signal.

Upon excessive deviation between the two measurements, or the failure of either one, control actions are prevented (blocked), and an operator alarm generated. In the event of a deviation, the operator may then select one of the two based on other plant corroborating data as the “more correct” signal by bypassing the offender. Automatic control can resume and maintenance can be performed on the bypassed signal without loss of runtime.

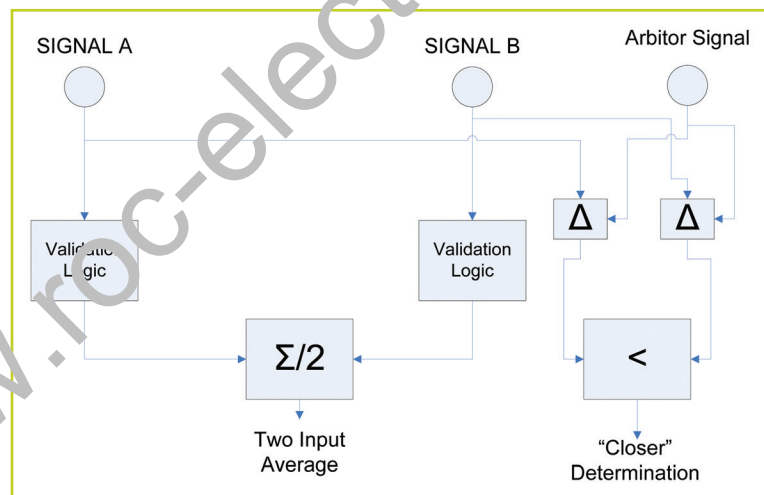


Dual Transmitter Algorithms have been used for feedwater controls such as Feedwater Pump recirculation flows.

Enhancement #1.2 – Dual Transmitter Input Algorithm with Arbiter (Voter)

Two independent measurements of the same process variable are monitored from separate field devices. When both transmitters are functioning properly, the **Average** of the two is used as the resultant controlling signal.

Upon excessive deviation between the two measurements, or the failure of either one, the control system automatically selects the signal that is closer to the arbiter, and an operator alarm is generated. Automatic control continues, uninterrupted. Maintenance can be performed on the offending signal without loss of runtime.

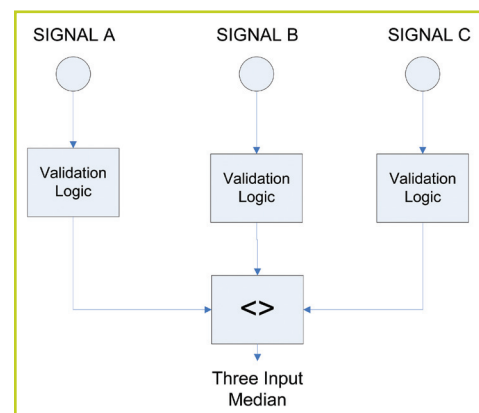


Dual Transmitter Algorithms have been used for feedwater controls such as Steam Generator Feedwater Flow and Steam Generator Steam Flow.

Enhancement #1.3 –

Triple Transmitter Input Algorithm

Three independent measurements of the same process variable are monitored from separate field devices. When all are functioning properly, the **Median** of the three is used as the resultant controlling signal. Upon the failure of one signal, the control system automatically continues to select the **Median** value and automatic control continues, uninterrupted. Maintenance can be performed on the offending signal without loss of runtime. If one signal deviates significantly without failure, it is excluded from control by the **Median** selector.



Variations of the triple input algorithm include:

Using the **Average** of the three inputs – When all are functioning properly, the **Average** of the three is used as the resultant controlling signal. Upon the failure of one signal, the control system automatically reverts to the **Average** of the remaining two inputs and automatic control continues, uninterrupted. Maintenance can be performed on the offending signal without loss of runtime.

Using the **Median** of the three inputs – When all are functioning properly, the **Median** of the three is used as the resultant controlling signal. Upon the failure of one signal, the control system automatically reverts to the **Average** of the remaining two inputs and automatic control continues, uninterrupted. Maintenance can be performed on the offending signal without loss of runtime.

Triple Transmitter Algorithms have been used for feedwater controls such as Steam Generator Main Steam Pressure, Steam Generator Feedwater Header Pressure and Steam Generator Level.

Enhancement #2 – Redundant Valve Outputs

Redundant Valve Outputs are utilized to eliminate single point of failure vulnerabilities within the control application and improve reliability and robustness of the system and its ability to automatically control the plant over its full power range for the entire fuel cycle. The I/A Series Fieldbus Modules include the FBM218, which is capable of providing redundant, channel isolated outputs to field devices. If a failure is detected in one of the Fieldbus Modules, its output is driven to 0 mA and the corresponding channel in the tracking module automatically continues supplying the proper current to the output current loop.



Redundant Valve Outputs have been used for feedwater controls such as the Start-Up Bypass Feedwater Valve and the Main Feedwater Valve controls.

Enhancement #3 – Fully Integrated Single Element/Three Element Control Philosophy

Traditionally, the feedwater control system operated in Single Element control at low power using only the Start-up Bypass valve to maintain Steam Generator Level. Above ~25% power, a Three Element system was employed using only the Main Feedwater Regulating (MFWR) valve. Steam generator level is more robustly controlled using the three elements of steam flow, feedwater flow, and steam generator level. As reactor power increased from 20% to 25%, operators would perform a manual transfer from the Single Element Start-up Bypass valve to the Three Element MFWR valve. Similarly, as reactor power would decrease from 25 to 20%, operators manually transferred from the Three Element MFWR valve back to the Single Element Start-up Bypass valve. These manual transitions require intense operator involvement, and have been the cause of many unplanned unit trips.

The enhanced design utilizes split ranging of the Start-up Bypass valve and the MFWR valve such that they sequence as if there is only one full range valve. Advanced control techniques are utilized to enable the control system to control the transfer from Single Element to Three Element control during the times when reactor power is increasing, and from Three Element to Single Element control during times when reactor power is decreasing. This allows the control system to be in Three Element control while still on the Start-up Bypass valve, improving the dynamic response of the control at a much lower power level than was attainable with the prior design. The system closes the Start-up Bypass valve when appropriate and automatically transfers control from the Start-up Bypass valve to the MFWR valve without any operator intervention. For power shutdown, the system automatically transfers control from the MFWR valve back onto the Start-up Bypass valve. Both of these transfers occur without operator intervention. The automated transfers alleviate the operator from the time consuming and manually intensive transfers required in the older methodology.

If all Steam Generator Level signals are lost, the Three Element/Single Element control system will transfer to MANUAL, mitigating the degree of level perturbations.

Enhancement #4 – Control Element Assembly Position Indication Logic

Control Element Assembly (CEA) Position Indication is used to support reactor engineering and rod position operational functions. CEA has five functions. They are:

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SINGLE ELEMENT/THREE ELEMENT CONTROL

Incore Flux Monitoring function senses millivolt analog signals derived from Rhodium Incore and Background flux detectors. The detectors produce a microampere signal that is converted to the sensed millivolt signal across a precision shunt resistor. The signal values are recorded and instantaneous signals are made available for view. The alarm limit checking of the detector signals provides the plant operational function of "Linear Heat Rate Monitoring." The application also includes automatic depletion calculation and correction to the flux signals based on a selectable 12 or 24-hour correction cycle. Information generated from the Incore Flux Monitoring function is used to support reactor engineering functions.

Calorimetric Monitoring senses process driven analog and discrete signals. Calculations are performed and information presented to the operations, engineering, and maintenance staffs. The information presentation is through small flat panel display devices showing spatially dedicated information, operator and engineering workstation displays, printed reports, and on-demand historical trends. Both raw Unit information as well as calculation and redundant sensor algorithm results are available for real-time and historical presentation. The calorimetric calculation provides the % Power basis for plant operation to ensure plant operation is within the licensed limits.

For analog inputs not including redundant sensors, additional FBMs can be included to provide continuous monitoring of the same signal through the additional module. This design provides for continuity of operation for selected critical signals in the face of a signal channel failure or during the replacement of a failed module. In the unlikely event that a channel Analog to Digital converter fails and emits a constant output, a deviation alarm can be generated when the two channels diverge.

Enhancement #7 – Sequence of Events Recording

Sequence of Events Recording (SOER) senses change of state of designated field contacts and records that time. Information generated from the SOER function is used to support the engineering functions of post-trip review and transient analysis.

The current time is determined from the master timekeeper station that can be synchronized to GPS satellite signals. The master timekeeper synchronizes stations within the I/A Series system using Network Time Protocol (NTP). All control processors are thus synchronized in time, although their operation is asynchronous. The control processor hosting the SOER function synchronizes its contact input FBMs with a 1 msec resolution.

Enhancement #8 – Atmospheric Steam Dump Control

The atmospheric steam dump control system provides for automatic operation of the steam dump valves following large turbine load reductions and reactor trips. A validated pressure value is obtained using the desired Redundant Signal algorithm such as the three input median selector. The validated Pressure for each Steam Generator is compared to the setpoint for that Steam Generator's Relief Valve controller and a signal is sent to the valve. The outputs to these signals can also be redundant to provide an additional measure of reliability.

Enhancement #9 – Steam Bypass to Condenser Control

The Steam Bypass Valves are used for the warming and initial loading of the main turbine. During normal plant operation, these valves are closed. In the event of a turbine trip, the Steam Bypass to Condenser Controls bypass steam around the turbine to the condenser, maintaining steam pressure at a stable value as the reactor is powered down and controls the rate of change of T_{AVG} .

CONCLUSION

Invensys Operations Management is a world leader in feedwater control system implementation using both the Foxboro I/A Series DCS and the Triconex Tricon TMR PLC for safety-related applications. Using our unique technologies, Invensys has helped to improve startup times and runtime performance while reducing unplanned unit trip outages. And while operators are more informed, less interaction is required because the control system manages normal operations and transient or abnormal incidents. With recent enhancements, Invensys Operations Management offers the proven best feedwater control systems for nuclear power generation.



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