

Geothermal Wellfield Control Using Foundation Fieldbus

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ABSTRACT

The Western GeoPower plant is a new 38.5 MW steam dominated geothermal power project being installed at the Geysers area north of San Francisco California. California's H₂S emissions standards are extremely strict and the wellfield must be brought online very carefully in order to minimize atmospheric venting of steam. This paper describes a unique control strategy in which the central DCS (distributed control system) provides supervisory control flow setpoints to local PID (proportional, integral, derivative) control algorithms which reside in the local wellhead flow control motor operated valves (MOVs). This Foundation Fieldbus (FF) enabled MOVs execute a PID control algorithm internally and gather their process variable information directly via FF communications from their local instrumentation peers. The result is a truly distributed control system in which the control logic resides inside the wellhead MOVs and instrumentation with no need for a stand-alone wellhead PLC or other traditional control system.

1. INTRODUCTION

The new 38.5 MW Western GeoPower project consists of seven production wells and two injection wells distributed over the steamfield's remote well pad sites, a Fuji single admission steam turbine, a shell and tube steam surface main condenser, a turbine bypass system, a hybrid liquid ring and steam jet ejector NCG removal system, an NCG H₂S incinerator system, a wet cooling tower, and miscellaneous plant auxiliaries.

California's strict emissions policies require that atmospheric steam venting to the plant's rock muffler be minimized at all times, including during plant startups and shutdowns. Rather, all steam should pass to the main steam surface condenser so that the non-condensable gases may be extracted by the vacuum system and routed to the H₂S incinerator system. When the steam turbine is not available during plant startups, shutdowns, or system upsets; all of the plant's incoming steam should be diverted around the turbine to the main condenser via the turbine bypass valve. In the event that the condenser should become unavailable due to a loss of cooling water flow, the wellhead valves should ramp closed as quickly as possible.

During plant startups, the turbine bypass cannot be utilized until condenser vacuum is established, and vacuum cannot be established until sealing steam has been applied to the turbine glands. Therefore the steamfield controls must be tightly integrated and coordinated with the central plant control system.

Wellfield steam production must be balanced with the plant's steam consumption capabilities at all times in order to avoid atmospheric venting. It is important to have the wellfield control tightly integrated with the central DCS. At

the same time, it is desirable to have local control at the wellhead rather than using DCS remote IO (with the control algorithms executed back at the plant) such that even if communications to the wellfield are severed, the local wellhead control logic will continue to function. Finally, due to the presence of corrosive H₂S gases and the potential for temperature extremes in the remote wellhead panels, an industrial hardened wellfield control system is called for. Foundation Fieldbus technology meets all of these requirements.

2. THE CHALLENGE

California has strict limits on the amount of H₂S laden steam that can be vented during the startup of the Western GeoPower geothermal power project. In order to meet these requirements it is vital that the wellfield steam production and the power plant startups, shutdowns, and trips be carefully coordinated such that all of the steam is routed through the main condenser and flows onwards to the H₂S incinerator system. There is a sequence of operations and conditions that must take place prior to the condenser being ready to receive steam. Prior to synchronizing the turbine/generator to the grid, a turbine bypass system is used to divert the steam directly to the main condenser. But the condenser must be at its normal operating vacuum in before it can receive steam.

First, one or several wells must be cracked slightly open in order to purge the steamfield piping of air and to begin to warm the pipeline and well casings. Once the system has been purged of air, the rock muffler atmospheric vent valves are driven closed and a small amount of steam pressure is allowed to build in the line. This small amount of steam pressure is sufficient to apply sealing steam to the turbine glands so that the vacuum pulling operations may begin, but low enough such that atmospheric steam venting is not required. Roughly 30 minutes after the vacuum pulling operation begins the condenser pressure is sufficiently low that the turbine bypass system, which discharges to the main condenser, may be placed into operation. At this point the production well flow rates may be ramped up at a rate designed to minimize well bore stresses while the steam pressure setpoint upstream of the turbine bypass is ramped up to normal operating conditions in anticipation of turbine/generator synchronization. During a normal plant shutdown, the production wells are ramped closed in coordination with the turbine and turbine bypass systems. In the event that there is a sudden loss of cooling water flow to the main condenser, the production wellheads must be ramped closed as quickly as possible in order to minimize atmospheric steam venting.

3. THE SOLUTION

One common method for steamfield control is to utilize stand alone controllers at each wellsite. This method has several drawbacks. A stand-alone PLC controller is relatively costly to purchase, install, and maintain. The PLC's copper components will be at significant risk of

damage from the corrosive effects of H₂S gas and it can be difficult to ensure that the PLC's cabinet is airtight. The best PLC enclosures have an IP (International Protection) rating of 65 (protection from low pressure water jets with some ingress permitted). There is always some doubt about how well the cabinet door will continue to seal over years of use. Ambient air temperatures and sun impinging on the PLC enclosure can greatly shorten the useful life of electronics. Unless a dedicated cooling system is employed, the other electronic components inside the PLC enclosure (power supply, UPS, etc) may cause heat to accumulate inside the enclosure to the point that the PLC's rated operating temperature is exceeded. In addition, maintaining the databases and programming of each wellsite's PLC increases project cost and complexity.

Foundation Fieldbus devices on the other hand, such as motor operated valves and transmitters, are designed for continuous operation outdoors under the most extreme operating conditions. These devices have a typical environmental rating of IP68 (permanent immersion under pressure). Foundation Fieldbus is an open non-proprietary standard which is published and maintained by a non-profit organization (www.foundationfieldbus.org).

This organization has developed a technology which can be used to network field devices from a wide array of manufacturers together into a seamless whole. Each device contains logic function blocks that can work together with the other devices on the local network to implement a single comprehensive control strategy.

The non-profit Foundation Fieldbus organization (www.foundationfieldbus.org), in conjunction with industry manufacturers, has developed a two way serial communications and control protocol for field devices (transmitters, valves, etc). Each device is "intelligent" and has a number of embedded logic function capabilities, which typically include at least one PID function block. Software may be used to tie the logic blocks from the various devices on a wiring segment together into a integrated logic control strategy. A supervisory control system, such as a plant central DCS, can provide setpoints, receive alarms and status, etc. but the local field devices work together autonomously to run their shared control strategy even if communications back to the central control system is lost.

There are two forms of Foundation Fieldbus communications: H1 and HSE. H1 communications is the field device level interface. H1 uses a twisted shielded pair cable just as is used for the traditional 4-20 mA hardwired signals. H1 communicates at 31.25 kbps with communications and power on the same pair of wires. Up to 16 devices may be connected to one H1 wiring segment. HSE (high speed Ethernet) FF communications are typically used for communications from a H1 linking device to the DCS. FF HSE operates at 100 Mbps, utilizing the Ethernet communications standard. Not all control system vendors who support FF H1 also support FF HSE. Some vendors instead rely on their own proprietary communications to H1 field device communications modules.

Every device that carries the Foundation Fieldbus logo has been successfully tested by the FF organization and the

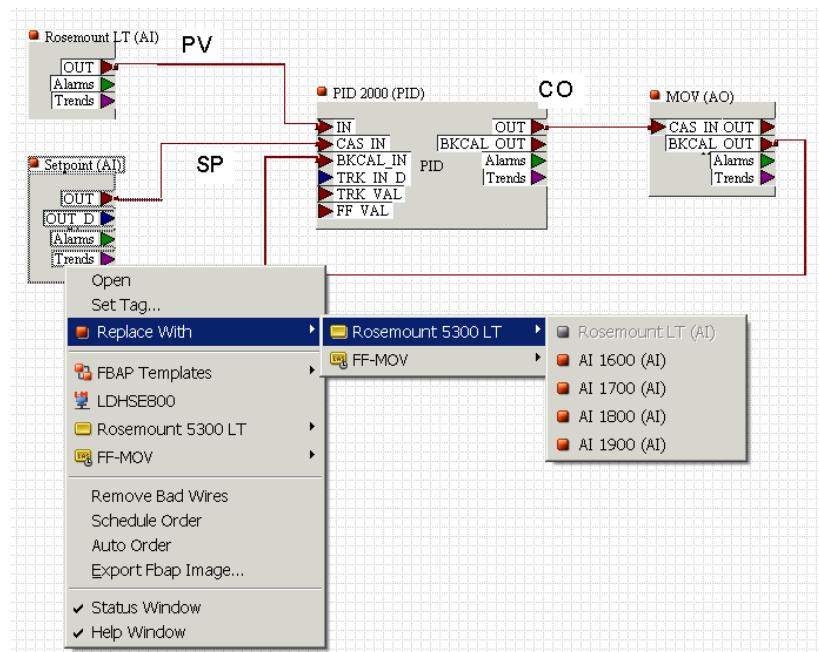
device descriptor (DD) files for that device may be downloaded from their website. These DD files may be imported into a software logic configuration application such as the National Instruments NI-FBUS program and then all of the function blocks for that device become available for the designer to drag and drop into a control strategy. The designer then uses a line tool to connect the inputs and outputs of the various blocks as appropriate for the desired control strategy.

In the following example, the AI (analog input) block on the top left exists in a level transmitter and is used as the PV (process variable) for the PID controller. The AI block on the lower left also exists in this transmitter and is used as the PID setpoint. This SP value may be written to by the central DCS. If communications to the DCS are lost, the SP can be configured to retain the last good value it received from the DCS or to go to some predefined value. The block in the center is a PID controller block which would typically reside in the final control element, a motor operated valve in this case. The AO (analog output) block on the right also resides in the final control element, the MOV. This is the actual output that drives the valve position. The connector on the BKCAL OUT of the AO block which loops back around to the BKCAL IN input on the PID block is used for tracking when the PID controller is placed into manual mode. This provides a bumpless transfer between manual and automatic operating modes. This bumpless transfer, the inputs and outputs shown on these blocks, integral windup protection, alarming, and many other features are all part of the Foundation Fieldbus standard. Device manufacturers must adhere to a minimum baseline of features for their blocks in order to get certified by the FF organization. The pop up menu shown below the function blocks is a NI-FBUS specific implementation where the user drops the blocks they want and can then right click on any block and quickly replace that block with a block from any other of the devices on that segment. Other control system vendor's software implementation may differ in appearance.

The FF technology has several very useful built in features that, per the FF standard, all field device vendors must support.

Every signal out of a block includes a status along with the value. The status can be "good", "uncertain", or "bad". Downstream blocks can take action, such as failing to manual mode in the event of a bad measurement (configurable). With a hardwired 4-20 mA signal, the control system would have to wait until the signal had dropped below 4 mA before realizing that the signal was bad, but with FF the downstream blocks are immediately made aware of this in a single scan cycle. This status will automatically propagate through the downstream blocks to any other blocks that are further downstream.

When a FF valve actuator reaches the end of travel, this information is automatically propagated upstream. Any upstream PID blocks will automatically stop integrating, providing reset windup protection. If the valve actuator should fail for any reason, a "bad" analog output value is propagated upstream and the PID controller automatically reverts to manual mode.



Each H1 network has an associated schedule that is controlled by one device that serves as the LAS (link active scheduler). The LAS defines the order of function block execution and the total length of each cycle. The total cycle length, referred to as a macro-cycle, is the length of time it takes for all the blocks to execute plus some time duration at the end for background communications between the field devices and the DCS. If the primary LAS should fail, any of the other devices on the segment can be configured as a backup and will automatically take over the LAS responsibilities. An excellent source of further information on the FF technology is *“Fieldbuses for Process Control: Engineering, Operation, and Maintenance”* by Jonas Berge.

4. PROJECT IMPLEMENTATION

There are several control system platforms associated with the Western GeoPower project.

A Fuji Micrex-SX is used for the control functions and systems associated with the turbine. The Fuji controller communicates to the central DCS using hardwired signals for critical IO and via Modbus RTU over RS485 for supplementary data.

An incinerator system is used to remove H₂S gases from the NCG exhaust from the condenser gas removal system. There are two small Allen Bradley PLCs associated with the H₂S incinerator, one for overall control and one for the burner management system. These PLCs communicate to the central DCS via DeviceNet and Modbus TCP.

An Emerson Ovation DCS provides all of the balance of plant control and serves as a single operator interface for the entire plant including for the turbine and H₂S incinerator subsystems.

The balance of plant control for the Western GeoPower project is implemented using an Emerson Ovation DCS. The Ovation platform is feature rich, advanced control system. SAMA style logic configuration with PDF based self-documentation is one of the features of the Ovation system. Logic configurations are developed by dropping function blocks onto a page and then connecting them together with signal lines, in the same manner as the Foundation Fieldbus standard. Logic blocks that are executed in the DCS central processor and those that reside

in the FF field devices can be implemented together seamless in an integrated logic algorithm in a way that is transparent to the programmer.

Once all of the logic sheets have been developed, the configuration software is used to generate a PDF file that provides the as-built logic configuration that can be shared with and reviewed by anyone with the free Adobe PDF viewer software. By hovering over a logic block in the PDF, the various customized parameters associated with that block appear in a small pop-up window. If the logic sheet has off-page links, the reviewer can simply click on the off-page connector to navigate to the referenced page.

Emerson Ovation has tested and certified Foundation Fieldbus function blocks from a large number of instrument and field device manufacturers, and mapped these function blocks to blocks in their DCS configuration software. Ideally, control system manufacturers would not require mapping of Foundation Fieldbus blocks to their configuration software. In general however, all of the major DCS vendors currently require this mapping and device specific certification. Prior to finalizing procurement, end users who wish to implement a Foundation Fieldbus solution should request and evaluate a list of approved Foundation Fieldbus devices from their control system vendors. This limitation was not found to be a problem on the Western GeoPower project because the extensive list of Ovation certified devices covered all of the field devices required for this project.

Foundation Fieldbus technology is used throughout the steamfield. The operator normally only provides supervisory setpoint for these control loops, but may take manual control of the final field devices if desired. The steamfield control loops include PID production well steam flow control, a cascaded control loop for reinjection (reinjection flow with a supervisory setpoint based on sedimentation basin level), and on/off condensate tank collection tank level control.

Foundation Fieldbus technology allows the production wellhead MOV's (motor operated valves) to receive a supervisory setpoint from the plant DCS, monitor its local wellhead flow transmitter's process variable, and to execute a PID logic algorithm in order to maintain the flow at the

desired setpoint, even if communications to the DCS are severed.

Ethernet based single-mode fiber optic communications are used to connect the central plant control system and local control panels at each wellpad. Each wellpad control panel contains a FF gateway device with a built in power supply filter, a 24VDC power supply, a UPS (a battery backed uninterruptible power supply), a fiber patch panel, a Hirschmann industrial Ethernet switch (with copper and fiber ports), and a Rosemount 848L FF logic transmitter with interposing relays. The 848L supports FF and provides digital outputs for actuating the reinjection pump motor starter contactors.

During startups, the steam pressure is initially controlled by venting to a rock muffler. To meet strict emission requirements, atmospheric steam venting should not exceed roughly 8% of the full load steam flow prior to enabling the turbine bypass system. Once turbine gland sealing steam, and subsequently, condenser vacuum has been established; the steam pressure may be controlled by venting to the condenser via the turbine bypass system. Pressure control by means of the turbine bypass system is greatly preferred because, in this operation mode, the H₂S non-condensable gases are contained and routed to the abatement system. Once the turbine has been started and synchronized to the grid, the turbine governing valves take over control of the steam pressure and the turbine bypass and rock muffler vent valves automatically close. In the event of a turbine trip, pressure control will revert to the turbine bypass system. If the turbine bypass system is unavailable, due to a lack of cooling water or condenser vacuum, the rock muffler vent valve will resume responsibility for control of the steam system's pressure and the production wellhead MOV's will quickly ramp closed.

During normal operation, the operator will place all three pressure control loops in automatic (turbine inlet pressure regulator, turbine bypass valve, and rock muffler vent valve). The turbine pressure control regulator will normally have the lowest setpoint, with the turbine bypass somewhat higher, and the rock muffler with the highest setpoint. These setpoints are selected based upon the preferred order of pressure control.

In the event of a turbine trip, if the turbine bypass permissives have been met (condenser vacuum OK and at least one circulating water pump running), then the turbine bypass valve will open to control the steam pressure. If the turbine bypass system is not available for operation or the system pressure continues to rise, the rock muffler vent valves will begin to open. At the same time, the flow setpoints for all of the production wells will automatically ramp down to a minimum flow setpoint. The operator can then manually close in the production wells either from the

plant control system operator interface or manually at the wellhead.

An operator interface screen provides a table of flow setpoints for all fo the production wells. The operator may enable/disable the flow from any well, enter a manual flow setpoint fro that individual well, or enter flow percentage value for each well with respect to the total steam flow. A single master flow setpoint for the entire steamfield can be enabled and adjusted to raise/lower the total wellfield steam flow based upon each well's flow percentage valve.

A sedimentation basin a the plant receives and excess water from the cycle or from storm runoff. This water is then re-injected into the reservoir into wells that are at an elevation that is approximately 240 meters below the level of this basin. The basin level is monitored by transmitters hardwired to the plant control system and the level controlled by Foundation Fieldbus motor operated valves at the injection wellheads. A cascaded PID control loop is used to maintain the sedimentation basin at setpoint. The operator enters a level setpoint for the sedimentation basin. A PID algorithm running in the central plant control system monitors the basin level and develops a desirecd injection flow setpoint. This flow setpoint is apportioned to each reinjection well that is currently in automatic mode, based upon a pre-defined table of injection well capacities. PID algorithyms running in each injection well MOV monitor their local flow transmitter's process variable and automatically adjust their position to maintain the flow at the setpoint. The result is that all the reinjection wells work together, and with the central plant control system, to regulate the total injection flow rate such that the sedimentation basin level is maintained at the desired setpoint.

5. CONCLUSIONS

Foundation Fieldbus technology provides a cost effective, highly reliable, and functionally rich solution for geothermal wellfield control. Eliminating wellfield local controllers improves the overall system reliability and reduces the complexity and cost of maintaining the system.

DCS manufacturers support a wide array of final field devices whos FF logic blocks can be integrated seamlessly into an overall plant/steamfield control strategy. Control system vendors should be encouraged to continue to improve their FF implementation in order to eliminate the device specific mapping of the FF field device manufacturer's function blocks. The ultimate goal should be that the field device descriptor files could be downloaded from the www.foundationfieldbus.org website, imported directly into the control system vendor's logic configuration program, and all of the field devices function blocks would be available for use by the programmer.