Technology Improves Rafter Habitat
Chili Bar Controls Upgrade

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ABSTRACT
Article describes newly implemented technology by Pacific Gas & Electric (PG&E) that improves the control of river flows at the Chili Bar Dam and Powerstation and enhances the habitat of one of the local species: the river rafter. Original mechanical governors, partially upgraded in 1992, now feature completely redundant PLC controls and new hydraulic actuators for both the turbine governor and bypass valve control. New system features model-based flow control and redundant hydraulic control valves. Driven by stringent river level ramp rates required by FERC, PG&E incorporated automatic plant control, remote control and monitoring, and fail-safe modes into the system. River flow setpoints can now be adjusted remotely from PG&E’s Dispatch Center. Start-up and commissioning was completed in June 2002.

INTRODUCTION
The South Fork of the American River is one of the country’s most frequented rivers for recreational uses and historic sights. This premier tourist destination, located in the Sierra Nevada Mountains west of Lake Tahoe, features the most popular white water rafting and kayaking in the West. The 21-mile stretch downstream from PG&E’s Chili Bar Plant, near Placerville, California, is the most rafted segment of the river.

The Chili Bar plant was commissioned in 1964. In 1992 the turbine was refurbished and the governor was partially upgraded.

FERC has stringent requirements for PG&E to abide by. Minimum flow and orderly control of flow changes are specified for the Chili Bar Dam in order to accommodate both the vibrant downstream recreational

<table>
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<th>PLANT DATA:</th>
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<tr>
<td>Turbine: Allis-Chalmers, 106” Vertical Adjustable Blade Kaplan</td>
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<td>Rated output: 9,700 HP</td>
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<td>Bypass Valve: 84” Howell Bunger Valve</td>
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<td>Generator: Allis Chalmers, 7,800 kVA, .9 PF</td>
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<td>Max gross head: 57 feet</td>
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<td>Rated flow: 1,690 cfs</td>
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<td>Normal unit speed: 200 RPM</td>
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<tr>
<td>Forebay elevation: 996.5 Feet Max. / 980.0 Feet Min</td>
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<td>Controls: Mechanical Cabinet Actuator</td>
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community, mainly rafters and kayakers, and native fish and wildlife. An excerpt from PG&E’s FERC license follows:

“The licensee shall operate the Chili Bar Diversion Dam and Powerplant so as to smooth the downstream discharge and maintain stream flow; controllable discharge changes shall be gradual and no greater than 500 cubic feet per second (cfs) per hour from 100 to 1000 cfs, and not to exceed one foot in elevation during any one hour period above 1000 cfs except during natural spill conditions. Such river stage changes shall be measured at a control point of representative width downstream from Chili Bar Dam by the stream gauge installed under the supervision of the U.S. Geological Survey pursuant to article 6. At no time shall the flow past the gauging station be less than 100 cfs.”

In addition to the FERC requirements, PG&E tries to maintain a flow of 1200 cfs during the hours of 7am - 1pm for the benefit of whitewater rafters.

PG&E communicates with both the Sacramento Municipal Utility District (SMUD), the operator of a larger Dam and Powerhouse upstream, and local whitewater rafting organizations in order to fulfill their responsibility to work within the FERC requirements to best serve the community. Rafters are most satisfied when PG&E can offer predictable and reliable downstream flow throughout the year. Any aberration in flows can cause poor or even dangerous rafting conditions.

In years past, the SMUD plant directly upstream released very stable flows, and did not ramp up or down quickly or often. However, due to restructuring of the electricity industry in California, flow volatility has increased as SMUD takes advantage of electricity generation pricing swings. As a result, Chili Bar must be a much more responsive plant to meet downstream flow requirements. The old control was not designed for the precise, reliable responses to SMUD changes that are necessary. The sluggish and irregular response was a leading cause of flow deviations. The new system satisfies the response needed for any incoming flow situation.

Some stakeholders, in particular the rafting community, consider PG&E’s electricity generation at Chili Bar is considered secondary to the needs of downstream rafters. Nearly fifty commercial outfitters utilize the downstream flow throughout the year and based on a recent economic study, this generates approximately $20,000,000 in annual income for the region. The lost electricity generation pales in comparison to the economic consequences of a squandered rafting opportunity.
OLD SYSTEM CAN'T KEEP UP
Given the more volatile upstream flows in recent years, PG&E’s operations occasionally yielded short-term, accidental variations from the FERC requirements. PG&E was also unable to supply reliable and predictable downstream flows for whitewater rafters. In several instances, normal rafting flow of 1200+ cfs was inadvertently dropped to near minimum flow of 100 cfs leaving thousands of rafters stranded. These flow deviations were attributed to the old governor equipment and software that was utilized.

PG&E was unable to adjust control parameters sufficiently to correct these problems, and had no access to the underlying software due to the propriety nature of the system. Worse, the OEM was phasing out support for these controls. The digital control utilized was less than 10 years old, yet availability of spare parts and service had become unreliable and extremely costly.

NEW SYSTEM PROVIDES SOLUTION
PG&E determined that flow anomalies were occurring because of a number of technical issues with their original equipment. Early in 2002, PG&E decided to completely revamp the turbine and bypass control systems in order to minimize further deviations and provide reliable and predictable flow for rafters. American Governor was contracted to provide the new systems.

The following discussion describes the major problem areas and how they were fixed:
Predictive vs. Reactive Control
The original system controlled flow based on a sensor hundreds of yards downstream of the plant. This introduced a lag into the system. The governor was reacting to past flow data and could not predict upcoming problems.

The new system utilizes a model-based flow algorithm that controls flow at the plant, not at a point downstream. The downstream sensor is used for monitoring purposes only. A mismatch between the calculated and actual values causes an alarm. This allows for a trained operator to respond to and evaluate the special circumstances that caused the situation.

Automation
The old system required frequent operator input to maintain desired downstream flow.

The new system has numerous new features allowing PG&E to provide minimal input to meet flow requirements. The controls work together to insure that the river flow setpoint is met. Upon a turbine shutdown, the bypass opens quickly to provide the precise amount of water that was flowing through the turbine. Even the starting and stopping of the turbine follows a shared sequence that prevents the possibility of flow deviations from occurring. The Bypass controller and Turbine controller share information and work together to maintain the desired river flow.

Remote Control
With the old system, PG&E had very little monitoring information available remotely, and no remote control. Since the plant is normally unmanned, when the old system had a problem, PG&E had to dispatch a technician to the plant. This took approximately one hour, enough time to cause a FERC deviation or a large flow swing affecting rafters.
The new system allows PG&E remote access to critical system data, such as Gate Position, Bypass Valve Position and Flow Calculations. PG&E now has the ability to take action remotely by opening or closing the bypass valve, changing flow setpoints and starting or stopping river flow ramping. This new remote ability gives PG&E new flexibility to quickly meet recreational needs and FERC requirements.

Reliability, Redundancy and Fail-Safe Features
A single component failure or malfunction in the old system could easily have caused a flow deviation. Some of these critical components included electronic modules, power supplies, interposing relays, motors and numerous mechanical control devices.

The new system was designed to be robust and has numerous fail-safe features. Redundant PLCs with health monitoring were provided to allow the Turbine PLC to control the bypass valve upon loss of the Bypass PLC. Redundant proportional valve manifolds were provided for the bypass valve to insure uninterrupted flow control upon the loss of a proportional valve, shutdown solenoid valve or LVDT position sensor. The system also has redundant power supplies and position feedback sensors for the wicket gates and bypass valve. If any sensor fails, alarms are generated and the other device is used.

The independent Bypass and Turbine controllers share a wealth of information regarding current system status. Positioning decisions are made in each controller based on this shared information. The overall goal of the system is to do everything possible to keep the river flows and the ramp rates within the FERC specified parameters.
The burden of controlling the downstream flow has been taken away from the operators and integrated into the system control logic. The operators (local or remote) tell the system what they would like for a final river flow. The system takes the request and makes the internal changes necessary to meet the new requirement. The system assumes responsibility for controlling the river ramp rates by following a rule-based algorithm designed to prevent deviations. Except in an emergency, the operators do not have direct access to the setpoints that ultimately control the Bypass and Turbine positions. This forces all requests to be evaluated and handled by the control system and its internal logic. The operator can request a change in the river flow and turn his attention from the unit, knowing that the request will be satisfied in a controlled and safe manner, without the risk of causing a flow deviation.

Diagnostics and System Monitoring
The old system had minimal data available for monitoring or troubleshooting.

The new system has two color touchscreens that provide local display of all unit information, historical data trending, an event log, start and stop sequence status, alarm status and status of all inputs and outputs (see screen captures below). The system also has extensive self-diagnostics and generates alarms on numerous events, including signal mismatches (flow, speed, gate & bypass position), signal trouble on any input (speed, gate position, blade position, bypass position, level, flow), dirty oil filter, and power supply failure.
System Tuning and Troubleshooting
Tuning of the old system was difficult. It required a skilled technician and numerous mechanical adjustments. Only a few control parameters were user-adjustable, and documentation was poor.

The new system allows tuning of variables and troubleshooting via the touchscreens. One particularly useful tunable is Percent of Maximum Ramp Rate, allowing PG&E to run aggressively or conservatively. Of course, the maximum allowed rates still conform to the FERC requirements. All tunables are password protected.

Precise Control
The original system had many mechanical linkages, gears and mechanical feedback with cables and pulleys. These mechanical devices introduced position error into the system due to worn parts, sticking, slop, backlash, and feedback cable stretch. Gate, blade and bypass positions were key variables that were affected.

The new system eliminates most of this error from the control loop through the use of precise position sensing and speed sensing. The new electronic gate, blade and bypass position sensors are much more accurate than the old mechanical sensors. Speed sensing is now performed digitally utilizing a potential transformer. The output from the speed sensor feeds the PID controller, which operates as a conventional speed droop governor.
Dependence on Vendors
The old system had a proprietary hardware platform along with a proprietary software platform. PG&E was completely reliant on the OEM for spare parts and support. When the OEM began phasing out support, prices rose to over $10,000 each for some of the electronic modules. System software modifications were even more cost prohibitive.

The new system uses mostly off-the-shelf hardware, including Allen Bradley PLCs and valves with standard mounting patterns. Spare parts can easily be obtained for many years to come from multiple sources. PG&E also has all software, site licenses and source code, and has the ability to modify both the PLC and HMI programs. This allows PG&E to easily reprogram their system as requirements change or new features are desired.

Factory Acceptance Test
All equipment was tested in the factory before shipment. A turbine and river simulator and test stand was used to model all operating and flow conditions. During the factory acceptance test, PG&E engineers and operators were able to adjust the program to best meet their requirements. This greatly reduced the amount of test time on site.

Installation and Startup
The old equipment was removed and the new equipment was installed in approximately one week. The new equipment was tested for several days and flow curves were verified. The project timetable was set up to minimize the effect on rafters and had little impact on rafting.
WHITEWATER RAFTERS APPLAUD
Bill Center, owner of Camp Lotus, located directly downstream of the Chili Bar Dam, has communicated with PG&E about river flows since the 76-77 drought and is the key rafting industry point of contact with PG&E. Prior to the upgrade, Bill found the uncertainty of river flows to be “frustrating, at times dangerous, and had a significant economic impact.” On several occasions numerous rafters were actually stranded after flow was abruptly reduced to minimum flow. Since the upgrade, Bill hails, “You can almost set your watch to the consistency in which the flow comes up and down!” He adds that, “the new system has removed all uncertainty about the ability to deliver flow” and that “the rafters appreciate the level of confidence and flexibility PG&E now gives them”. The following charts illustrate his point.

Sample Downstream River Flow – Before Upgrade

Sample Downstream River Flow – After Upgrade
SUMMARY
After ten months of use, PG&E’s upgraded control system at Chili Bar has operated successfully without any FERC flow violations and to the satisfaction of the recreational users of the area.

REFERENCES
The Flow Graphs are from the California Department of Water Resources Division of Flood Management.

AUTHOR
Daniel Berrien, PE, is a Project Manager at American Governor Company, where he has worked for three years. He has commissioned dozens of digital governor upgrades. Prior to American Governor, Dan worked for GE Fanuc Automation as a Project Manager. He was also a Field / Application / Commissioning Engineer for Woodward Governor and a Design Engineer for Lockheed Martin on the Space Shuttle Program.