

INCREASING PEAK POWER GENERATION USING SCADA AND AUTOMATION: A CASE STUDY OF THE KAWEAH RIVER POWER AUTHORITY

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ABSTRACT

The Kaweah River Power Authority (KRPA) is a joint powers authority comprised of the Kaweah Delta Water Conservation District (KDWCD) and Tulare Irrigation District (TID) in Central California. The KRPA operates a 20 megawatt (MW) generator at Terminus Dam (Dam) on the Kaweah River. In 2002 with the assistance of the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo, the KRPA developed a plan to generate and supply more power during the peak demand hours (12 p.m.–6 p.m.). This was accomplished through a change in power plant and river operations, along with the installation and use of SCADA and gate automation at key points along river and canal system. The SCADA system also provided water management benefits to Tulare Irrigation District (TID) and Kaweah Delta Water Conservation District (KDWCD).

INTRODUCTION

Prior to the project, the KDWCD, TID and other users on the river would attempt to manage their irrigation water behind the Dam in a manner that would optimize power generation while still serving their main purpose of delivering irrigation water to the area's growers. The KRPA has a long-term contract with Southern California Edison (SCE) to purchase the power generated at the Dam. The structure of the contract is such that during the late spring and summer (June through September) the price paid for power generated during the peak hours is at a premium. Also, in light of the recent energy problems in California, the California Energy Commission (CEC) had grant funding available for water districts and growers for projects that would reduce the peak power demands on the state's power grid.

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In 2002, the ITRC began working with the KRPA, TID, and KDWCD to try to develop a means to help increase the amount of peak power generated at the Dam – which the CEC accepted as an alternative project to one that would remove peak load consumption from the grid. The idea formed during those discussions was to vary deliveries from the Dam. During peak hours, higher releases would be made. During off-peak hours, lower releases would be made. Potentially, the flowrate could change 400 cubic feet per second (cfs) from peak hours to off-peak hours. Overall, the releases made at the Dam would deliver the volume of water ordered by downstream irrigators for the day. TID is the largest demand on the river, and has two reservoirs near the head of its system – located approximately 24 miles downstream of the Dam. These reservoirs would be used to re-regulate the deliveries to the growers at a constant rate. By doing this, TID's growers would not experience any undesired fluctuation in their water delivery.

One problem was that during the height of the irrigation season, the water demand from the Dam can exceed the capacity of the generator. When this occurs, the extra water is delivered through a bypass penstock in the Dam to the Kaweah River, and some potential power production is lost. To overcome this, TID can increase the water they receive from the Friant-Kern Canal (FKC) (which diverts water from the San Joaquin River) during times when the Kaweah and St. Johns River demands exceed the power plant capacity. On days when the plant does not anticipate bypassing deliveries around the power plant, then TID can take their Kaweah River water and maximize the generation operations.

KDWCD and TID had the basic transportation facilities (canals and diversions) in place needed for the project. However, the Districts needed to make changes in how they operated their systems. Neither KDWCD nor TID had a SCADA system or automation on any of the en route structures. The KRPA had only a local SCADA system at the power plant. Automation, with SCADA for monitoring, was essential to the project since the flow fluctuations made at the dam during the day may not arrive at the various diversion points until late at night when the number of operations staff is limited.

ITRC identified a number of sites that would need to be modified. Figure 1 below is a map of the Kaweah River system that shows where the projects are located. Beginning at the Dam, the flows would travel down the Kaweah River to McKay's Point. At McKay's Point, the flow downstream to the Lower Kaweah River would be controlled, and the flow fluctuations would be sent down the St. John's River. Once in the St. John's River, the fluctuations would travel to Rocky Ford where TID takes delivery of their Kaweah River water supply. At Rocky Ford, the fluctuations in flow would be delivered into TID's Main Intake Canal (MIC). However, along the way, there were other diversions from the river that needed to be modified and monitored so that they were not impacted by the changed operations.

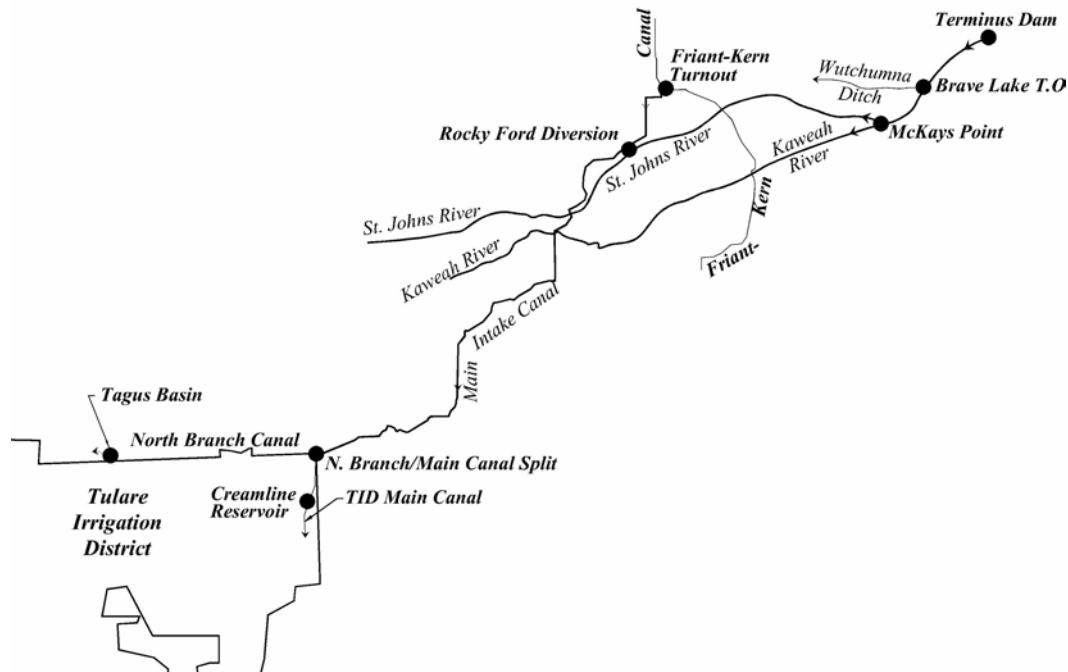


Figure 1. Map of the Kaweah River System and Locations of the Project's Components.

ITRC and KRPA approached the CEC for grant funding for the project. Their approach to securing the grant funding was that the project helped meet the state's goal of alleviating the stress on the power grid by providing more peak power, rather than reducing peak power consumption. The CEC concurred, and approved \$512,000 in grant funds for approximately half of the estimated project costs to help the KRPA to implement the project. The grant was performance based; half of the grant would be paid when the project was built, and the other half would be paid upon successful demonstration that the project worked as designed.

DESIGN AND CONSTRUCTION

Overview

The automation of control structures and the use of SCADA to monitor performance and remotely change target flows and target depths (distributed control) allows the flow fluctuations to be routed to TID's diversion from the St. John's River and then on through TID's system to its regulating reservoirs. Gate automation for either upstream water level control or flow control is used at major control points and at diversions in the system to ensure that the flows to the other water users on the river are held constant, and to provide safe operation in the main route. Remote monitoring and control of TID's regulating basins and

other sources of water deliveries allow TID to verify the system is operating properly, and alert them to potential problems.

ITRC developed the design and specifications for the SCADA system and developed the control algorithms used at three of the control sites. Provost & Pritchard Engineering Group, Inc. (P&P) was hired by KRPA to help prepare construction documents for the Districts to build the project, to assist in soliciting bids from qualified integrators, and to coordinate the efforts of the agencies and integrator.

The specifications developed by ITRC mandated a number of things that are crucial to the success of any SCADA project.

1. Open Architecture. The integrator was required to submit full documentation of the software prior to installation. This gave the KRPA the ability to troubleshoot programming using either its own staff, or any integrator/programmer of their choosing.
2. Editable Constants. All of the constants used in any calculations had to be able to be changed through a screen in the Lookout[®] program at the human machine interface (HMI) in the offices. By requiring this, the KRPA and TID can easily change variables for initial calibration and future recalibration, without reviewing and editing the ladder logic.
3. Redundant Sensors. At all automation sites, two different types of sensors were used to collect the data for each variable needed for control. In the event that the primary sensor is found to be faulty, then the operators can change which sensor is used for computations at the site's remote terminal unit (RTU). The redundancy also applied to the analog to digital signal converters. Each sensor sends the 4-20 ma signal to its own analog-to-digital (A/D) converter which then sends the digital signal to the RTU.
4. Training and Spare Parts. The contract with the integrator specified that the KRPA, KDWCD, and TID staff be trained on how to use and troubleshoot the equipment. The contract also specified that a number of spare sensors and other equipment not readily available be provided for the project in the event that a component failed during the irrigation season.

The algorithms for water level control developed by ITRC were based on proportional-integral-filter (PIF) control logic. A proportional algorithm was used by ITRC for flow control. Three sites were supplied with the algorithm: Wutchumna Ditch Turnout, North Branch Split, and Creamline Reservoir. The algorithm was modified slightly to fit the needs of each site. Control diagrams for each site were then provided to the integrator to incorporate into the sites'

programming. The integrator however, was responsible to develop the programming for the communications, HMI screens, and data collection.

The construction schedule for the project was fairly aggressive. The project was bid to integrators in October 2003. Concepts in Controls (CIC) of Visalia, CA was selected as the integrator for the project. After some redesign of the project facilities to reduce costs, preparation of license agreements with other agencies and landowners to install some of the SCADA equipment, and negotiations with the integrator, construction began in February 2004. The CEC grant deadline was July 2004. This gave approximately five months to order, install, program, and field test the system. Ultimately, the deadline was extended because of the tight schedule and the diligent prosecution of the work by the Districts' staff.

Terminus Dam

KRPA has at the power plant an existing SCADA system used to run the plant. KRPA did not want to incorporate the plant's SCADA system into this project, so a separate RTU was placed at the Dam that retrieved selected information from the plant's system. This information included the flow rate through the generator, water level behind the dam, and other ancillary data. The information was then radioed to each of the Districts offices. At the offices, the Districts could only view the data and had no ability to change the operations of the plant.

Badger Hill Repeater Station

Because some sites were located in the foothills and some on the valley floor, a repeater station needed to be built. The Badger Hill site was chosen because many other communications facilities existed at the top of the hill, and space could be leased inexpensively with very little improvements required to install the repeater. All of the data for the project was sent to the repeater, and was relayed to the two offices (KDWCD and TID).

Wutchumna Ditch Turnout

The diversion to Wutchumna Ditch is owned and operated by the Wutchumna Ditch Company (Wutchumna). This site is upstream of McKay's Point, so fluctuations in water level caused by the flow changes would affect the flow into the Wutchumna Ditch. To alleviate any problems that could be caused by the flow changes, the gates were automated to control the downstream water level in a rated section in the ditch. Wutchumna gave permission to the KRPA to install the SCADA system and electrically actuate and automate two of the three existing manually operated slide gates at the diversion.

ITRC developed an algorithm that stabilized the flow in the ditch within five minutes of a change in flow. Wutchumna's operators would be able to move the gates using the actuators to the position they desired, similar to their previous

operations. After the operators set the gate positions, the RTU would take over automation of the site and maintain the downstream water level. Since the actual flow would not be measured by the SCADA system, the gates would maintain downstream water level in the ditch, thereby maintaining the downstream flow, at least as well as the previous operations. A stilling well with level sensors was placed downstream of the diversion in the ditch.

McKay's Point

McKay's Point is the location where the St. John's and Kaweah Rivers split. At this location, two Langemann Gates, 24 feet wide, manufactured by Aqua Systems 2000, Inc. (AS2000) were installed. These gates were chosen for a number of reasons.

1. They come from the manufacturer as a package unit. The manufacturer supplies the gate position sensors, PLC, control programming, motors, solar power cells and batteries. Having solar power was also beneficial because the nearest power source was approximately one-quarter mile away.
2. They have the ability to collapse virtually out of the flow area of the structure. KDWCD found this feature to be a benefit during times when large flood releases and maximum capacity is needed.
3. The gates programming can be toggled to either control downstream flow, or upstream level. This ability gives the KDWCD the flexibility to change operations as they see necessary.

At this site, an AS2000 algorithm was used to control gates based on the flow desired in the Lower Kaweah River. This control regime then forced flow fluctuations and the large changes in flow due to peak power operations to flow down the St. John's River. To accomplish this, level sensors were placed upstream in the pool created by the diversion structures in the river, and in an existing stilling well positioned at a rated section on the Lower Kaweah River. These sensors provided the data used in the control algorithm. The gates were programmed to stabilize the downstream flow if a 100 cfs change in flow occurred, and do so within five minutes.

The KDWCD has historically operated this site, and was given control of the SCADA and gates for this site. TID was able to monitor the operations of the gates.

Rocky Ford

At Rocky Ford TID diverts water from the St. Johns River to their MIC. The MIC also brings water from TID's FKC turnout, upstream of Rocky Ford. The

MIC has a capacity of approximately 825 cfs. ITRC determined that a capacity of approximately 1,100 cfs would be needed to handle the increased flows during peak hours. As a result, choke points in the canal were modified to increase the capacity of the canal.

Two Langemann gates were also used at this site – one 11 feet wide, and the other 17 feet wide. The gates were chosen for the same reasons as at McKay's Point. At this site though, the gates would control the upstream level using an AS2000 algorithm. These gates kept the level constant over the diversion weir in the St. John's River so that flow changes could be captured by TID without impacting the downstream water users. As a safety feature, the gates can switch automatically into downstream flow control if the flow measured in the MIC downstream of Rocky Ford exceeds the 1,100 cfs capacity of the canal.

Two side-looking acoustic Doppler flow meters were used to measure the flow rate upstream and downstream of Rocky Ford. These flow meters were used because there was not enough head available to obtain an accurate flow measurement using a Replogle flume or similar flow measurement structure. The MIC is an earthen canal, so to provide a constant cross-section for the flow meters concrete lining was poured at each location. The flow meters were mounted to a shoe that slid on an I-beam mounted to the concrete lining. The design of the shoe and the slide allowed TID to remove the sensor from the canal when the canal was dry and place it back in the canal, in the same position, when the canal was in use.

Friant Kern Canal Turnout to TID

TID's turnout from the FKC needed to be monitored to ensure correct operations of the project. Since it is not uncommon for TID to take delivery of water from the FKC at the same time as they divert water from the St. Johns River, the potential existed to overtop their MIC when peak hour flow changes reached the canal. By monitoring the turnout, then KRPA and TID could determine how much water could be used for peak power generation without overtopping their canal.

North Branch Split

The North Branch Split is located in the northeast corner of TID, and is approximately 10 miles downstream of their Rocky Ford diversion. At this site, flows are split into the North Branch Canal and Main Canal. Each canal has a Parshall flume downstream of the bifurcation. TID had Stephens chart recorders in each stilling well to track the amount of water entering the District. These recorders were kept in place, but sensors were added to measure the level and flow through the Parshall flumes.

There are four existing sluice gates at the site – one hydraulically actuated, and the other three are manually operated. Two electric actuators were placed on two of the manually operated gates. Gate positions were monitored for all four gates. ITRC developed an algorithm to control the gates at this site, similar to the algorithm used at Wutchumna Ditch.

The design of the site was such that TID had the flexibility to direct the flow changes either down the North Branch Canal or down the Main Canal. Typically, the flow changes would be sent down the Main Canal to the Creamline Reservoir. However, using a toggle in the programming, the direction of the flow changes could be switched. The gates would be controlled based on the flow measured in the chosen canal.

Creamline Reservoir

Creamline Reservoir is an existing 56 acre reservoir with approximately 300 AF of storage capacity. The reservoir is divided into four cells with two on either side of the MIC. Lateral weirs and culverts connect the reservoir to the canal. The reservoir water level “floats” with the water level in the MIC upstream of the radial gate. A Littleman controller controls the radial gate movements to maintain a constant downstream flow in the MIC.

The new SCADA design updated the technology used at this site. An RTU was installed at the site to control the gate and replace the Littleman controller. ITRC developed an algorithm to control the gate based on downstream flow.

Based on information provided by TID, the existing maximum flow rate delivered to Creamline was 250 cfs, or 496 AF per day. Using the information, calculations were performed to determine if Creamline needed to be expanded. The calculations showed that if TID reduced the maximum delivery during the off-peak hours to 175 cfs at Creamline, then the full 300 cfs flow change could be absorbed at Creamline, and still meet the downstream user requirements. Figure 2 below illustrates the results of the calculations. For this project to work, Creamline would need to have at least 110 AF of storage available prior to peak flows arriving at the site.

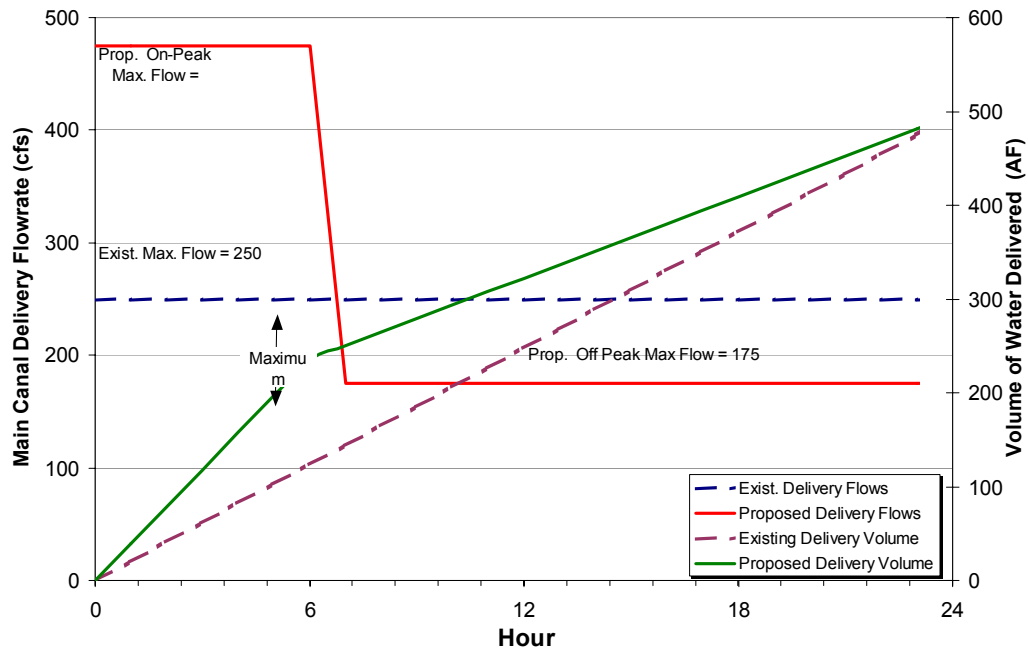


Figure 2. Proposed and Existing Operations at Creamline Reservoir.

Tagus Reservoir

In the event that Creamline Reservoir is not available to take the flow changes, TID could change the operations at the North Branch Split, and send the changes to the Tagus Reservoir. Because Tagus would be a back up in the system, the level in the reservoir was only monitored. The outlet gate was not automated.

District Offices

The HMIs for each office were designed virtually the same. The only notable difference was which office had control over which site. However, each office was able to view all of the information for each site. Each office purchased a new top-of-the-line computer dedicated to the SCADA project. Each office also purchased a laptop computer to take to the field in the event that a site's controls needed to be modified, or troubleshot.

PERFORMANCE

Upon substantial completion of construction, the various project elements were tested. ITRC was responsible to test the control algorithms, and to index and calibrate the acoustic flow meters at Rocky Ford. The flow meters were indexed using a method developed by the ITRC (Styles, et. al 2003).

Beginning in July 2004 CIC began to debug the system. After initial debugging, a 300 cfs flow change was made at the Dam to test the system. During the test, the gates generally moved as required. Some tuning was still needed though. The test identified some areas where the system needed adjustments and improvements. Over the next couple of weeks, the improvements to the HMI's were made, constants were adjusted and deadbands tightened.

In late July, tests were run again on the control sites to verify that the changes made worked. After reviewing the data from the second test, it appeared that the project was operating satisfactorily, although some minor adjustments were still needed.

CHALLENGES

The tight timeline posed serious challenges – especially scheduling contractors, getting manufacturers to produce equipment on time, debugging the systems, and obtaining access to a radio relay site. Nevertheless, through tight coordination, those challenges were overcome. The lesson learned is that it is essential to have a good project coordinator and full cooperation of the complete team.

A second challenge was to develop/implement the control algorithms and verify the degree of control that could be obtained. This project combined two very different approaches to selecting and tuning gate automation algorithms. AS2000 has a “resident” algorithm built into its package. AS2000 does not use hydraulic simulation modeling to develop and test algorithms and constants, but rather uses a heuristic approach. ITRC did provide some modeling results to AS2000 to provide an idea of the response times before the gates were installed – but the tuning requires actual field observations and adjustments. ITRC uses hydraulic simulations, combined with knowledge of gate dimensions, to develop and tune its algorithms so that they are capable of working in extreme conditions “out of the box” with minor tuning using field measurements. It should be noted that field verification is essential not only because of the algorithm tuning, but also because sensors may not be calibrated properly, there may be mistakes in programming, etc. Therefore, there is no true “out of the box” solution.

Three different entities – ITRC, CIC, and AS2000 were involved in various portions of control and the SCADA system. The HMI, developed by CIC, could not be implemented and tested until CIC received all of the register and tag number/names from ITRC and AS2000. This requires close coordination between the entities.

One of the challenges was to get everyone comfortable with various flow measurements. The districts had historical means of estimating flow rates. This project required some new flow measurement devices, and calibration of existing devices. In some cases, the SCADA-reported flow measurements did not agree

with the operators' estimation of actual flow rates, and the inclination of the operators is to just disconnect the automation because the numbers don't agree – even if the automation is working fine to maintain whatever target it is assigned. The lesson learned is that it takes several years of patient troubleshooting and talking to resolve problems and to ensure accuracy and confidence by the operators.

SUMMARY

KRPA is now able to generate more power during peak demand hours, which helps alleviate the stress on the power grid, and provides an opportunity for them to generate more revenue that ultimately helps reduce the cost of providing water to the KDWCD and TID landowners. Furthermore, TID and KDWCD both now have the backbone of SCADA systems installed in their offices. TID is beginning an aggressive program to expand automation and monitoring throughout the remainder of its system.

REFERENCES

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