CASE STUDY: PATTERSON IRRIGATION DISTRICT'S USE OF SCADA FOR TOTAL WATER & ENERGY MANAGEMENT

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ABSTRACT

Making accurate, informed operational decisions in water and energy management can have significant resource and fiscal impacts on irrigation districts. The need for accurate and reliable real-time and historical data is key in making these vital decisions. The use of every acre-foot of water and every kilowatt-hour of energy, resource management, has become the topic of scrutiny in today's world. The protection of these valuable water and energy resources, held in trust and managed by the irrigation district, on behalf of its' landowner constituents, is one of the vital functions of the Patterson Irrigation District (PID). Plant Control and Supervisory Control and Data Acquisition (SCADA) systems can provide the link between data and effective District operations and management.

This case study will outline the initial development, expansion and subsequent upgrade of the Patterson Irrigation District's Plant Control and SCADA systems, the role in data acquisition and daily district operations, the benefits the district and its water users have accrued from accurate real-time and historical data and finally, the lessons learned in the development, implementation and evolution of a state-of-the-art Plant Control and SCADA system for irrigation district use.

In its first full year of operation, 1999, historical data verified an increase of 23% in total Station #1 pumping plant efficiency on a kW-hr per acre-foot basis.

INTRODUCTION

Patterson Irrigation District holds pre-1914 water rights on the San Joaquin River which serves as its major source of irrigation water supply. The water diverted from the San Joaquin River must be pumped and lifted through a series of five – (5) pumping plants. Pumping Plant #1 at the San Joaquin River consists of seven –(7) pumps ranging in flow from 15-35 ft^3/sec (0.42 – 0.99 m^3/sec), typically lifts the water 28-35 feet (8.5-10.7 meters) and its downstream pool length is 7,300 feet (2,224.9 meters). Pumping Plant #2 consists of seven – (7) pumps ranging in flow from 11-44 ft^3/sec (0.31-1.25 m^3/sec), typically lifts the water 11-12 feet and

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its downstream pool length is 5,400 feet (1,645.8 meters). Pumping Plant #3 consists of six – (6) pumps ranging in flow from 6-44 ft^3/sec (0.17-1.25 m^3/sec), typically lifts the water 11-12 feet and its downstream pool length is 4,200 feet (1,280.1 meters). Pumping Plant #4 consists of five – (5) pumps ranging in flow from 7-30 ft^3/sec (0.20-0.85 m^3/sec), typically lifts the water 11-12 feet and its downstream pool length is 3,000 feet (914.4 meters). Pumping Plant #5 consists of four – (4) pumps ranging in flow from 7-21 ft^3/sec (0.20-0.59 meters), typically lifts the water 11-12 feet and its downstream pool length is 650 feet (198.1 meters).

Water can also be introduced into the Main Canal system from the Delta-Mendota through a concrete monolithic gravity pipeline system. This pipeline system runs parallel with the Main Canal on its north side and allows water to be added into the system at any reach or any lateral. The Main Canal supplies irrigation water to 13 laterals as shown in Figure 2.

The size of the district is 13,500 irrigated acres (4,925.2 ha) and the capacity of the main pumping plant is 180 cfs (5.1 cms). There are 772 turnouts approximately 49 miles (79 km) of open laterals and 84 miles (135 km) of pipeline sub laterals. The District has over 450 landowners and 625 water users with an average irrigated field size of approximately 20 acres (7.3 ha), with only five –(5) individual irrigated fields over 100 acres (36.5 ha). The flow rates and demands on the main canal pumping system are ever changing making it very difficult to manually operate the Main Canal pumping system for optimum efficiency and water level consistency.

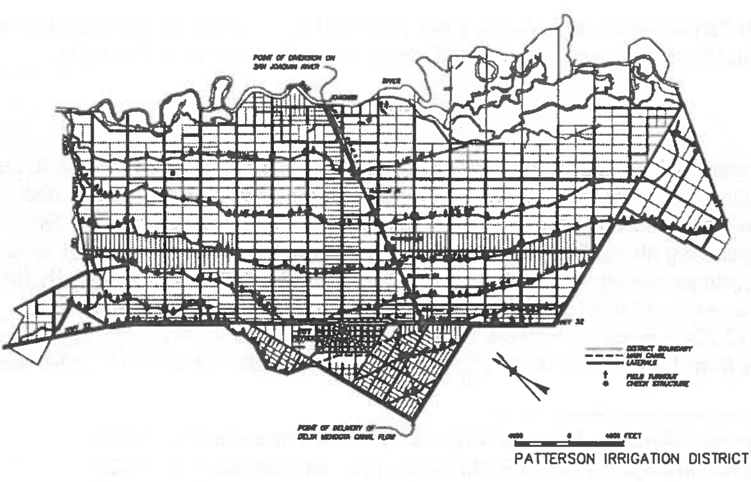

Figure 1. District layout.

INITIAL AUTOMATION FAILURE

Patterson Water District (now PID) installed a proprietary automated pump control system on its Main Canal prior to the 1996 irrigation season. The original automation scheme was never modeled for hydraulic stability, therefore it did not provide hydraulic stability. In addition, this original automation system was not scalable, did not provide for remote monitoring or control, did not gather or collect data and was not designed with readily available off the shelf parts and materials. The system was operated in 1996 and very shortly in 1997. The system flaws and short-comings created frustration with field personnel and doubt about the feasibility of automation at the Board level. Due to constant changes in water levels, pumps kicking on and off, lateral flows varying greatly, general system alarms being triggered constantly, and multiple flooding occurrences the automation system was scrapped and the pumps were once again operated manually with still no remote monitoring. Typical manual operations provided for controlling the pool depths just over the operational spills allowing 5-8 cfs (0.14-0.23 cms) to spill to the next lowest pool and be re-circulated. Although not energy efficient, this operation scheme provided the best fit between existing pumping flexibility and manual system operational errors.

CONTROL SYSTEM BEGINNINGS

In the beginning of the 1997 irrigation season District staff presented the District Board with a phased modernization plan and received the go ahead to begin modernization. The plan consisted of the District working with the Irrigation Training and Research Center (ITRC) and the United States Bureau of Reclamation (USBR) to modernize and automate key District facilities, primarily the Main Canal pumping and distribution system. The District would receive technical support and expertise from the Irrigation Training and Research Center through its contract to provide technical assistance on behalf of the Mid-Pacific Region of USBR to its water service contractors. This support included hydraulic modeling in CanalCAD and development of control algorithms for the Districts pumping plants. In addition, the District would apply for USBR grants through the Mid-Pacific Region Field Services Program. The District dedicated field and technical personnel plus significant capital resources to implement the modernization plan.

The first phase consisted of the automation of Pumping Plant #1 including a Remote Terminal Unit (RTU), Spread Spectrum Radio communications, a variable frequency drive (VFD) on the largest flow rate pump, SCADA software and a Main SCADA computer terminal at the District Office. All hardware and software utilized was open architecture, industry tested, readily available and manufacturer supported. The new RTU at the pumping plant was hard wired into the pump contactors, water level sensors, and level cutoffs. The RTU processed information, controlled pumps (including the VFD) and provided real-time

monitoring, alarms, and supervisory control at the District office. All pump control programming and logic resided in the RTU. This eliminated the possibility of a computer, radio communications or office power problem from halting or interfering with automatic system operation. The office computer terminal acted only as a monitoring and data gathering station. In the event of office system failures the worst that could happen was lack of remote monitoring as the automation system continued to work. A basic layout of the initial SCADA concept is shown in Figure 2. A key safety component of the automation system was an emergency level cutoff switch in the return canal. This switch would shut-down operations at the pump station in the event the return canal water level became dangerously high. The RTU would send an immediate alarm to the SCADA terminal notifying the District of the occurrence. The SCADA terminal would also send a text specific alarm message to alpha-numeric pagers. These pagers are carried and monitored by two District field employees at all times including weekends, nights and holidays. This would allow the District to react immediately by shutting down other pumps stations, troubleshooting the problem and getting the system back up and running quickly and safely.
In its first full year of operation, 1999, historical data verified an increase of 23% in pumping efficiency on a kW-hr per ac-ft basis with the automation of Pumping Plant #1 utilizing a VFD and a downstream controlled algorithm. This reliable control and monitoring system also allowed the District to divert pump operator personnel hours to other vital maintenance and District operational needs. Project results included money saved, efficiencies improved and a shift in labor to other pressing District system needs; thereby improving service and reducing costs to the customer.

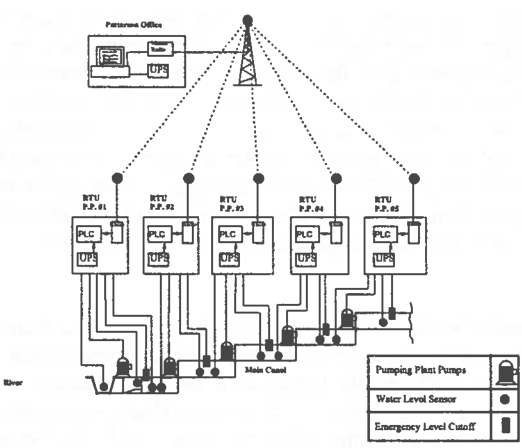

Figure 2. Plant Control and SCADA system layout.

THE INTEGRATION APPROACH

The District chose to implement the first phase of the control systems using an integrator. An integrator is a person or entity familiar with all aspects of such systems including hardware, software, communications, RTU programming, Human-Machine Interface (HMI) software programming, computer set-up, etc. An integrator was solicited to provide a cost estimate based upon a project concept and on a list of system desires and functions. In this case the ITRC helped the District find an integrator and the District, the ITRC and the integrator sat down and developed the "project scope". The District performed all the field work within its collective employee's abilities such as trenching, laying conduit, installing junction boxes, pulling signal cable and installing stilling wells and pressure transducers. District staff also learned to program the HMI software allowing the District to use its own labor for some initial programming debugging and subsequent additional system function desires. The ability to program the HMI software allowed District staff to set-up an alarming system using alpha-numeric pagers and develop data logging applications which tracked water diversions, electrical usage, pumping hours, water elevation data, pump starts/stops, etc.

The approach requires adequate technical expertise and understanding at the District level to manage all aspects of the project construction and integration. The District must also decide on the level of detail it can live with regarding project documentation such as material lists, catalog cuts, equipment and fabrication layouts and details, schematics, wiring and interconnection diagrams, software and hardware programming printouts and electronic copies, system and component test reports, operation and maintenance manuals and as-built drawings. In the District's experience adequate documentation is a key component to a successful project and system. As there are many integrators, electrical contractors, and engineering companies who service, design and upgrade these systems documentation will provide flexibility when needing additional control system services. Money and man hours saved on non-inclusion of documentation in the beginning of a project can be costly and time consuming when service, troubleshooting, component replacement, modifications, additions and upgrades are desired in the future, as somebody has to figure the system out to do anything with it.

ADDITIONAL SCADA PHASES

By using the open architecture system approach, the District was positioned to expand on its successful first phase. Prior to the 2000 irrigation pumping season, using Pumping Plant #1 as the model, Pumping Plants #2 and #3 were automated and tied into the SCADA system. With some gathering of water elevation data and continuing to work with the ITRC, the first three pumping plants were working in unison and debugged in the first couple months of the pumping season. The District continued to operate Pumping Plants #4 and #5 by hand at the plants, but there were now no full-time staff dedicated to pump operations. The pump operation duties were shared by the water department personnel.

Prior to the 2001 pumping season the District added five -(5) solar powered remote RTU sites along the Main Canal. These sites provide the District with monitoring of all the flows in main laterals coming off the Main Canal; either by 4-20 mA output signals received from McCrometer open flow propeller meters or 4-20 mA output pressure transducers reading water elevations over broad-crested weirs. By logging volume data the District can now look at individual lateral delivery efficiencies on any time basis and move toward further delivery efficiency improvements where needed. The District can also monitor flow and remotely operate its three deep wells on its main canal system and gather and store volume data for any time period reference. This reduces field personnel time needed to travel and perform these tasks as well as staff time needed to update historical diversion spreadsheets. While trenching and installing conduit and signal cable for the pressure transducers on each lift the District pre-wired for future use of gate actuators at the heads of the main laterals.

The District also added a sixth remote RTU site for monitoring and control of its turnout on the Delta-Mendota Canal. This site is 5 miles from the District office and was equipped with an old flow meter that did not have instantaneous flow reading capability. The site is now equipped with two –(2) digital display McCrometer open flow propeller meters and two –(2) Limitorque electric gate actuators. The gates can be operated both remotely and on-site and have full flow control capability. The District now has valuable real-time data allowing more precise and frequent analysis of data for water and energy management purposes without leaving the office.

The District favors the phased implementation approach for a small District like PID. This phased approach served the following needs of the district:

- Allowed the system to be implemented in stages providing maximum reliability and benefits to the district. Each stage can be evaluated and debugged before the next step is started.
- Economics – as capital costs for SCADA systems can be rather large, phasing these costs in over a period of years can provide less "sticker shock" than doing a complete, sophisticated SCADA system at once.
- Allowed the district to become familiar with the system one piece at a time
- Allowed the district to maximize its in-house personnel for installations as they became familiar with the equipment and the system from phase to phase
- Allowed the District to maintain maximum flexibility with critical site installations on an as-needed basis.

UPGRADING TO INTELLIGENT MOTOR CONTROL CENTERS

In the Spring of 2000 the District hired an electrical engineering firm to complete a system study of the District's Main Canal Electrical Distribution System. The District receives preference power from the Western Area Power Administration (WAPA) for its pumping loads along the Main Canal. The interconnection point with Pacific Gas & Electric Co., which provides transmission of the District's WAPA power, is at Pumping Plant #2. From this interconnection point the District owns its own distribution lines and wires which travel east to Pumping Plant #1 and west to service Pumping Plants #3 through #5. The study documented installed hardware, including motor control centers, power factor correction capacitors and the pole mounted transformers (installed on concrete pads on the ground) used to transform the power from 11.47 kV to 480 volts. As may be the case in many older Districts some records were not kept up as well as others. The study also looked at reliability, remaining useful life and reliability of all system components. The study clearly showed neglect and age was quickly catching up with the electrical equipment and reliability would quickly become an issue. Safety issues were also identified. Of main concern was the remaining useful life of the 1960's vintage GE Motor Control Centers, the ineffectiveness of the existing capacitors and the safety and liability issues involved with the transformer installations.

As the District is almost entirely reliant on its Main Canal electrical and water system to accomplish its water deliveries, replacing the Motor Control Centers (MCC) and the transformers were made top priorities. In developing the specifications for new motor control centers, the District expressed interest in more advanced intelligent motor control centers with soft start capabilities, a central Programmable Logic Controller (PLC) and both power monitoring and radio communications capabilities. Included in the specifications were desired documentation, warranties, standards, enclosures and bus, electrical ratings, solid state motor controller alternatives, power factor correction capacitors, circuit breakers & protectors, digital multifunction meter to monitor the incoming WAPA power, and PLC requirements. Using these specifications requests for bids were sent out to major manufacturers for replacement of the existing motor control centers at Pumping Plants #1 and #2. Bids were received from only two manufacturers. Of the bids received it was evident that the standout product and also the most cost effective was the IntelliCENTER line by Allen-Bradley, Rockwell Automation. The IntelliCENTER was a complete hardware, software and communications system fully configured and tested, as close to plug and play as we could get, a complete solution which met the District's needs as outlined in the specifications for bid. The District was sold on the IntelliCENTER's as a complete product including the communications and software which would allow integration into the Districts current SCADA system monitoring and controlling main canal operations. Considering all factors the Board approved the purchase of the IntelliCENTER's for Pumping Plants #1 and #2 in late 2000. The District concurrently awarded the contract for the MCC installations. They were installed and ready for operation prior to the 2001 irrigation season.

INTELLICENTER SOFTWARE

One of the main features of the IntelliCENTER system is the IntelliCENTER software which provides the following:

- preconfigured screens which provide MCC line-up with nameplates and indicators so users can get needed information at a glance (Figure 3)
- Individual unit views allow for easy changing of parameters to be viewed and monitoring (Figure 3)
- Allows MCC monitoring locally or remotely; using Ethernet, ControlNet and DeviceNet
- Optimized polling to ensure software system performance, real time status and historical trending
- AutoCAD documentation including unit wiring diagrams, elevation drawings and single line drawings
- User Manuals
- Event Logging such as warnings, faults and parameter edits

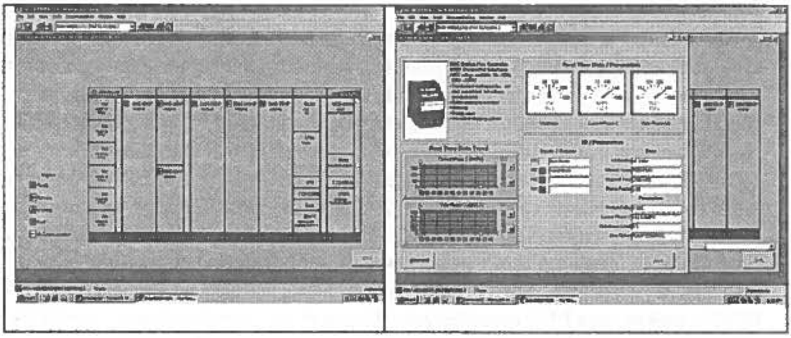

Figure 3. MCC Line-up showing nameplates, indicators and individual unit view allowing monitoring, parameter viewing and editing.

Monitoring the MCC's in real time would provide the district with real answers on a SCADA PC as opposed to locked in an enclosure in the field, such as in the event of an MCC or unit failure. This would simplify troubleshooting and minimize downtime and eliminate the need to have a dedicated electrician at the District. With the IntelliCENTER software, User Manuals, drawings, diagrams and parts lists, existing District personnel can handle maintenance and troubleshooting of the MCC's.

SCADA RTU AND MCC PLC CONNECTION

As the canal control equations and logic were still housed in the original RTU's the District was at a crossroads. Should the District move all canal control programming into the MCC PLC? This would eliminate the need for two PLC's, and the associated software knowledge maintenance requirements. As the District was comfortable with the current RTU's from the prior year and the current irrigation season was upon us, the District decided to postpone moving the canal control programming from its current RTU. It was originally intended that the digital I/O from the RTU would be hardwired to the MCC and continue to monitor and control pumps as it had prior. This would likely have been the best idea, but the District chose to have an integrator develop a cable connection and have the existing RTU poll and direct the MCC PLC for pump status and control commands via Modbus communications. As it turned out having two PLC's communicate over a cable connection was not in our best interest. There were some bugs in the new I/O addressing and Ladder Logic modifications. The District learned to live with the limitations created by this decision and knew there would be time to correct the problem after the irrigation season.

UTILIZING THE INTELLICENTER'S

Throughout the first year of operation the IntelliCENTER's proved their worth. As the year 2001 began it was clear California was facing uncertainty in the electric utility arena due to problems associated with the States deregulation of energy markets. In response to these conditions the California Energy Commission (CEC) began an energy conservation grant and funding assistance to encourage irrigation and water districts to improve efficiencies and reduce loads. The District participated in this program by testing all pumps on its main canal for pumping plant efficiency. The IntelliCENTER ability to display load information made it extremely simple, safe and quick to determine pumping loads at Pumping Plants #1 and #2. In contract it was difficult to obtain good load data at Pumping Plants #3 - #5 as hand held power meters were required using complicated procedures. There were also safety issues as the 480 volt panels had to be opened while charged and two sets of hands hand to be used to make all required connections. The poor condition of the capacitors at Pumping Plants #3 - #5 also proved a hindrance in collecting good load data, as power quality was a problem. As the District has approved the installation of IntelliCENTER MCC's at Pumping Plants #3 - #5, pump testing will be redone at those plants. Obtaining load data in the future for frequent pump testing of all Main Canal pumps will be easier, safer, more reliable and far less time consuming than in the past.

As with any complicated electrical device, the District did experience problems with individual MCC units and motors. The soft starters proved valuable in displaying fault conditions such as thermal overload, current imbalance, device status, warning status, trip history, etc. Looking up fault conditions in the user manual, helped guided District personnel through the proper procedures to get the motor back up and running or determine if there were greater problems in need professional attention. In the past if a motor were to trip, standard procedure was to reset the breaker and start it back up. Only call for help if you smell smoke or see fire. It is anticipated that the IntelliCENTER system will help the District better protect motors and electrical panel equipment by pinpointing problems that may otherwise have gone unnoticed and attending to them at the proper time – not upon complete failure.

UTILIZING INTELLICENTER'S FULL CAPABILITIES

Going into the 2002 irrigation season, the District will perform the following tasks to allow the District to utilize the complete capabilities of the IntelliCENTER's for total water and energy management:

- Install IntelliCENTER MCC's at Pumping Plant #3, #4 & #5; PLC's will be Control Logix with Ethernet Radio capabilities
- Add a Power Monitoring SCADA PC and Terminal at the Office which will run IntelliCENTER software and monitor all MCC's via Ethernet Radio communications
- Upgrade the PLC's at Pumping Plants #1 and #2 to Control Logix and add Ethernet Radios and antenna's
- Add new Modified Bi-Val Control (Proportional Integral with Filter) algorithms developed by the ITRC using CanalCAD to IntelliCENTER Control Logix PLC's at Pumping Plants #1, #2, #3, #4 and #5.

The District also had to modify its existing office network (Figure 5) for receiving of both serial and Ethernet radio communications. Ethernet communications are required at the pumping plants to make this total SCADA system effective for real-time remote operation. High bandwidth and frequent polling is required as there are 5 MCC's with 29 individual motor buckets with over 100 I/O points to monitor for each bucket. This is in addition to all the water system data being polled. The remote RTU sites will continue to communicate via Modbus (Figure 5). The original RTU equipment removed at Pumping Plants #1, #2 and #3 will be saved and used as spare parts for existing remote RTU sites or utilized for the creation of additional remote SCADA sites in the future, such as lateral spills or a proposed tailwater recovery reservoir.

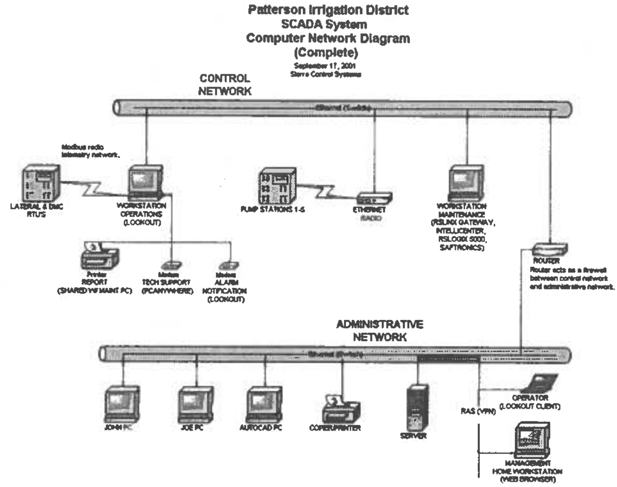

Figure 5. SCADA System Network with Firewall Router

SUMMARY

This paper documents the development of a Plant Control and SCADA Systems using a phased approach. These systems have changed the way water distribution systems can be run and automated the once manual arduous task of gathering vital field data used to make resource management decisions. In this case a Plant Control and SCADA system integrated into an intelligent motor control center, combined with the technical expertise to develop effective downstream canal control algorithm's, has proved to modernize a small irrigation district, improve distribution system operational efficiencies and help it manage its resources. The remote monitoring functions of SCADA also allow for real-time reaction to system malfunctions and shut-downs which in the past may have gone un-noticed.

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