Power Management and Automation Scheme for Water Canal Networks

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Abstract—**Most of the technological emphasis in power and energy automation focuses on improving the safety of operations and the efficiency of the generation, transmission, and distribution of power. However, injuries, unscheduled downtime, and loss of productivity are also concerns that drive the urgency to modernize the consumption of power as part of industrial processes. As an example, the reduction of faults and defects in power distribution that cause interruptions in water delivery systems significantly improves personnel safety, process efficiency, and, as a result, agricultural yields.**

Water solutions include flow differential and overflow prevention, similar to the line current differential and overcurrent schemes used in power systems. Water canal control automation systems must simultaneously and precisely monitor and control the flow of both the water and the power required for water delivery. To achieve this objective, more efficient and intelligent automation solutions for water conveyance applications are required. The devices, logic algorithms, and communications of automation systems are no longer limited to process-specific choices. Modern solutions combine process and power management for efficient energy utilization and new data and services that are invaluable inputs to the safety and efficiency of process automation. This is an obvious benefit to the many utilities that manage water and power systems in parallel. Combining the protection and automation of both processes into one system provides better decision-making information, ease of operation, and lower costs. At the same time, revolutionary new process management becomes available via the integration of knowledge and the control of the power delivery system driving the industrial processes. This combined process of power management and automation is now accomplished with the same smart, robust, and multifunctional automation technology presently performing the protection and automation of utility and industrial power systems.

This paper describes the benefits of applying multifunctional technology to water canal control automation systems. Similar to a power distribution application, standardized logic and communications protocols and rugged devices are used to monitor and control water flow while also managing power necessary for the process. Precise and dependable control systems protect personnel from electrical faults and equipment malfunctions. As a result, the process is safer, more reliable, and economical to operate. Also, the downtime of the system is reduced significantly. The secure communications scheme maintains the confidentiality of the data while also providing a reliable link between the remote sites and the centralized control console. The backup power features ensure scheduled on-time delivery of water and fail-safe operations during power outage conditions. The solution also incorporates BLUETOOTH® communication to provide an inexpensive and flexible human-machine interface (HMI) and diagnostic operator interface via portable laptop and tablet applications. This redundant operator display is separate from both the local HMI and the centralized supervisory control and data acquisition (SCADA) system. The solution exchanges decision-making information among monitoring, control, and operator sites to automatically and precisely react to dynamic real-time variations in the water system. This is a dramatic improvement over the presently used legacy methods of isolated devices following fixed algorithms with no information from neighboring sites.

I. INTRODUCTION

Water is the most important natural resource and has great social, economic, and environmental value. Everything we use in our daily lives has a water footprint in it. For example, the electricity we generate, paper we use, food we eat, and clothes we wear all depend on water. The variability of rain and changing weather conditions have resulted in water scarcity in more and more parts of the world, as evidenced by changes in snowpack, sea level, and river flow. For example, the northeast region of the Iberian Peninsula near Girona, Spain, has experienced extreme drought in recent years [1]. And the countries in West Asia and North Africa will soon be diverting water from irrigation to supply industrial and domestic needs [2]. A series of droughts and water crises in several parts of the world has reinforced the importance of the efficient management of water resources that flow through open channels. According to a survey conducted by researchers at the University of Twente in the Netherlands, agriculture accounted for 92 percent of the average global water footprint from 1996 to 2005 [3]. Aged irrigation water delivery systems are based on traditional methods of human intervention and imprecise monitoring that result in a massive loss of water due to unnoticed channel seepage and blockage. Accurately monitoring and controlling the flow of water are fundamental to the efficient management of water resources.

Because of the dynamic nature of water flow, water delivery cannot be controlled on the basis of a fixed equation. Rather, real-time, intelligent control systems are required. Water distribution control is like electric power distribution control in that it is greatly improved when system-wide communication and automation are added.

In the past, closed-loop protection and control strategies for electric power systems were isolated to networks of collocated intelligent electronic devices (IEDs) where communication permitted quick data exchange for control and feedback. Now, distributed communication and automation controllers provide closed-loop automation of the entire electric power distribution system. Water distribution systems can be automated and improved in the same way with similar technology. With the use of rugged, high-speed automation controllers and dependable wireless communication, water distribution is being modernized to be more capable, efficient, precise, and dependable. Standalone flow sensors and gate controllers are enhanced with closed-loop automation logic that is dependent on communication among the main intake and delivery turnout gate structures. Data from real-time operations and infrastructure diagnostics and health information are collected, analyzed, automatically acted upon, and presented to the operator. Therefore, from the perspective of automation engineers, there is great similarity between the operational control of the flow of water and the flow of power.

This paper describes how existing technology developed for the safe, reliable, and efficient transportation of power can be used to measure, monitor, and control the flow of water through open channels. Most of the advancements in the agricultural sector in regard to automation have been made in improving the processes of plowing, harvesting, and processing crops. This paper provides a modern-day perspective into the efficient management of water and power resources as an agricultural process. This paper discusses the following:

- A conventional flow monitoring and control system.
- An analogy of the water system to the power system.
- A dynamic, efficient, and multifunctional automation system for the monitoring and control of water flow through open channels and the associated power consumed by the process.
- How radios in a dual-ring loop topology allow a differential water flow calculation, similar to a differential current calculation.
- The high-speed detection of channel leakage, overflow, and blockage conditions.
- The featured benefits of a modern water delivery solution.
- Future research opportunities that include the optimization of water and energy usage in fields by combining climate information, soil water content information, real-time water usage metering, and the reduction of operational costs by improving the process for mixing fertilizers by providing the ability to mix fertilizers at the water delivery sites.

II. CONVENTIONAL FLOW MONITORING AND CONTROL SYSTEM

Traditional flow monitoring in open channels has been done by monitoring water levels (stages) using a staff gauge as a surrogate. A stage-discharge relationship is developed by using periodic discharge measurements at the site over a range of water levels and time to develop a rating curve. For sites with variable backwater, such as irrigation gate control systems, no reliable stage-discharge relationship can be developed. At these sites, a velocity-index relationship is typically used. A velocity-index relationship is provided by a cross-section survey between the stage and cross-sectional area [4]. Based on the discharge measurements, a flow equation corresponding to the geometry of a specific open channel is developed that provides an approximate flow rate corresponding to the different water levels in an open channel. The irrigation gate position is adjusted manually to compensate for the required target flow by rotating the wheel on top of the gate. The efficiency of the system is very dependent on accurate discharge measurements and precise geometrical calculations for the open channel.

The discussed methods have several shortcomings, such as the following:

- Inefficient flow calculations due to static and asynchronous water monitoring processes.
- Required periodic site visits to calibrate the gate position for the required flow rate.
- Undetected water loss through the open channel due to channel leakage.
- No remote access to monitor and control the site.

These shortcomings not only result in inefficient water resource management but also increase the operational costs. Undetected flood conditions in the open channel result in damaged crops and roads, which have an impact on safety and economics.

Fig. 1 shows a conventional irrigation gate control system with a rotating wheel to control the gate opening and therefore the flow through the open channel.

Fig. 1. Conventional Open Channel Flow Control System

Considering the increasing demand for freshwater resources and the need to sustain agricultural production at current levels, there is an increased need to better quantify channel flow. There is also a new demand to quantify flow in smaller channels, such as irrigation turnouts. With the development of Doppler-based flow sensors and the advancement of automation systems over the past decade, great improvements are now possible to make water flow monitoring and control efficient, economical, and predictable.

III. ANALOGY TO THE POWER SYSTEM

If we compare open channel waterways to electrical transmission and distribution lines, then the water flow measurement could be considered analogous to the measurement from a current transformer. Water flow is measured as the amount of water that flows past a point over time—the flow rate, *Q*. Electrical flow in a wire is measured as the amount of charge that flows past a point over time—the charge flow rate or current, *I*. In this analogy, an open channel acts as a conductor, similar to a distribution feeder, responsible for transporting the current (water flow) from Point A to Point B. Water gates used to manipulate the flow of water from the upstream side (the side with the higher water level) to the downstream side (the side with the lower water level) act as distribution transformers. In power systems, voltage on the low-voltage (downstream) side is manipulated by changing the number of windings (gate position) on the transformer (irrigation gate) via a load tap changer (LTC). Similarly, open channel water flow on the downstream side is controlled by manipulating the height of the gate opening.

Additionally, the relationship between the water flow, water level, and channel is similar to the relationship between the electrical current, voltage, and conductor. As we discuss in Section VIII, overflow conditions are avoided and/or monitored by calculating the channel flow differential to mitigate the risk of flooding by manipulating the water flow upstream (intake). Close similarity between the two processes allows us to apply the automation and communications technology invented for the power industry to modernize the water flow control application.

IV. TYPICAL SYSTEM REQUIREMENTS

Some irrigation districts are modernizing their aging water conveyance systems and have started using available technologies to monitor and control the water flow through open channels. The requirements and functionality of a typical water control system include the following:

- Continuous water flow rate monitoring.
- Upstream and downstream sensors for differential head calculation.
- Local and remote monitoring and control of open channels.
- A centralized supervisory control and data acquisition (SCADA) system for operator control and report generation.

These requirements parallel power system remote SCADA methods developed decades ago.

V. ENHANCED SYSTEM CAPABILITIES

Because flow control sites are installed in open fields, they are exposed to extreme temperature conditions. Most of the present control hardware used in the water industry does not meet the environmental requirements in certain parts of the world. Because the power industry has higher safety, reliability, and performance requirements in comparison with the water industry, flow control applications are revolutionized by using the rugged technology developed for the power industry. Power automation information and control technology (ICT) networks support advanced local processing as well as communications-assisted, closed-loop, wide-area control. Also, the power industry product features, such as rugged hardware, extended temperature range tolerance, and extended product life, drastically improve the reliability of water control operations because flow control sites are subjected to the same environment conditions and physical standards. Moreover, general industry attributes, such as excellent technical support and an extended warranty on products by manufacturers, provide a new higher level of support than is presently available in the relatively unorganized water automation market.

The analogous operation of power and water will bring constant innovation to the irrigation water industry. The previously described factors will also bring functional enhancements to the system, such as the following:

- Local and remote acquisition, storage, and display of energy consumption information for the underlying process.
- Automated flow control of a user-defined target flow rate in the canal using the IEC 61131 capabilities of controllers.
- Secure and reliable communication to the centralized control system as well as among monitoring and control sites.
- Enhanced water conveyance operations with high-speed detection of channel leakage, seepage, and blockage via channel flow differential similar to current flow differential.
- Open channel flood prevention similar to overcurrent and overvoltage protection in the power system.
- Redundant data display on operator consoles, tablets, and smartphones.

VI. SYSTEM DESCRIPTION

For the efficient management of water resources, we propose a water flow control system that incorporates enhanced system capabilities. The proposed system consists of irrigation gates equipped with electrical actuators. The actuators are integrated via various digital and analog inputs and outputs, such as gate status, gate position, gate control, and so on, to the I/O interface of an on-site automation controller with communications and IEC 61131 logic capabilities. The automation controller performs water monitoring using a flow sensor or differential level measurement and power monitoring by measuring the real-time currents and voltages in the process equipment. The user interacts with the system in numerous modes via a centralized SCADA server, local operator interface terminal (OIT) display, local annunciator light-emitting diodes (LEDs), or manual switches. Each site is equipped with a BLUETOOTH® interface to provide on-site wireless monitoring via a laptop, tablet, or smartphone. The BLUETOOTH capability reduces the time spent in the field by quickly providing simple monitoring of each site. It also improves personnel comfort and safety during extreme temperatures and at dangerous locations because the field devices can be accessed by a technician from inside a service vehicle.

The SCADA and remote access system communicate over serial radios operating over an unlicensed frequency spectrum (900 to 928 MHz) to provide secured data acquisition to the centralized control system and engineering workstation. The system redundantly logs data in the automation controller as well as in the centralized SCADA server. These data are easily retrieved and viewed.

Fig. 2 shows a flow control station panel enclosure.

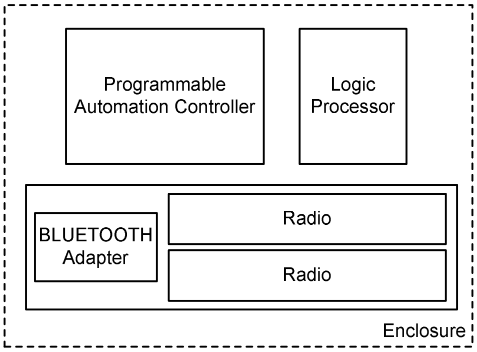

Fig. 2. Flow Control Station Panel Enclosure

The system has dual-layer redundancy at the hardware and software levels, which ensures fail-safe operations. Multifeatured devices support the flexibility of hardware and software redundancy to accomplish specific tasks in numerous ways, therefore increasing the overall reliability of the control system. The redundant operations are indicated in Table I.

TABLE I
SYSTEM REDUNDANT OPERATIONS

Functionality	Primary Component	Redundant Component
Data acquisition	Primary level sensor	Secondary level sensor
Data display	OIT, human-machine interface (HMI), front-panel annunciator LEDs	Tablet or smartphone
Data storage	Automation controller	Centralized server
Alarm	OIT, SCADA, front-panel annunciator LEDs	Mobile phone multimedia messaging (MMS) or email

VII. COMMUNICATIONS TOPOLOGY

Modern ICT systems rely extensively on communication for the discrete elements of the control system to collectively accomplish specific tasks. Because of the critical functions performed by control systems, great care must be taken in regard to security, reliability, dependability, and availability while designing the communications scheme. The proposed system provides redundant or backup communication for SCADA data using multiple channels on radios. The sites communicate in a dual-ring topology, as shown in Fig. 3. The first ring provides peer-to-peer communication among various sites and uses the MIRRORED BITS® communications protocol because of the advantages of low latency, low cost, and simple direct data exchange [5]. An important feature of this peer-to-peer MIRRORED BITS communications protocol is that it constantly sends data both directions around the ring. This ensures fast, redundant delivery of all information and correct operation, even in the event of a device or link failure. The second ring serves as a dedicated channel for SCADA communication and uses the DNP3 protocol because of its advantages of low message overhead, event buffering, and time-stamping of data records [6].

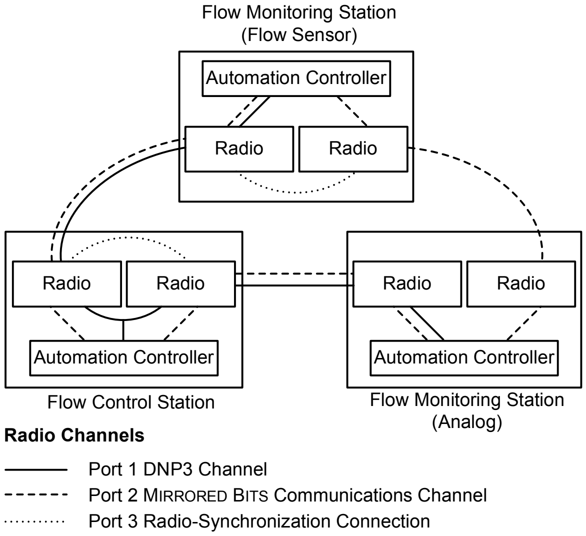

Fig. 3. Dual-Ring Topology

There are numerous advantages when using the dual-ring topology, including the following:

- Multiple channels between sites provide dual-ring redundancy for more reliable communication and no single point of failure.
- Every site has equal access to the resources, resulting in a more flexible network and more sophisticated automation.
- The data load between sites is shared over multiple channels for consistently enhanced performance and data flow balancing.

Simultaneous measurements and the exchange of flow data from multiple sites support the innovative calculation of channel flow differential. Channel flow differential calculations have the following advantages:

- They dynamically measure and record seepage as a channel characteristic for different water levels. Typical seepage reflects “charging” the channel at a certain water level prior to supporting flow.
- They detect a mismatched flow rate between interconnected open channels to help in the early detection of faults, such as atypical channel leakage and channel blockage.
- They enable the efficient transportation of water through open channels.

The dual-ring communication allows independent, rapid, redundant peer-to-peer communication for innovative automation and closed-loop algorithms while also supporting centralized SCADA and engineering access.

VIII. TERMINOLOGY AND CONTROL ALGORITHM

Like every industry, the water industry has its own terminology. Even though processes are modernized with time, old terminology remains because of the convenience of understanding that has developed over time among operators and technicians. The terminology encountered during flow control applications is as follows:

- Differential head is the difference between upstream and downstream level sensors.
- Upstream is the direction of the open channel against the flow.
- Downstream is the direction of the open channel with the flow.
- Backflow is when water reverses direction downstream.
- Target flow is the required flow rate at turnout.
- Cubic feet per second (CFS) is the unit of flow of water.
- Flow rate is the amount of water flowing through the channel in CFS.
- Flow error is the difference between the current flow rate and the target flow rate.
- Gate error (in feet) is the difference between the current position and target position of the gate.
- Acre-foot is the volume of water in an acre of surface area with a 1-foot depth.
- Totalized volume is the volume of water over a period of time in acre-feet.

The on-site logic processor monitors the analog signal from a level sensor and calculates the average flow rate within a fixed time interval because water flow is very turbulent and there are inaccurate peaks in real-time raw flow data.

The gate error is linearly related to the flow error. Ideally, the gate error and flow error should be zero, except when a gate is changing position. However, considering the percentage tolerance in all mechanical components, the gate error is near zero. In manual mode, gates wait for the user command to adjust their position. While in automatic operation mode, a non-zero flow error results in the automatically commanded movement of gates in a particular direction.

Electrical actuators are an obvious choice to be used with irrigation gates because they require less maintenance and are more reliable than hydraulic and pneumatic actuators. Water delivery depends largely on reliable power delivery for these actuators. Interruptions in power delivery deteriorate the delivery of water to the fields. The proposed system includes the logic for metering power based on appropriate current and voltage measurements. Various alarms related to power, such as power failure, phase failure, and overcurrent detection, are included to make the application safer and more reliable and protect equipment from damage. For example, the loss of a single phase to a three-phase motor can result in excessive heat in the motor windings prior to the thermal overload detection because it is drawing all its current from the remaining two lines. Also, attempting to start a three-phase motor on a single phase can cause the motor to draw locked-rotor current, and the motor will not start.

A. Channel Flow Computation

IEC 61131-based controllers provide high-speed and precise computation of flow rates and flow control algorithms. Irrigation delivery channels are small in size, making it hard to install Doppler-based sensors. To achieve the required precision in flow measurement, upstream and downstream sensors can be used to calculate flow based on differential head by using a flow equation.

A typical delivery measurement site will have a submerged flow orifice equation such as (1).

$$Q = C_d \bullet A \bullet C_c \bullet H^{0.5} \tag{1}$$

where:

Q is the flow rate in CFS.

C_d is the channel discharge coefficient (dimensionless).

A is the orifice area in square feet. A = OW • OH, where OW is the orifice width in feet (assigned through OIT or SCADA) and OH is the opening height in feet (measured by a string pot or potentiometer).

C_c is the equation constant for the particular type of site or channel.

$H^{0.5}$ is the head differential in feet for submerged flow. *H* is the difference between upstream and downstream levels [7].

The corresponding flow computation logic in structured text is shown in Fig. 4.

```
//Calculates flow using the orifice equation
Diff_Head := (AVG_US_LEVEL-AVG_DS_LEVEL); //Differential head calculation
IF(Diff_Head < 0 OR Diff_Head = 0) THEN //If upstream level is less than downstream level
        QVALUE :=0; //Zero flow condition
         AL_Diff := TRUE; //Set low differential head alarm
ELSE //Compute flow using orifice equation
QVALUE:= Dis_Coeff*(GATE_WIDTH)*(GATE_POS)*(Eqt_Var)*EXPT(Diff_Head, 0.5);
AL_Diff := False; //Sufficient differential head
END_IF
```

Fig. 4. Flow Computation Logic

The following are definitions of the terms used in Fig. 4:

- Diff_Head is the differential head.
- AVG_US_LEVEL is the average level from the upstream side.
- AVG_DS_LEVEL is the average level from the downstream side.
- Dis_Coeff is the discharge coefficient.
- GATE_POS is the present opening of the gate.
- GATE_WIDTH is the width of the gate.
- AL_Diff is the low differential head alarm.

Table II defines some various operation modes.

TABLE II
SYSTEM OPERATION MODES

	Local Mode	**Remote Mode**
Automatic Mode	Logic processor	Logic processor
Manual Mode	Manual switch, OIT	SCADA screen

B. Channel Flow Differential

Kirchhoff's current law states, "The sum of the currents entering the junction must equal the sum of currents leaving the junction. Thus, the algebraic sum of all the currents at a junction is zero" [8]. We use the same law during running water conditions through the network of open channels. We can state that the sum of water flowing into a network of open channels is equal to the sum of water flowing out of the network of channels. If the water flow rate differs by more than the expected water loss, such as from typical seepage, that indicates channel blockage, seepage, or failure and generates an alarm.

Fig. 5 depicts a T-shaped network of open channels. The three sites shown in the figure communicate with each other as well as with the centralized server. This closed-ring communications topology allows high-speed detection of faults.

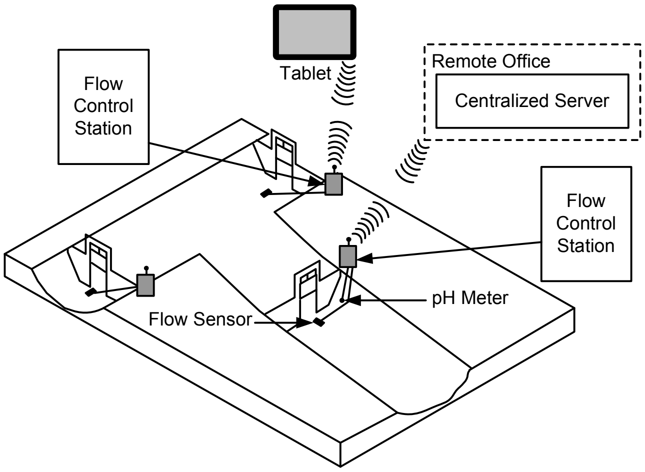

Fig. 5. Complete System Overview

IX. SYSTEM FEATURES

The proposed solution provides much more functionality than existing water management solutions.

A. Monitoring

The parallel real-time monitoring of water and power is performed. This provides more visibility into the health of the system and helps in the early detection of faults in the power delivery system. Newly available high-accuracy water flow calculations enable high-speed fault detection in the water conveyance system.

1) Water Consumption Monitoring

The system monitors the real-time flow rate of water through the channel using the differential head from upstream and downstream level sensors. It calculates and logs flow daily, monthly, and annually for historical water delivery trending.

Differential and overflow calculations provide an early warning of the poor health of instruments or the failure of a channel.

2) Power Consumption Monitoring

The system continuously monitors the power drawn by the actuators and provides the opportunity to predict or detect mechanical problems, improving the reliability and safety of operations. Also, unexpected continuous power consumption by a motor is used to create a malfunction alarm.

B. Control

A closed-loop control operation is performed by the system to precisely manage the flow of water and power. This helps reduce the waste of water resources while optimizing the power consumed.

1) Water Flow Control

The system controls the flow of water by controlling the position of the water gates based on the commands given by the user or based on the flow error while running in automatic mode. Moreover, it detects the failure, leakage, or blockage of the channel.

2) Power Flow Control

The system continuously monitors the power consumed by the actuators and provides the opportunity to reduce power consumption by optimizing the number of active gates for low flow conditions. This results in less wear and tear on mechanical components and reduces maintenance costs.

C. Scheduling

1) Automated Water Delivery Schedule

The system automates water flow throughout delivery turnouts in a particular region. The system automatically adjusts the irrigation gate positions after fixed preprogrammed intervals to achieve the target flow rate. Each change notification is sent to the irrigation authorities and user.

2) *Demand-Based Water Delivery Schedule*

The system data are accessed over a secured website, which provides the ability for farmers or users to log in with proper credentials and vary the water delivery based on their requirements. This demand-based water delivery system results in smooth operations with minimal user interference.

3) *Water Delivery Contract Compliance*

Precise water flow calculations at the upstream and downstream sides support previously unavailable delivery and contract comparisons. Even in instances where the upstream gate is controlled by another district, a monitoring station with these same features and accuracy can be installed. Consistent, precise, and accurate reading of water flow at every gate supports the validation of water delivery into and through the system and the comparison with contractual obligations.

X. SYSTEM BENEFITS

Apart from the technical benefits, such as remote access and accurate energy and water metering, the system features provide long-term economic benefits. The system is also helpful in the following ways:

- Revenue metering. Energy metering at all sites helps managers calculate the costs associated with water delivery operations. Knowing the operational cost improves overall operational efficiency by identifying the least efficient sites and equipment.
- Asset management. The system provides more visibility into the application, which helps users in predicting and detecting the probable failure nodes.
- Maintenance scheduling. The detailed continuous monitoring of the application supports better maintenance scheduling, thereby improving the safety of water operators. Also, equipment is scheduled for maintenance or replacement when not in service.
- Decision making. All of the benefits provide top-level management for faster and more effective decisions based on statistical analysis.

XI. FUTURE OPPORTUNITIES

Further enhancements are available using additional advanced hardware and software capabilities in the IEDs developed for the safe, reliable, and economical delivery of electric power. Potential sophisticated canal automation enhancements include but are not limited to the following:

- Climate and rainfall information via weather stations.
- Soil water content via moisture sensors.
- Water quality via oxygen and pH sensors.
- Crop health via on-plant sensors.

To counter the impact of increased cost due to sites with time-of-use-based charging methods, water flow can be scheduled during off-peak times. Additionally, sites with substantial differential head can be integrated with microhydrogeneration turbines, which can make water control sites self-sustainable and potentially provide power back to the grid.

Large amounts of money are invested in spraying fertilizers using small planes. That cost can be eliminated by mixing fertilizers in the water at the delivery point. This economical and efficient method provides more targeted delivery of fertilizer and the potential to detect and manipulate the optimal amount to be delivered.

XII. CONCLUSION

In order to enhance the performance of existing open channel water delivery systems, irrigation districts must understand the future challenges of increasing water demand, stringent regulations, and time-of-use-based charging methods for the power consumed. The automation solution for the simultaneous management of power and water that this paper describes realizes significant system benefits over conventional flow monitoring and control methods. The advanced automation solution improves the safety, reliability, and controllability of the flow of both water and power consumed by the process.

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XIV. BIOGRAPHIES

David Dolezilek received his BSEE from Montana State University and is the research and development technology director of Schweitzer Engineering Laboratories, Inc. He has experience in electric power protection, integration, automation, communication, control, SCADA, and EMS. He has authored numerous technical papers and continues to research innovative technology affecting the industry. David is a patented inventor and participates in numerous working groups and technical committees. He is a member of the IEEE, the IEEE Reliability Society, CIGRE working groups, and two International Electrotechnical Commission (IEC) technical committees tasked with the global standardization and security of communications networks and systems in substations.

Amandeep Kalra is an automation engineer with Schweitzer Engineering Laboratories, Inc. (SEL) in Pullman, Washington. He has over three years of experience in developing and marketing system-level solutions for the water and wastewater industry, including pump station automation, canal automation schemes, and communications systems. Amandeep worked as a consultant in various technical roles for irrigation districts throughout California and obtained his EIT certification before joining SEL. He has a bachelor of technology degree in instrumentation and control engineering from the National Institute of Technology, India, and a master’s degree in electrical engineering from California State University, Northridge.

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