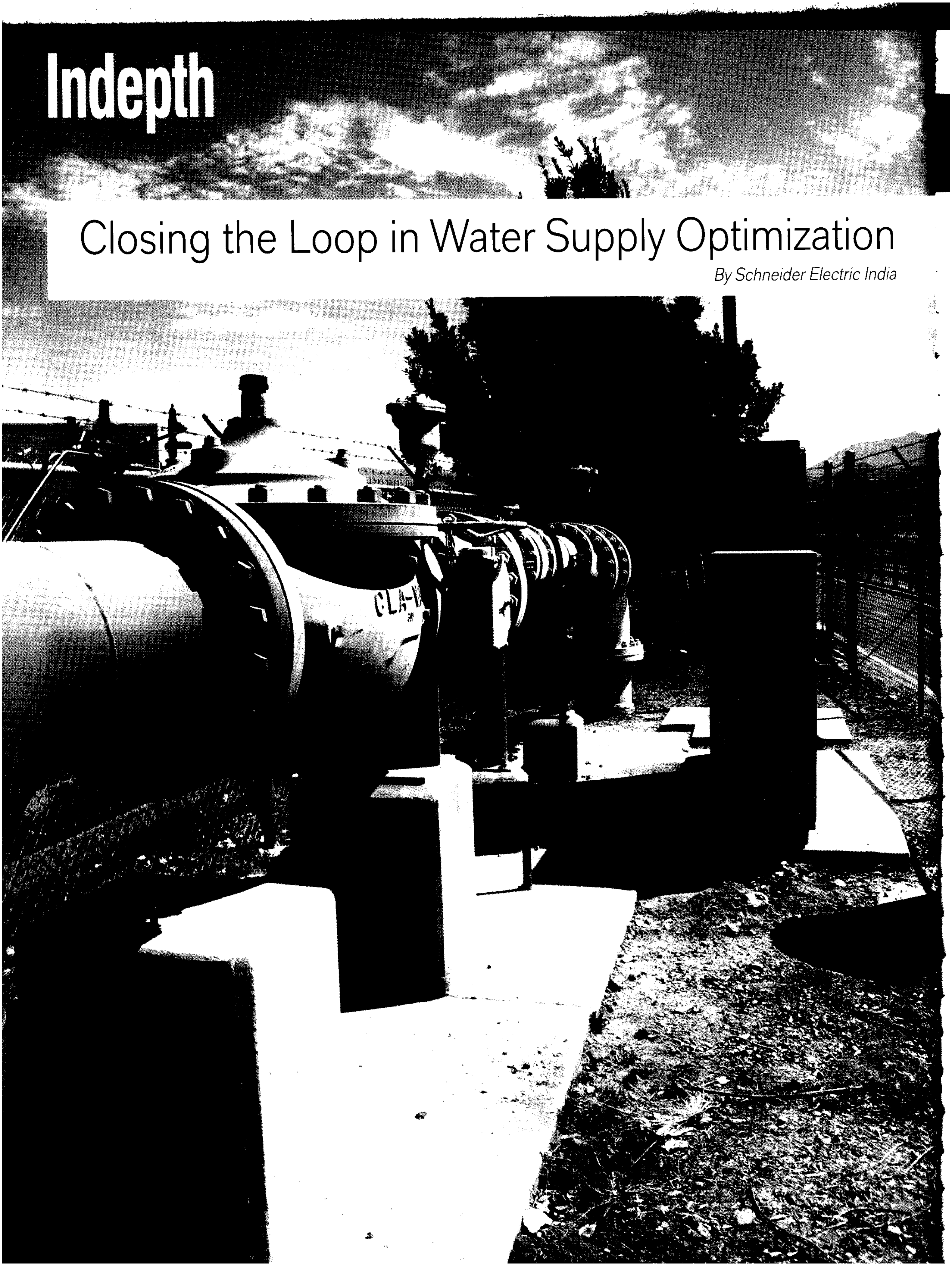
Closing the Loop in Water Supply Optimization

By Schneider Electric India



Large investments made in automation & control systems by water utilities over the last 20 years has produced necessary infrastructure for global optimization strategies.

Introduction

Implementation of sophisticated SCADA systems in the water industry has given plant operators unprecedented capability to monitor and control all aspects of water production & distribution from a centralized control centre. Sophisticated utilities recognize that SCADA need not be composed of one or more isolated 'islands of automation' but can and should be a single system operating on a Wide Area Network, and integrated into their enterprise wide information technology system. The next logical step following implementation of a SCADA system is to leverage off this investment using state of the art software to allow predictive as opposed to reactive control of water system. Resulting benefits can include improving water quality through reduced water age, minimizing energy costs and improved system operations without compromising operational reliability. This article discusses where innovative optimization software has significantly improved operation and achieved rapid pay-back through energy cost savings.

Since the mid 70s automation has made inroads into the traditionally manually controlled processes of treatment and distribution of potable water. Prior to the 70s most treatment plants used simple alarm lamp panels, dial gauges and panel displays such as circular chart recorders as an adjunct to manual operations. Later smart instruments and analyzers such as turbidity meters, particle counters and pH meters were introduced. These could be used to drive chemical dosing pumps to maintain consistent delivery standards. Eventually fully automatic operation of treatment plants using PLC or Distributed Control Systems arrived in the early 80s. As the technology improved so did the control processes. An example of this is the use of streaming current meters as a secondary control loop behind the primary flow pacing for coagulant dosing. A consistent problem was that the thinking derived from individual instruments continued to persist in the industry. Control was still designed as if one or more physical instruments were to be wired together to drive a single output variable. The true power of the PLC is the ability to combine large quantities of digital and analogue data and produce algorithms of greater complexity than can typically be achieved through combinations of single instruments.

Having achieved a level of sophistication at the treatment plants it was natural to carry on and try and achieve the same level of control in the distribution system. The early development of telemetry was fraught with the problems of low data transmission speed, high latency, and the unreliability of radio or leased line communications used. This is still a problem today, but has largely been overcome through the use of high reliability packet switching networks or ADSL connections for the telecom's wide area network. All this does not come cheaply, however investment in a SCADA system is a necessity for a water utility, few would consider trying to operate without one. It can be difficult to provide cost payback justification for the considerable expenditure required to install a SCADA and telemetry system, however, in reality there is little alternative. Labor reductions through the use of a centralized pool of skilled staff to control widely distributed system and the ability to monitor and control quality are two of the most common justifications used.

Just as the installation of the PLC in a treatment plant provides the framework to allow advanced algorithms to be produced, the implementation of a widely distributed telemetry and SCADA system allows far more sophisticated control of water distribution. Indeed system wide optimization strategies may now be incorporated into the control system. The field-based Remote Telemetry Units (RTU), the telemetry system, and control systems at the water treatment plant can work in unison to unlock significant cost savings and other benefits for water utilities. Significant progress has been made in the areas of water quality, system security, and energy efficiency. As an example research is currently being carried out in the United States to look at real-time responses to terrorist attacks using live data and instrumentation in the distribution system.

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Distributed or Centralized?

Instruments such as flow meters and analyzers can be quite sophisticated in their own right and capable of running complex algorithms using multiple variables, and with multiple outputs. These are in turn attached to PLCs or smart RTUs who are capable of highly complex supervisory control. The PLCs and RTUs are themselves connected to a centralized control system typically located in water utility's head office or at a large treatment plant. These centralized control systems can comprise of a large PLC and a SCADA system, each of which is also capable of running very complicated algorithms.

The question then is where to locate any intelligence or indeed whether it is worthwhile replicating intelligence at multiple levels. There are advantages in having localized control at the RTU level, in that this makes the system relatively immune to loss of communications from the centralized control server. The downside is that the RTU is only aware of localized information. An example may be a pump station, which does not know the level of the tank it is pumping into the level of any fore bay it is pumping from.

On system wide scale, individual algorithms at RTU level may have undesirable consequences at treatment plants, such as requesting too much water at inappropriate times. A global strategy is desirable. Therefore, it seems best strategy is to have localized control to at least provide basic protection in case of loss of communications, and still allow centralized system to make global decisions. This idea of using cascaded layers of control and protection seems to offer the best of both worlds. The RTU controls can lay dormant, triggered only by unusual conditions or loss of communication. A secondary benefit is that relatively dumb RTUs can be used in the field since they are only required to run relatively simple operational strategies. Many utilities installed RTUs in the 80s, when relatively low-cost 'dumb' RTUs were the norm.

The framework is now in place, but little has been done to achieve system wide optimization until recently. Derceto® Aquadapt is a real-time supervisory program that attaches to a SCADA system to automate a water distribution system. It reads live data from the SCADA system on current storage levels, water flows and equipment availability and then creates schedules for treatment plant raw and finished water flows and all pumps and automated

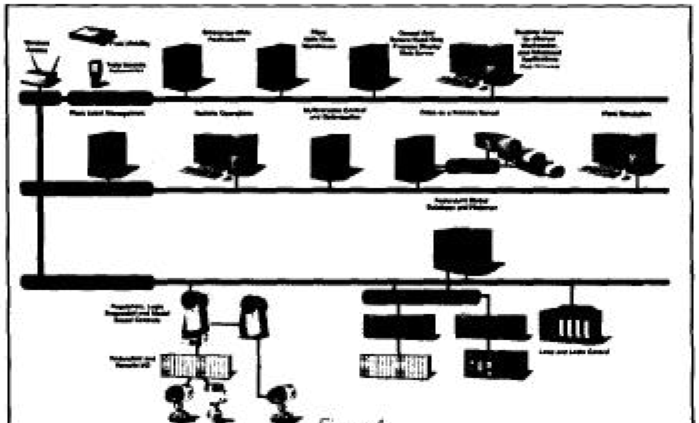

Figure 1

Figure 2: The Aquadapt Operator Panel,
a Thin Client GUI Which Can Run Across Low Bandwidth WANs

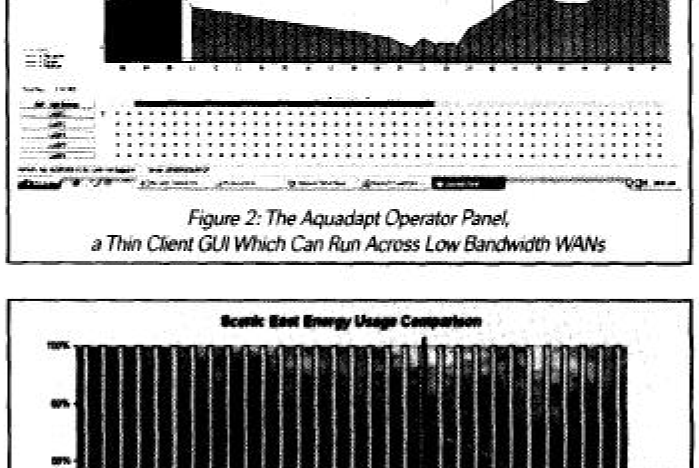

Figure 3: Make Up of Energy Prices at East Bay MUD Before and After Aquadapt

valves in the system for the next 48 hours. It achieves this in less than two minutes. Every half an hour it runs again to adapt to changing conditions, primarily demand changes and equipment failure. Controls are automatically initiated by Derceto allowing for fully automated unattended operation of even very large distribution systems. The primary goal of Aquadapt is to reduce the cost of distributing water, primarily the energy cost.

The Optimization Problem

A great deal of research and effort has gone into solving the problem of scheduling production, pumps and valves in water distribution systems. Most of this effort has been confined to academia although there have been a few notable attempts to create a commercial solution in the market place. In the 90s a group of US utilities got together to promote the idea of an Energy and Water Quality Management System (EWQMS) under the auspices of the AWWA Research Foundation. This project led to a number of trials including two companies working with EBMUD and a Nevada water system amongst others. The Water Research Council (WRC) in the UK explored similar approaches in the 80s. However both the US and UK were constrained by the lack of control systems infrastructure as well as the lack of commercial drivers in the industry therefore unfortunately none were successful and all have been subsequently abandoned. There a few add-on packages for commercial hydraulic modeling programs that use evolutionary genetic algorithms to allow a competent engineer to make informed design decisions but none of these can claim to be targeting automatic real time control of a distribution system. The rewards of getting it right are huge:

The more than 60,000 water systems and 15,000 wastewater systems in the United States are among the country's largest energy consumers, using about 75 billion kWh/yr nationally - 3% of annual U.S. electricity consumption.

Most approaches to this problem show that significant savings could be made through appropriate pump scheduling decisions, especially when multi-objective evolutionary algorithms (MOEA) are used. Typically energy cost savings of 10%, 15% or more are predicted. The problem has always been one of implementation of these systems into real-world applications. Solutions based on MOEA have always suffered from relatively slow speed of solution, especially in systems with more than a trivial number of pumps. Solution speed increases exponentially so that as pump numbers reach the range of 50 to 100 the solution time can be measured in days or more. This appears to relegate MOEA to design side problems or advisory systems rather than real-time automatic control. Aquadapt has a linear increase in solve time with increasing problem size. Any proposed solution to globally solve least cost water distribution needs a number of key ingredients. Firstly, it must be able to run quickly enough to cope with changing real-world circumstances, and be able to interface with the centralized control system. Secondly, it must not interfere with the basic protections inherent in the existing control system. Thirdly, it must achieve its goal of reducing energy cost without negatively impacting on water quality or reliability of supply.

Although the algorithm is proprietary its speed of solution is public domain. Now with four major installations in the US there is an extra supporting data on the speed of solution and the achievement of the objective to reduce distribution costs. The solution speed is phenomenal, EBMUD solves a 24-hour schedule for half hour blocks in 53 seconds, Washington Suburban in Maryland do it in 118 seconds, Eastern Municipal in California achieves solves in 47 seconds and WaterOne of Kansas City in under two minutes. These are orders of magnitude faster than MOEA based systems. Computer hardware in all cases is identical, a relatively modest Dell 1850 rack mounted server with a single 3GHz CPU and 2 GB of RAM.

Defining the Objectives

Electricity is a major cost in water treatment and distribution systems, typically second only to labor costs. Of this electrical cost, pumping typically makes up 95% or more of all energy purchased by a water utility, the balance being for lighting and heating, ventilation and air-conditioning. For these four major operations, the annual energy bills were, EBMUD $2.7M, WSSC $8.1M, WaterOne $5.5M and EMWD $1.7M, with all using more than 95% of their respective figure for pumping. Obviously reducing energy costs was a primary driver for these utilities, but not at the expense of increased operational risk or decreased water quality. Any optimization system had to be able to take into account changing boundary conditions such as tank operational limits and plant production requirements. There are always a substantial amount of constraints in any real world system. These constraints included minimum run times for pumps, minimum cool down times for pumps, minimum flow rates and maximum discharge pressures for valve stations, minimum and maximum plant production rates, pump station pressure rules such as starting smallest pumps first, pump stagger timing to prevent surge or hammer.

Water quality rules are harder to set and quantify as the relationship between operational minimum storage requirements can conflict with the need to turn over storage regularly to reduce water age. Chlorine decay is closely tied to water age but also heavily affected by ambient temperature making it difficult to set hard and fast rules to guarantee a desired level of residual chlorine at all points in the distribution system. Where rules could be established these had to be coded into Aquadapt as constraints.

An interesting phase of each implementation project was the ability of the solver to determine the 'cost of constraint' as an output of the optimizer. This allowed us to challenge some of the clients' perceptions with hard data, and through this process some constraints were relaxed. This seems a common issue with large utilities where over long periods of time operator preferences can get confused with hard constraints. For eg, a large pump station may have a restriction that no more than three pumps can run at the same time, for valid reasons in 1980s when the station was built. Over time with bigger discharge pipelines and more customers some of the discharge pressure issues will have disappeared, yet the maximum pump rule remains. Aquadapt uses hydraulic modelling to determine the maximum discharge flows from a pump station over the day to stay within any pressure constraints. This can shake loose constraints which are no longer valid. Having determined the physical structure of the distribution system, defined the pressure zones and selected the equipment that will be automatically controlled by Aquadapt, and having an agreed set of constraints, an implementation project can proceed. This customization and configuration typically takes three to four months followed by two months of extensive testing. Testing is carried out on a faithful hardware duplicate of the clients SCADA system. Real historical data is back-fed into the duplicated SCADA system from a SQL database recreating exactly the conditions from any selected date, faults and all. It is against this realistic environment that testing has real value.

The Aquadapt Software Solution

While solving the very complex scheduling problem is of interest to many it is in fact only one part of many steps required to create a usable robust and fully automatic optimizer. The main steps are:

1. Initialize any long term settings such as annual water extraction limits
2. Read data from the SCADA system, detect and correct any errors

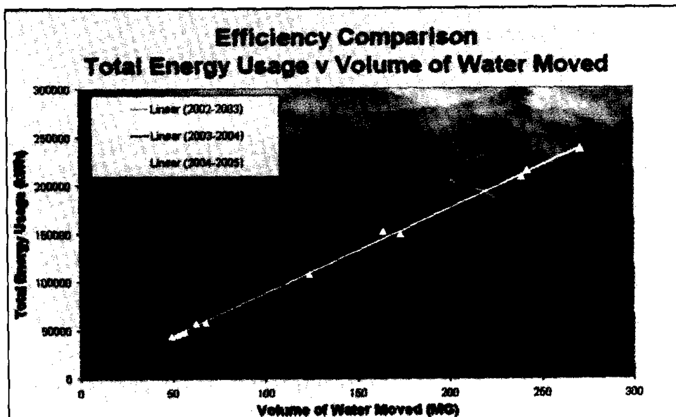

Figure 4: Efficiency Gains of 9% Overall Were Achieved in the First Full Year (2004-2005) of Aquadapt Operation at EBMUD

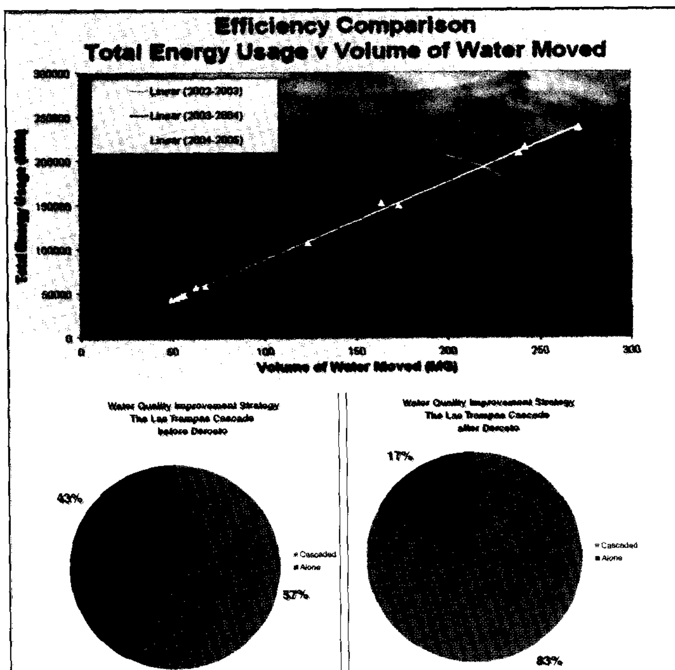

Figure 5: Aquadapt Succeeds in Delivering Fresh Water to the Top Tank in a Cascade System at EBMUD

3. Set the target volumes required in storage to achieve security of supply and turn-over
4. Read any changing third party data such as electricity real time prices
5. Calculate schedules for all pumps and valves
6. Write data to SCADA system to start pumps or open valves
7. Update any analysis such as predicted demand, costs, water production estimates

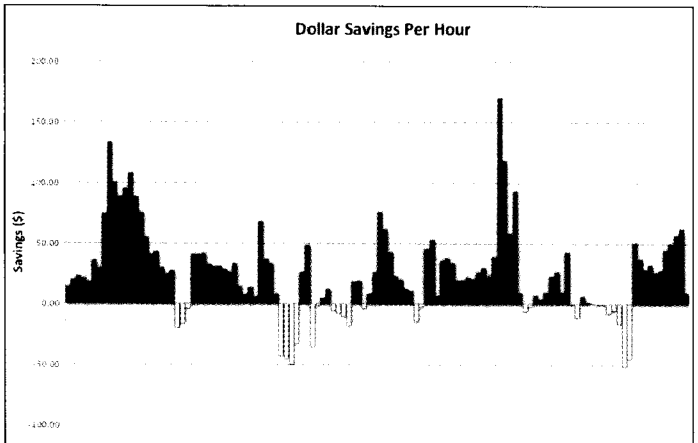

Figure 6: Hourly Improvement in Savings Analysis in a Real-Time Market for WSSC for the First Week of June 2006

Most steps in this process take only a few seconds, the solver is still the longest step, but as described above is still fast enough to be run interactively. The water distribution operators can view the Aquadapt predictions and outputs on a Windows based GUI thin-client. In Figure 2, the top graph shows demand, the middle graph shows storage tank level and the bottom row of dots is the pump schedule. The yellow bars indicate current time, anything before the yellow bar is history, anything after is future prediction. The predicted storage tank level rise in response to the pumps running (green dots) is evident. All four customers run exactly the same software. The only difference is in the configuration of Aquadapt within a database. In many ways this is similar to a commercial SCADA system where exactly the same software is configured to suit the individual user environment. This substantially reduces risk since the same proven engine is being used by all the clients. Aquadapt is designed to seek cost reductions in production costs as well as energy costs, however energy cost does tend to dominate.

For energy cost reduction it seeks savings in three main ways:

1. Moving energy use into cheaper tariff periods, using storage to supply customers.
2. Reducing peak demand charges by limiting the maximum number of pumps at these times.
3. Reducing energy required to deliver water in distribution through running a pump or group of pumps closer to their optimal efficiency.

Results for EBMUD

The system at EBMUD went live in July 2005. In its first year of operation Aquadapt achieved independently measured savings of 12.5% to reduce the energy costs from the previous year's $2.7M by $370,000. In its second year of operation it has done even better and looks likely to achieve nearer 13.1% in savings. Mainly this has been achieved through moving electrical load within a three band tariff regime. Prior to Aquadapt EBMUD had already made a considerable effort to reduce energy costs through manual intervention by the operators, and had sliced $500,000 off their energy bill. They had built sufficient elevated storage to allow them to stop pumping altogether for a six hour peak tariff window of around 32 cents/kWh. Aquadapt had to schedule pumps to move from two brief shoulder periods on each side of the peak, priced at 12 cents/kWh to the 10 hour off peak night rate of 9 cents/kWh. Even with this small differential in energy price the gains were significant.

Each pump station had multiple pumps and in some cases different sized pumps were mixed in one pump station. This provides an optimizer with many options to deliver a range of flows into distribution system. Aquadapt solves non-linear hydraulic equations to determine which combination of pumps will deliver required daily mass-balance at highest efficiency and lowest cost. Even though EBMUD had spent a lot of effort improving pump efficiency, Aquadapt was successful in reducing total amount of kWhs required to deliver flow by 9% overall. At some pump stations, it improved efficiency by more than 27% purely from selecting right pump or pumps at right time.

Quality improvements are harder to quantify. EBMUD had three operational rules which they attempted to achieve under manual operation which they considered would improve water quality. The first was smoothing the treatment plant flow rates, with only two rate changes per day. Smoother production flows allows chemical dosing to be optimized producing consistent low turbidity counts and stable chlorine rates at the plant clear water tank. Aquadapt now consistently determines the two treatment plant flow rates through good demand prediction and sticks with these rates throughout the day. The second requirement was to deep cycle storage tanks to reduce average water age. Being a mass balance tool this was an easy strategy for Aquadapt to achieve. The third requirement was by far the hardest. Where multiple tanks and pump stations existed in a cascade, moving up through pressure grades, EBMUD wanted all pump stations to run concurrently when the top tank needed water, so that fresh water would be delivered from the bottom of the cascade rather than aged water from an intermediate tank. Again this was achieved.

Results for WSSC

This system has been in operation since June 2006. WSSC are almost unique in the US in purchasing more than 80% of their energy under real time energy pricing. They are in the PJM (Pennsylvania Jersey Maryland) market and buy power directly through independent market operator. Rest of the pump stations ran under differing tariff structures from three separate energy supply companies. Obviously to automate pump scheduling optimization in a real time market means scheduling must be flexible and must be responsive to hourly energy price changes. Aquadapt solving in less than two minutes makes this possible. The operators were already achieving success in moving load at the major pump facilities in response to pricing for whole year before Aquadapt was installed. Within days of going live noticeable improvements in scheduling were evident. In the first week savings of around $400 per day were seen at one pump station alone, using an independently produced baseline tool. In the second week this climbed to $570 per day and then just over $1000/day in the third week. There are another 17 pump stations to measure. Figure 6 shows the operators when Aquadapt was making better scheduling decisions than they had traditionally achieved over a week. Blue bars above the line show increased savings, white bars below the line show when operators historically did better with each bar being a one hour block. Diagrams like this were instrumental in explaining to operators why a fully automatic optimizer was required to extract additional cost savings.

The WSSC distribution system was extremely complex with a very large number of uncontrolled pressure reducing valves making demand calculation and optimization difficult. Storage in the system was limited to about 17.5% of daily demand reducing the ability to move load to cheaper periods. The most complex constraints were around the two large water treatment plants where no more than four pump changes per day were allowed. These constraints may eventually be relaxed to increase savings as a result of capital improvement projects already underway before Aquadapt was installed.

Interfacing with the Control System

In both of these examples Aquadapt was required to interface with existing control systems. The EBMUD system already had a sophisticated centralized pump scheduling package comprising a table with entries for each pump with up to six start and stop times. It was relatively easy for Derceto to utilize this existing capability and have Aquadapt pump schedule fill in these tables after each solve. This meant little if any change was required in the existing control system, and existing overflow and under four protections for storage tanks could be utilized. The Washington suburban system was far more complex to build an interface for. There was no centralized PLC at the head office. In addition an ongoing programme to replace dumb RTUs with smart PLCs in the field was ongoing. A significant amount of logic was added to the scripting language within the SCADA package, Wonderware, and was further complicated by the need to maintain redundancy in the SCADA servers.

The use of automatic global automation strategies leads to an interesting situation. When the operator is manually filling storage in the zone, they are conscious of which pumps they have started, and are therefore also cognizant of which storage tank levels, they should be monitoring. If they are used to storage taking a few hours to fill they will be inclined to view those storage tank levels within a few hours of starting the pumps. If during that period of time, a communication loss occurs they are still likely to recover the situation by stopping the pump station anyway. However, when a fully automatic system like Aquadapt start pumps, the operator is not necessarily aware that this has happened and the system is therefore far more dependent on automatic localized controls to protect the system. This is the role of the localized logic in the field RTU. Like any complex software project success of the outcome is dependent on the quality of the inputs and the robustness of the solution to outside interference. Cascading layers of interlocks and safety controls are essential to provide the level of security needed by an essential utility.

Conclusion

The large investments made in automation and control systems by water utilities over the last 20 years has produced the necessary infrastructure for global optimization strategies to be implemented. Various agencies such as the US Department of Homeland Security are actively pursuing techniques to use this infrastructure to minimize the risk following terrorist events. Water utilities themselves are developing ever more sophisticated software to improve water resource use, reduce leakage, and improve overall water quality. The Derceto Aquadapt software package is one example of how financial gains can be achieved through leveraging off the considerable prior investment in automation and control. In many ways there are parallels with the Internet. No one foresaw the technology that only became successful after the investment to create the Internet itself was completed. Examples such as You Tube™, the Wiki Encyclopedia and My Space™ only exist through their ability to leverage off of the underlying infrastructure of the Internet.

Water utilities are likely to acquire even more sophisticated monitoring and control in the face of regulation and increasing security concerns. Advanced centralized control was cascade simple local security at the RTU level appears to be the way forward.

About the Contributor

As a global specialist in energy management with operations in more than 100 countries, Schneider Electric offers integrated solutions across multiple market segments, including leadership positions in energy and infrastructure, industrial processes, building automation, and data centres/networks, as well as a broad presence in residential applications.

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