Implementing an Energy Management System for Distribution Pumping

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INTRODUCTION

The East Bay Municipal Utility District (EBMUD) is a publicly owned utility that provides water service to over 1.3 million people in the San Francisco/Oakland area of California. The service area includes 20 incorporated cities and 16 unincorporated communities in parts of Alameda and Contra Costa Counties in the eastern part of San Francisco Bay Area. Water consumption averages 220 MGD and peaks at 341 MGD. The system includes 6 water treatment plants, approximately 3900 miles of water mains, 135 pumping plants, 180 treated water reservoirs and over 125 pressure zones. EBMUD operates two hydroelectric power plants which generate an average of 185 GWh of electricity in a medium year. In 2004 EBMUD electric bill totaled approximately $12 million of which $8 million was for water distribution pumping.

HISTORY & BACKGROUND OF THE EWQMS

In the early 1990s the increasing pressure to monitor and improve water quality within the water distribution system, as evidenced by the Total Coliform Rule and the increasing cost of energy consumed within the distribution system at EBMUD, sparked the quest for an integrated water quality and energy management operation. The urgency of this need was further amplified by the onset of electric deregulation in California and on the East Coast in the mid 1990s.

In 1993 EBMUD performed a study of water quality in its water distribution system. This study lead to the development of a number of operating techniques to maintain water quality in the distribution system. (Reference 1) With the advent of Time of Use (TOU) electric rates, water quality operations had the potential to increase energy costs. Starting in 1995, EBMUD participated in two projects partially sponsored by the American Water Works Association Research Foundation (AWWARF) aimed at eventually developing an integrated Energy and Water Quality Management System (EWQMS). The first project provided an outline for an EWQMS and evaluated the cost benefit of developing an
EWQMS through a forum of users or on an individual basis. The cost benefit indicated a forum approach is the most effective. (Reference 2)

In 1997, EBMUD participated in the second project which developed, through a forum process, a functional specification for the EWQMS Software. (Reference 3) The complexity of the envisioned EWQMS and the expected cost to develop a system that could work for multiple utilities essentially put further efforts through a forum process on hold. An AWWARF Tailored Collaboration Project subsequently developed a prototype for a portion of the EWQMS. (Reference 4) In a parallel effort, EBMUD utilized knowledge gained from the development of the functional specification to embark on the development effort for a modified, but fully operational, EWQMS. Since no system existed capable of optimizing the operation of EBMUD’s distribution system for energy cost and water quality, EBMUD focused the EWQMS system on the optimization of energy costs while using EBMUD’s water quality operating rules to address water quality. This significantly reduced the complexity of the optimization process. In order to limit the financial risk associated with state of the art software development, EBMUD developed a shared savings compensation process for the development effort. EBMUD issued its first Request for Proposals (RFP) in April 1999. The large costs of development ultimately lead to the first vendor’s bankruptcy, and EBMUD was forced to reissue the RFP. The second vendor, Derceto Inc., successfully completed development and installation of the EWQMS in September of 2004.

ENERGY MANAGEMENT AT EBMUD BEFORE EWQMS

In 1994 EBMUD instituted energy optimization procedures for our 135 distribution pumping plants against a fixed TOU energy tariff. The predominately manual pump scheduling process included providing the Water Distribution Operators with tools and information to make pump scheduling decisions. This included outfitting the Operations Control Center with a clock (Figure 1) highlighting the three different energy cost periods in Pacific Gas and Electric”s,(the local electric utility) tariff structure, providing energy cost information on each distribution pump for the on-peak energy period, and developing a peak period cost tracking tool.

The three different TOU cost periods are defined below:

<table>
<thead>
<tr>
<th>TOU Period</th>
<th>Summer (May 1 through Oct. 31)</th>
<th>Winter (Nov. 1 through April 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-peak</td>
<td>12:00 noon to 6:00p.m. (Mon. – Fri.)</td>
<td>None</td>
</tr>
<tr>
<td>Part-peak</td>
<td>8:30a.m to noon; 6:00 to 9:30 p.m. (Mon. – Fri.)</td>
<td>8:30a.m. to 9:30p.m. (Mon. – Fri.)</td>
</tr>
<tr>
<td>Off-peak</td>
<td>Nights, weekends and holidays</td>
<td>Nights, weekends and holidays</td>
</tr>
</tbody>
</table>

Figure 1 "The Clock"
The operator’s use of these tools aided in curtailing nearly all distribution pumping during the peak energy period. This approach initially saved EBMUD $500,000 to $700,000 per year in energy costs. Figure 2 shows the relationship between this pump operating scheme and the TOU electrical tariffs.

![Medium Size Electric Accounts](image)

**Figure 2 Pump load versus energy costs**

As water demands increased, coupled with EBMUD’s commitment to maintain operations that ensure water quality, the energy savings began steadily decreasing as demonstrated in Figure 3. EBMUD decided to search for a more advanced solution in order to further control energy costs.

![PEAK PERIOD PUMPING COST](image)

**Figure 3 On peak pumping costs**
What is the Derceto Inc. Version of a EWQMS

The EWQMS developed by Derceto Inc. is a real-time energy optimizer with a distinct set of water quality operating rules. The system generates an optimized pump schedule solution for the next 24 to 48 hours. Telemetry data on treated water reservoirs levels and pump flows is received from the Supervisory Control and Data Acquisition System (SCADA) every 10 minutes. Derceto takes account of daily zonal demand variations, available supply capacity, system constraints, and power cost information. Every half-hour a schedule for each pump is generated for the next 24 to 48 hours. These schedules are then updated based on real-time demand data and reservoir levels, which may be varying from predicted values. The Derceto EWQMS contains six major components. A water demand forecaster, a pump schedule optimizer, water quality module, energy cost calculator and a state estimator/data cleaner and the SCADA interface. Each of these components is described below:

A Water Demand Forecaster- This component predicts water demands for each pressure zone in the system’s control area for the next 24 hours to 48 hours. The forecaster was originally envisioned to report in one hour increments, though Derceto software makes predictions in half hour increments. The forecaster also recognizes the difference between weekday and weekend demand patterns along with seasonal variations in both the demand pattern and quantity.

Pump Scheduler – This component will generate the optimized pump plant, rate control stations and water treatment schedules based on the forecasted demands, the current state of the distribution system, the electrical tariff for each pumping plant, and any operational limitations, including water quality operations.

Water Quality Module – This component allows for three different water quality operations. The first, synchronized pumping, schedules all pumps in a defined cascade to operate at the same time as much as possible. This reduces water age at the higher reservoirs of a cascade system. The second lowers operating ranges of the high and low operating points. This operation decreases the reservoir volume and allows for the “new” fill water to represent a greater percentage of total reservoir volume resulting in a lower overall water age in the reservoir. The third is deep cycling/ pulse flow. In this operation the EWQMS system checks the forecasted demand and the available operating storage in a pressure zone. If there is ample operating storage to curtail pumping for the next 24 hours the EWQMS system will not schedule any pumping. This results in allowing the reservoirs to deep cycle and fill on a pulse flow operation.

Energy Cost Calculator – This component develops energy costs based on the electric tariffs for each pumping plant. The module has the functionality to accommodate multiple electric tariff types, including TOU tariffs, demand and energy tariffs, and a dynamic energy tariff. The module is currently being retooled to accommodate the Critical Peak Pricing Structure being proposed by the California utility, Pacific Gas and Electric Company.
State Estimator and Data Scrubber - This function detects any errors or omissions in the telemetry data and then provides estimated or predicted values for this data.

SCADA Interface - The SCADA interface consists of both a SCADA read and a SCADA write function. The read function reads all the pertinent real-time SCADA data directly from the SCADA system database. The write function writes the pump schedules (pump start and stop times) into the SCADA system. The EBMUD SCADA system has a pump control program that receives the pump start and stop orders from the EWQMS and issues the actual pump start or stop command.

The Energy Management System Implementation Area

The entire EBMUD water distribution system is large and fairly complex hence a smaller area was selected to pilot the EWQMS software. The implementation area represents approximately 35% of EBMUD’s entire pumping energy costs, though only about 20% of the District’s water demands. The implementation area includes 20 electric power pumping plants containing 64 pumps, 3 rate control stations, 23 distribution reservoirs, and one water treatment plant, all serving 15 different pressure zones in the District’s San Ramon Valley service area.

Figure 4 shows the control area in relation to the District’s entire water service area.
The majority of the areas' water is distributed though a series of pumping plants, lifting water through a series of pressure zones until it terminates at the top tier of pressure zones. Figure 5 shows a schematic representation of this system. The area also contains four facilities that reside on the boundary of the implementation area, two pumping plants, and two rate control stations.

IMPLEMENTATION

The program development began with Derceto staff performing an initial design study. The intent of this design study was to scope the optimization system, estimate the energy savings potential, and to identify early on any potential road-blocks to a successful project. The results of this study were used to negotiate the terms of the contract, specifically the shared savings compensation terms.

One of the first steps undertaken in the implementation was to involve all relevant operational and engineering groups from EBMUD and the Derceto design team in a Hazards and Operability (HAZOP) study. This technique, which Derceto borrowed from the oil and gas industry, is a methodical method for analyzing equipment and processes from the water treatment plant through the pumping plants and rate control valves and on to the finished water storage tanks. It allowed EBMUD staff to present their concerns and issues and ensured that the Derceto design team would have a deeper understanding of the distribution system.

EBMUD provided Derceto Inc. with a hydraulic model of the implementation area. The model was used to confirm that the operational changes Derceto was considering were realistic and that these changes would not negatively impact any of the operational constraints imposed by EBMUD. The EPANET model is also used inside the optimization system to solve non-linear equations.
The entire water distribution system at EBMUD is monitored and controlled by a SCADA system. In early 2005 EBMUD had plans to upgrade the entire SCADA system to a new version of software. Therefore, Derceto staff developed two distinct interfaces for both SCADA versions. This task was made simpler since both SCADA versions had the same database structure. Derceto staff ran all tests of the optimization system against a complete version of the EBMUD SCADA system running on a PC in the Derceto offices. The initial roll-out of the EWQMS software at EBMUD included a successful SCADA interface. At the time of the writing of this paper EBMUD had yet to begin the upgrade to the new versions of SCADA software.

**BENCHMARK**

A key question that arises when implementing a payment schedule based on sharing of the savings is, “How do you measure the savings?” As part of the contract Derceto was to provide a baseline energy cost measuring tool or baseline calculator. Derceto developed the baseline tool based on the following methodology.

To estimate energy use based on historical operation, the baseline calculator must react to daily changes in system demand and be unaffected by the changes to TOU operation made by the EWQMS. The baseline calculator estimates energy use by TOU bands from the daily pumping plant flow. The relationship between daily pumping plant flow and energy use in each band is determined from historical pump flow and run-time data. This historic data is used to develop the coefficients for energy regression functions that relate the daily flow to energy use in each time of use band.

![Summer Weekday Total kWh](image)

Figure 6: Daily flow plotted against daily energy use, showing the strong linear correlation.

Comparing Figure 6 and Figure 7 below shows that although the daily energy use correlates well with the daily flow as expected, daily energy use by time of use band does not. This can be expected as daily energy use is physically related to daily flow, but the
separation of the total energy use into time of use bands is dependent on the operational procedure implemented for the pump. The energy regression functions assume that a linear relationship exists between the daily flow and the energy use in each time of use band, so the energy use value returned for a particular daily flow represents the expected value based on the historical average use in that band at that flow. The output of the baseline calculator is therefore a statistical expectation of the energy use.

![Graph](image.png)

**Figure 7:** Daily flow plotted against energy use for the partial-peak time of use band.

The regression functions generated from historical SCADA data are verified and calibrated by comparing electric accounts estimated by the baseline calculator to real accounts for the same period.

A few of the larger pumping plants have energy tariffs that include a demand charge for the maximum kW demand used in a monthly billing cycle. Derceto’s solution to modeling this type of tariff was to construct flow bands in which there is a probability that a certain number of pumps will be used (see Figure 8). By careful choice of probabilities, it is possible to generate similar behavior to the real electric accounts over a monthly period. As a probabilistic method, however, over short periods the demand charges are unlikely to be accurate, but over a 30-day billing period, the accuracy was found to be good.
RESULTS

The installation of Derceto’s EWQMS was expected to save between 7% and 20% or $190,000 and $550,000 per year on energy costs. The optimizer went on-line in late July of 2004 and was fully operational by mid August of 2004. The results from the first two months of operation were approximately $100,000 or ~15% off the energy bills. It is expected that savings in summer months (May – October) will be generally higher in dollars but lower in percentage than the winter months. Water demand is considerably higher in summer and consequently pumps have to run longer to satisfy this demand. Additionally, TOU electric rate differentials between on-peak period and off-peak are, however, very significant in summer so even a little improvement can yield significant electric cost savings.

A key concern to EBMUD besides the energy cost savings was maintaining our water quality operations. The Derceto EWQMS contains three specific water quality rules, synchronized pumping, lowering operating set points and deep cycling. These operations were modeled after EBMUD’s current water quality operations.

The result of the Derceto EWQMS synchronized pumping can be seen on Figure 9 below. Under previous level control operation synchronized pumping was achieved 57% of the time for the 2003 and 2004 calendar years combined. Under Derceto EQQMS control, the synchronized pumping has risen to 83% of the time while simultaneously achieving energy cost savings at these pumps stations greater than 20%.
Prior to Derceto EWQMS, deep cycle operation was usually achieved by the existing pump control system although it was complicated by the need to avoid pumping during the peak TOU period. As demonstrated in Figures 10 (left), sometimes the fill cycle prior to Derceto operation would occur during the on-peak energy period. The deep cycle function under the Derceto EWQMS would avoid the on-peak TOU energy period while still deep cycling the reservoirs (below right).

Figure 9: Before and after results of the synchronized pumping

Water Quality Improvement Strategy
The Las Trampas Cascade before Derceto

Water Quality Improvement Strategy
The Las Trampas Cascade after Derceto

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The impact of the Derceto EWQMS water quality operation on the actual water quality was not evaluated. The Derceto system was only evaluated for compliance to specific water quality operating rules and not to water quality parameters.

**NEXT STEPS**

EBMUD is currently in the first year of its shared savings contract and will monitor the performance of the EM system. EBMUD Operations staff is continuing to look for other opportunities to utilize the EM software to further achieve energy savings and enhance water quality. EBMUD will continue to look for opportunities to make enhancements to the software for improved performance. Within the next year, EBMUD plans to investigate the economics of expanding the system to other portions of the distribution system.

**REFERENCES**
