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Water Energy Nexus – The Next Frontier

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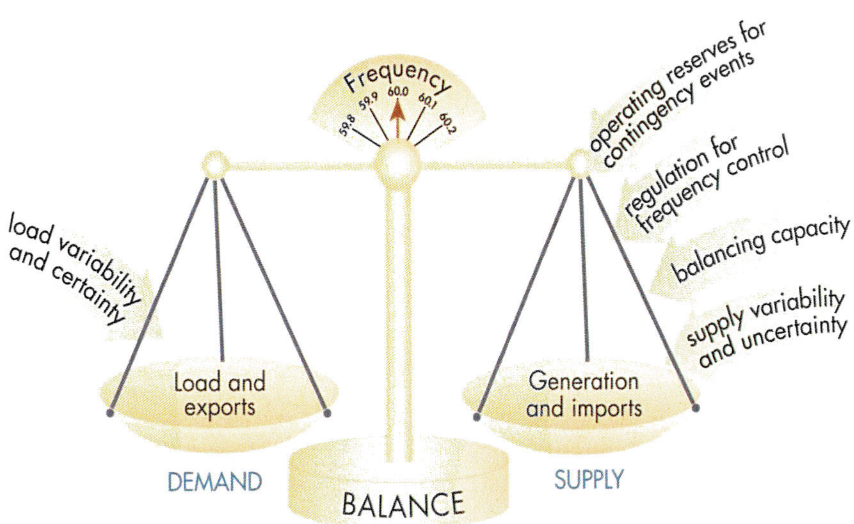
Introduction

There is growing recognition of this fact worldwide[1] that the Water and Energy sectors are interlinked. In the US about 4% of power generated is used in water supply and treatment and electricity represents about 75% of the cost of municipal water processing and distribution. Water and wastewater facilities' energy consumption is equivalent to 45 million tons of carbon dioxide equivalent greenhouse gas emissions. $4 billion is spent every year by water utilities in USA, equivalent to approximately 56 billion kWh. Water and wastewater facilities are generally energy-intensive accounting up to 35% of utility's budget, second to labor. Water-related energy use consumes 20% of the California's electricity, 30% of its natural gas, and 88 billion gallons of diesel fuel every year – and this demand is growing[2]. California water and wastewater agencies spend more than $500 million each year on energy costs. As energy costs rise, operating costs at these utilities also rise.

Therefore, if water utilities reduce their energy use, they see reduced operating costs, reduced climate impacts/ carbon footprint, sustainability of water infrastructure, and also save water.

The Energy industry is facing some real challenges due to regulatory initiatives aimed at dramatically



1: Balancing variability will require flexible capacity
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[1] http://www.worldpolicy.org/policy-paper/2011/03/18/water-energy-nexus, http://www.sandia.gov/energy-water/, http://www3.weforum.org/docs/WEF_WI_WaterSecurity_WaterFoodEnergyClimateNexus_2011.pdf
[2] California Energy Commission. http://www.water.ca.gov/climatechange/docs/ClimateChangeWhitePaper.pdf

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changing the electric power system[3]. They include: Increasing the Renewable Portfolio Standard from 20% to 33%; Drive to reduce Greenhouse Gas emissions; and Retiring/ Repowering of once through cooling power plants. The industry needs solutions and resources that will meet the challenges. Future energy supply will be less schedulable, dispatchable and firm; more distributed; and both closer to and further from loads. Electricity demand in the future, on the other hand, will be more dispatchable, price responsive, temperature and voltage sensitive; and less predictable. Future power transmission will be more observable, dynamically rated, coupled with distribution; and buffered with the deployment of storage devices.

Balancing variability will require flexible capacity. This can be achieved by re-configuring Demand Response as a flexible resource that will help balance the grid and improve operational and market efficiencies. Strategies to do this include Peak Load Reduction, Intra-Hour Variability, Ramp Smoothing, and Load Shifting/Over Generation Mitigation.

Energy Providers are facing significant supply issues along with the challenge of grid management. They are required to maintain continuous balance between market demand and generation to warrant reliable supply to all electricity users. Traditionally, this equilibrium was secured by fast-responding generation from reserve suppliers, such as gas turbine generators. With the proliferation of renewables in energy generation, volatility in production now creates stress in the grid balance. New generation, transmission, and distribution assets are also more difficult to get permitted and financed. This offers opportunities for water utilities to maximize their energy efficiency and assist the energy providers to meet their goals.

Currently, all discussions around energy use at water facilities revolve around energy efficiency. Energy audits are being performed around the country which yields a list of capital projects aimed at improving efficiency. These measures range from replacement of equipment with energy efficient equipment and few operational strategies that bring about energy use reduction and hence energy savings.

The water utilities benefit from this measure by reduction in the energy bills, hence lower operations cost and lesser need for an unpopular rate hike. The power industry benefits by energy efficiency projects due to reduced demand by customers and also receives approval/credits from regulatory agencies.

While load reduction is a commendable step towards achieving a reduced energy footprint at water facilities, much more can be done to achieve a true water-energy nexus. The water and energy utilities can come together and develop joint partnerships to address the each industry's needs. Water industry can load shift in response to the power industry's grid requirements by leveraging the excess capacity and inherent flexibility in the water assets. Automation is required to effectively achieve this, however with smart instrumentation that already exists in most water facilities; this can be achieved with relatively low investment. EPA estimates that 15 – 30 % reduction is 'readily achievable'.

[3] Information from Jill Powers, California ISO.

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Load shifting allows the power industry to treat the water facility as virtual power plants that can be called upon to deliver when the grid requires. In return, water utilities can receive revenue for being flexible. Energy market participation will be lucrative enough for the water utilities to consider load shifting as an important revenue-creating tool in their overall energy and operations strategy.

Focus on Energy Efficiency and Savings

Current Status of Water Industry

Many water and wastewater utilities are currently interested in "Water-Energy Nexus", but the focus is predominantly in achieving energy efficiency and resultant savings. Some utilities have performed self-assessment exercises or have hired consultants to execute energy audits. Consultant fees for these audits range from free to high five figures, and are available in a variety of levels from walk-through to 'investment-grade'. These audits typically identify capital improvements (motors, blowers, VFDs, etc.) and sometimes operational improvements. Some suggested operational improvements can result in substantial savings with little to no cost. For example, change in time of operations, load demand contracts, turning off unnecessary equipment, etc. Some of these audits also identify renewable energy opportunities.

Three levels of Energy Audits are common:

Level I

A Level I audit is a walk-through audit that last several hours at the facility/system. This audit usually suggests low cost improvements such as lights and HVAC. The projects have quick payback and often take advantage of prevalent energy utility rebates. These walk-through audits are often free and contracted through the energy providers.

Level II

The Level II audits typically undertake an energy survey and analysis. The auditors spend several hours at the facility or system and additional time reviewing energy bills, etc. Auditors estimate power usage by equipment type but do not usually perform detailed analysis of equipment specifications and performance. The deliverable is typically for low cost improvements to lights, HVAC and equipment upgrades in existing processes (e.g. VFDs, premium efficiency motors, etc.). Again, there is quick payback and the recommendations often take advantage of energy utility rebates. Costs of these audits are usually about $10,000 and there may be some cost share with energy providers. These audits usually do not cover any renewable energy evaluation or provide plant energy balance.

Level III

Level III audits are detailed process audits. It may take one or more days at the facility or system, time to analyze energy bills, develop pump curves and possibly several weeks of data gathering. The audit includes: review of energy use and rates, energy balance, pump system evaluation, process system evaluation, operations strategy evaluation, etc. The deliverable highlights the energy use in existing processes and suggests alternative processes. Potential design modifications are usually recommended

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along with optimization of processes and equipment. These detailed operational and process suggestions have both short and long term paybacks. Most reports include cost benefit analysis of proposed projects. Some projects suggested are capital-intensive and may require the utility to secure additional funding to accomplish. These audits, however, yield significant savings. Costs of audits vary on system size and can range from $8,000 to $60,000 and are sometimes compensated in part by the energy providers. The caveat for this cost share is the water/wastewater utility need to demonstrate willingness and ability to implement the recommended projects. The audits usually provide plant energy balance but may or may not include analysis of renewables.

Renewable Energy Assessments

Consultants also offer Renewable Energy Assessments separately as services. These start with small discussion and end in large $100,000+ feasibility studies. Some energy auditors do desktop analysis as a part of Level II or Level III energy audit and recommend further studies. Most water utility clients, however, find renewable energy projects cost effective only after all energy efficiency projects are completed. Some states have programs to fund assessments for certain types of renewable projects.

Energy Audits

CalEPA (Region 9) ran a pilot audit program in 2010-2011 with 15 water agencies. It was a mixture of Level II and Level III audits, 15 treatment facilities were reviewed at no cost to the facility owners. The following was observed:

- 17% savings in energy use, 26% savings in energy costs
- No statistical differences between small and large utility results
- 15 recommendations with <1yr payback period, with total annual savings of $190,000/yr (>100% ROI)
- Recommended projects had maximum payback period of 7.5 years
    - $1.4 million / year cost savings with a 4.5 year payback (16% ROI/yr)
    - 6900 MWhr/yr reductions

An energy audit process typically includes a review of historical energy costs, utility rate structures, and electrical demand. A thorough site inspection is conducted to assess the existing facility equipment and processes. Then options for improving efficiency and reducing utility costs are evaluated. This analysis includes advantages and disadvantages, capital costs, operation costs, electrical savings, and payback period for each alternative. The following are typical checklist items for an energy evaluation.

- Lighting Systems
- Building Envelope and Insulation Systems
- Mechanical Systems
- Utility Rate Structures
- HVAC/ Heating / Cooling Systems and Controls
- Control Systems
- Alternative Fuels
- Operation and Maintenance Procedures
- Pumping Regime
- Equipment Replacement
- Energy Efficient Motors
- Variable Frequency Drives
- Energy Use Monitoring Systems

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- Opportunities for Recycling (i.e., waste heat recovery)
- Distributed Generation
- Cogeneration/ Process Combustion
- Peak Load Reduction
- Conservation

Water and wastewater utilities hire consultants to perform these audits directly. This will usually be a competitive process. However, SCE, SDG&E, and PG&E have energy efficiency funds allocated to also perform these audits. The energy providers may go with a 50-50 cost share with the water utilities to perform these audits.

Focus on Dynamic Optimization and Revenue

The Opportunity

The Federal Energy Regulatory Commission (FERC) Order 745 represents a significant step forward in the evolution of electricity markets that would bring significant benefits to electricity consumers, particularly water utilities. The FERC has determined that electricity users who can reduce their consumption in response to changes in power prices should be paid for those reductions at the same rate that electric generators are paid. Generators who produce electricity and customers who cut their consumption of electricity are seen to be providing equivalent services because both actions have a balancing effect on the electric grid.

The rule change also helps achieve energy and sustainability goals. Price-responsive Demand Response, or Demand-Management, encourages energy users to reduce load at times when prices are highest. High prices are strongly correlated to peak system demand and thus, peaker-power plants, which are among the most expensive and pollution intensive resources that the grid calls on. By encouraging end users to reduce their load during critical periods, generators can meet the needs of end-users through a cleaner portfolio of resources that includes renewables. An increase in controlled load will place downward, competitive pressure on the electric rates paid by all other customers. This effect has been demonstrated repeatedly – when some customers control their load, other customers benefit in the form of lower rates.

Fair compensation for demand reduction will put an emphasis on behind-the-meter smart grid technology. Behind-the-meter technology comprises new innovations that allow consumers to manage their energy consumption and load, thus decreasing demand on our national electric grid which produces economic, environmental and efficiency benefits for the public.

FERC Order 745 is under consideration in California as the California Public Utilities Commission (CPUC) determines the conditions under which end-use customers will be able to participate in California electricity markets. The decision by the CPUC was to be made by May 9th 2011, but the CPUC has ruled to delay its final decision by 18 months. The main reason for the delay is to fully consider FERC Order 745 and what it means for California electricity rate payers. Approval of the FERC Order 745 by CPUC will open the doors for the water utilities to enter the power market as partners with the power generation and distribution companies. Even if this Order 745 is not approved by CPUC in the near term, there

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exists several opportunities for water utilities to participate in multitude of demand response programs already in effect.

The water facilities (distribution, collection, and treatment) have significant in-built capacity that is not currently being utilized. This is due to the typical 30+ year planning horizon and subsequent investment in capital projects that target the build-out for that extensive planning period. Most facilities do not focus on optimizing operation based on energy use, and focus only on the ability to provide quality of service (no outage, maintain water quality). Hence, there exists a significant amount of inherent flexibility at these facilities that can be effectively leveraged while still maintaining the quantity and quality goals.

Dynamic Real-time Optimization

A number of the water utilities are already engaged in some energy efficiency/demand response programs with their local power providers, but the dynamic real-time optimization is still not widely accepted and implemented. This optimization will provide the water and wastewater utilities the opportunity to use behind-the-meter dynamic real-time SMARTGrid technology to increase efficiency and flexibility to better manage their own energy use and to create a new, continuous revenue stream by entering the energy market. In the water industry, this can be achieved in two sectors – for the piped networks, and for the treatment plants.

For Piped Networks

This includes water, sewer, and recycled water infrastructure comprising of the network of pipes, pump stations, reservoirs, pressure reducing stations, and other appurtenances. At this time the piped networks are modeled using static water models used for periodic master planning exercise and subsequent updates. Some utilities have studied energy optimization of these piped systems, but most proposed methods for complex water system networks are usually strategies to take advantage of low-priced but fixed off-peak energy tariffs, whereby the cost saving is achieved by scheduling as much as pumping load as possible to occur at night when the energy rates are the lowest. This does not save actual energy, it simply redistributes it but still yields some cost savings for the water utilities.

The need is for a real-time hydraulic optimizer, an analytics engine that sits on top of the hydraulic model with coded operational strategies for various scenarios experienced in the piped systems. For example, the optimizer will be capable of measuring the efficiency of each pump within the system and ensure the pumps be positioned as close as possible to the best-efficiency point. This not only reduces the wear and tear on the pumps resulting in longer life span, it also makes the pumps consume the least amount of energy, hence savings. Furthermore, if water quality monitoring is available across the network, this software can implement rigorous water quality policies such as varying the operating set points to accommodate the different seasonal demands, deep cycling of reservoirs with low water turnover, and using synchronized pumping in cascade systems (where fresh water is sent to terminal tanks by bypassing intermediate tanks). Water pressure readings from each zone in the water network can be reviewed on real-time, and the network operational algorithms can be modified in 5 to 30 minute interval enabling the system to be flexible.

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In essence, the hydraulic optimizer will be an adaptive learning network, following a flowchart of decisions and continuously learning to solve the problems of modeling, prediction, diagnostics and pattern recognition in the piped systems on a real-time basis. The optimizing problem should ideally be solved in less than three minutes which in turn will enable prompt decision making and accurate implementation.

A simple version of this hydraulic optimization methodology has been implemented in some potable water systems in the US[4]. But more competition is needed in this space including further refinement of the technology. Development of an optimizer of this kind may be quite simple for software companies already developing complex gaming and analysis software. Essentially, the hydraulic optimizer should offer the following distinct salient features:

- Mimic real failures and outages and changes in demand at every node on the piped network.
- Able to handle several hundred pumps and control-valves, and scores of reservoirs and demand zones.
- Connect directly to telemetry/SCADA signals from the piped system and absorb and transmit information.
- Analytics that will evaluate past performance and make accurate forecasts / predictions.
- Decision making capability should be very quick including rapid adaptation to changing demand, tariff rates, and equipment availability.
- The output to be in the form of start/stop, ramp-up/down, and open/close commands should be routed directly to the PLC or RTUs controlling the assets in the field.
- Possess an intuitive interface is required for the system operator to be able to observe the real-world condition and initiate decisions on real-time.

At a typical installation, this optimizer will run every 5-minutes or on-call based on grid information and produce an optimal pump and valve operation schedule for up to 48 hours. On the energy side, there exists software[5] capable of receiving and reacting to dynamic energy pricing and also participating in multi-level demand response programs. The integration of the hydraulic optimizer with these software will provide the water utilities greater flexibility in their decisions and target not only energy efficient water systems but also enable the electrical utilities effectively balance the grid and power delivery.

By supplementing tariff information with day-ahead and real-time information feeds, synchronization of the hydraulic optimizer with the energy optimizer can bring a new forecasting component to the optimizer. With dynamic and forward-looking information the combined optimization package will be able make decisions to participate in demand response and significantly reduce the water utility's energy cost. In addition, the energy software may enable participation in ancillary services programs such as area regulation. For example, water systems can be leveraged to provide regulation, a critical ancillary service that balances supply and demand in the electricity grid in real time. Large loads, like

[4] For example, Derceto's Aquadapt™ and Optimatics' Optimizer WRT .
[5] For example, Viridity VPower™.

pumps in a water network, are ideal for demand-side participation in regulation because they have sophisticated controls that are capable of quickly responding to signals from the power grid operator and can do so over a sustained period of time, just like a generator. Depending on the availability and capability of pumping systems, when a reservoir level reaches a low point, pumps can begin to refill the reservoir running at reduced rate. The pump can ramp up or down to use more or less electricity in response to the power regulation signal. The difference in usage can be metered and verified as responsive to the power utilities regulation signal. By integrating market signals with device controls, the energy focused hydraulic optimizer will be able to help water utilities earn revenue for providing this critical grid balancing service.

2: Water Supply Pipelines © Proteus Consulting

For Treatment Plants

For treatment plants, the concept is very similar to the piped network optimization. The current process models for treatment plants are also static models typically used for periodic master planning purposes. A process optimizer need to be developed that will capture all process components, their functional and process limits, and strategy of operation. There are no known process-energy dynamic optimizers available in the market at this time. The following steps highlight the path in development of a dynamic optimization package at a treatment plant:

- Process Flexibility Analysis - Review the process, instrumentation, and electrical use data to identify the operational characteristics of the plant, including all process elements. Categorize operational parameters into critical and non-critical, i.e. detect and quantify flexibility options. Classify inter-relationships between operational parameters. Isolate opportunities of continuous operational optimization using existing infrastructure, e.g. pumping strategy, chemical dosing, aeration staging, digester operation, odor control, etc.

- Electrical Capacity and Flexibility Analysis - Review existing SCADA, BMS, and EMS systems. Review use existing energy assets including controllable loads, storage, and onsite supply. Perform operations focused workshops to identify plant control strategy with what-if scenarios. Identify opportunities for renewables – solar, wind, fuel cells, biogas plants, DME, etc. Identify strategies to sell-back / monetize including negotiation of tariff rates, capacity program, 30-min call, and grid reliability products.
- Development and Implementation of Energy-Process Optimizer – Design process optimizer that integrates process optimization opportunities with energy optimization software to create a customized software package. Calibrate program to test various strategies, incorporate tariff changes, different operational constraints and maintenance requirements, etc. Client interfaces and functionality checked and with operations and engineering.

3: Treatment Plants © Proteus Consulting

The Future

Dynamic Optimization along with power grid integration has not been done yet in the US and is a novel concept. Hence, projects of this kind will have to go through a concept verification phase. To fund such projects, water utilities may be interested to pay for the project or the power companies may offer cost-sharing because the implementation of such a program will be a win-win for both the water utility and power utility. There are other sources of funding:

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- US Bureau of Reclamation WaterSMART Grants – System Optimization Review and Water-Efficiency Grants

- US EPA Office if Wastewater Management, EPA Region 1, EPA Region 9, NYSERDA, and Mass Energy Insight have expressed interest in this kind of project and may help secure some funding.

- US DOE Industrial Assessment Centers have also expressed interest to work on projects of this scope.

- California Energy Commission (CEC) and California Public Utilities Commission (CPUC) also have funding programs where this kind of project can be eligible.

Water and wastewater utilities are passionate and sometimes aggressive about their operational parameters. It is also worth noting that they are driven by regulatory compliance and not as much by the cost of business. However, this sentiment is changing given the current economic times. The true water-energy optimization proposals presented here will not curtail or restrict any of their operations in lieu of energy management. The dynamic real-time optimization will be complementary to their current operations. The business case will clearly show that the 'unused capacity' and 'opportunities' are being maximized by dynamic real-time optimization and will create a revenue stream for the agencies.

About PROTEUS Consulting

PROTEUS Consulting is a boutique engineering and management consulting firm with the goal to catalyze the synergy between the Water, Energy, Information, and CleanTech sectors. We exist to bring about metamorphosis. With versatile high quality technical and management solutions we facilitate the transformation of business-as-usual to a high-energy and productive environment. We are known for our creativity and problem-solving skills, and clients appreciate the individual attention this small, flexible firm is able to provide.

Our success stems from our ability to quickly and effectively understand the unique physical, cultural, and economic opportunities of each assignment. We specialize in building creative solutions that honor each project's distinct features and are committed to integrating design, engineering, and community in a manner that conserves resources – human and material capital.

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