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Pump Station Optimization: Use Analytics to Find the Needle in a Moving Haystack

There are millions of ways to run a pump station equipped with variable-frequency drives, but intelligent pump management analytics can pinpoint the single optimal way. **BY DANIEL PETERSON AND DAVID PIERCE**

WE CARRY IN our pockets a computer powerful enough to maneuver a rocket to the moon, yet many pump station controls are archaic, failing to embrace modern computer technology. A massive computer network explores, analyzes, and optimizes, but intelligent pump station control has been slow to arrive.

Pumps are simply cycled on and off by controls that are only looking at a system pressure or distant tank level. Slightly more sophisticated stations might have closed-loop controllers that ramp pump speeds to achieve target flow or pressure setpoints, but their only objective is maintaining that setpoint. Traditional pump station operation is overly simple, given ever-increasing computing power and sophisticated software analytics.

Traditional pump station controls still deliver water from point A to point B, but they leave a lot of potential benefits on the table. Now it's possible to solve real-time hydraulic models on powerful, industrial computer hardware installed in a pump station. By incorporating a digital pump station model in the control loop, utilities can move water, operate at peak energy efficiency, and maximize pump life. Building and executing this model requires a powerful analytics engine running at the pump station. Although more complex to deploy than on-off or proportional, integral, and derivative controls, the benefits are compelling. Pumps last longer, pump condition is continually assessed, and efficiency is maximized.

STEP 1: BUILD THE HAYSTACK

Modeling a pump station to optimize operations isn't a trivial task. The computer analytics engine must be programmed to collect data to develop and update high-fidelity pump curves, track and update its model of suction and discharge system curves, and adopt an efficient methodology to explore the massive haystack of possible running pump and speed combinations to find the needle—the lone optimal solution.

The initial task in building the haystack is to capture high-fidelity in situ characteristic curves for each pump. The curves are generated using calibrated station pressure, flow, and power sensors. Factory or catalog pump curves aren't useful for predicting pump-operating behavior, as they fail to capture in situ hydraulic or normal pump wear and tear. Even new "identical" pumps aren't identical, and they start wearing as soon as they go into service. As noted in *Opflow*'s December 2018 article entitled "Centrifugal Pumps and Variable-Frequency Drives: A Match Made in Heaven?", pump characteristic curves shift significantly over time.

The next task involves combining the pump station piping model with measured station flow and pressures to compute current water system characteristic curves. Combining water system models with measured pump curves produces a complete digital pump station model that can predict a pump station's performance and efficiency for every combination of running pumps and speeds.

The final task in building the haystack involves finding all pump-operating regimes that minimize *specific energy*. Specific energy is the performance metric that can select for peak pump station efficiency. One can simply divide a pump station's input power by flow to compute the station's specific energy. Specific energy was more thoroughly explored in *Opflow*'s October 2018 article entitled "Specific Energy: A Comprehensive Measure of Pump Station Performance."

Figure 1 shows in red and blue the haystack of combinations of running pumps and speeds for a pump station with five pumps and five variable-frequency drives. The graph depicts specific energy (kW•h/MG) on the vertical axis versus station flow (gpm) on the horizontal axis.

Many pump station controls fail to embrace modern computer technology. By incorporating a digital pump station model in the control loop, utilities can move water, operate at peak energy efficiency, and maximize pump life.

PHOTOGRAPH: DMITRY KALINOVSKY, SHUTTERSTOCK.COM

Each graphed "×" represents a single combination of pumps and speeds and produces a specific flow, power, and head for each running pump. The model can also determine whether all pumps would operate within their preferred operating ranges (PORs). For centrifugal water pumps, the Hydraulic Institute defines POR as the range between 70 and 120 percent of a pump's best efficiency point (BEP) flow. When pumps operate outside their POR, pump wear is accelerated, reducing pump capacity and compromising pump efficiency.

The graphed red ×s represent pump combinations in which one or more pumps would operate outside POR. The blue ×s represent operating regimes in which all pumps efficiently operate within their PORs. This pump station has five variable-speed pumps, and although there are more than 28 million operating regimes, fewer than 1 percent of the regimes are blue. Virtually all depicted operating regimes would lead to reduced efficiency and accelerated pump wear. Pump stations without intelligent pump management routinely operate pumps outside POR.

In Figure 1, pumps running alone (shown on the left side of the graph) produce a simple characteristic specific energy swoosh. Each combination of multiple running pumps produces a cloud of points.

The next task lies in discovering the lower bound of specific energy versus flow points for each regime of running pumps. Figure 1 includes 31 optimal green and amber curves representing the optimal sets of pump speeds for each possible combination of running pumps. Green dots represent regimes in which all pumps would operate within POR. Amber dots represent regimes in which one or more pumps would operate outside POR.

With these optimal curves in hand, it's now a simple task to compute the optimal set of pump regimes to operate across the full range of flows, as shown in Figure 1. The black curves outline optimal operation and represent minimum specific energy for any desired flow. The mathematical term for the black curve is *convex hull*, which has flow gaps between combinations of running pumps and is interpolated across gaps.

To optimize energy efficiency, one would avoid the convex hull flow gap regions and instead operate for some time on either side of the gap to achieve the mean minimum specific energy depicted by the convex hull. For example, to produce a mean flow of 4,000 gpm optimally, one could choose to operate at 3,625 gpm (1,640 kW•h/MG) for a while and then at 4,625 gpm (1,790 kW•h/MG). The average specific energy consumed would be 1,700 kW•h/MG, as shown in Figure 1.

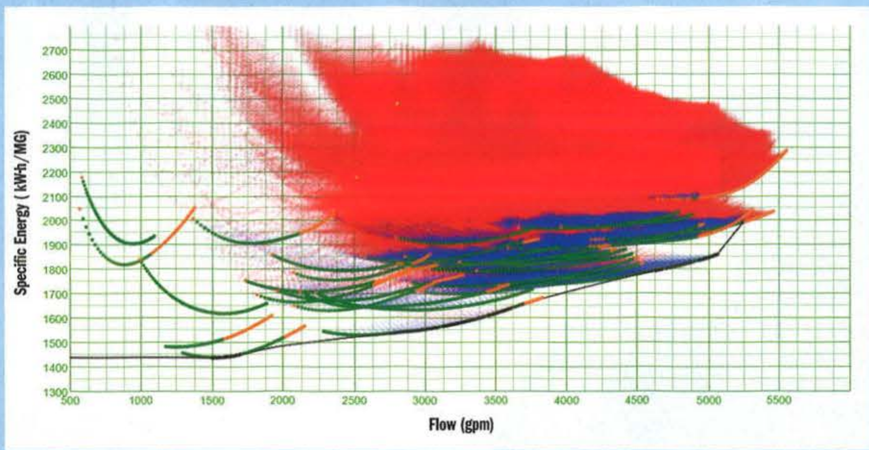
STEP 2: FIND THE NEEDLE

There now exists an optimal set of regimes for the pump station that can produce a range of flows. To automatically select the desired optimal operating regime, one can configure a set of desired operational constraints based on tank levels, desired pressure ranges, allowable maximum flow or peak power demand, or a combination of all of these.

By mapping these minimum and maximum constraints on the specific energy graph, an operational sandbox is generated that represents a range of allowable

Figure 1. Optimal Pump Station Operation

The lowest points on the specific energy map show how to optimally run the pump station for any desired flow. These operating points minimize energy consumption and promote pump health.



operating limits, represented in Figure 2 by the sand-colored region called the *sandbox*. The lowest point in the sandbox now represents the optimal operating regime for the pump station and is the proverbial needle in the haystack.

STEP 3: THE HAYSTACK JUST SHIFTED—GO TO STEP 1

Most pump stations experience changing system conditions throughout the day. Pressures fluctuate as customer demands vary. Valves open and close. Tank levels rise and fall. The carefully crafted specific energy map quickly goes stale and must be discarded and recomputed with a new set of system conditions.

Over the course of months and years, pumps wear, causing long-term shifts in the specific energy maps. The work of an intelligent pump management system is never done. The combined fast and slow changes to water system and pump station models force users to recalculate the specific energy map as frequently as once per second.

REAL-WORLD EXAMPLES

The authors have deployed intelligent pump management technology at numerous pump stations across the United States. The station whose specific energy maps were used in this article experienced an immediate 21 percent reduction in energy costs and an annual energy bill reduction of $37,500. Of course, the station's pumps always operate within POR, leading to reduced wear and increased pump life.

A different station employed intelligent pump management technology in 2014. Once the technology was installed, operators discovered the station routinely operated its three pumps well outside POR. Pump failure was common at this station—operators had to rebuild or replace one pump per year, on average. Since 2014, only one pump has been overhauled. In addition, minimizing specific energy led to an 18 percent reduction in energy usage.

TECHNOLOGY ADVANCES

Intelligent pump management is here. Recent advances in digital processing power and advanced analytics software have forever changed the landscape for a variety of industries. Water utilities are poised to reap the benefits of such technology. Operators gain from increased pump station insights and pump reliability, and customers enjoy lower water bills.

Editor's Note: *This is the fourth in a six-part series of* Opflow *articles that explores ways to optimize pumping efficiency. The fifth article will appear in the June issue and will discuss replacing "run-to-failure" pump asset management with a modern-day analytics-driven approach.*

Figure 2. Allowable Operating Limits

Constraints on flows, pressures, power, etc., define a *sandbox*, the set of operating points that meet current requirements.