Pump Up Savings Persistence: Ensure VFD Savings with Smart Pumps

Warren Fish, Northwest Energy Efficiency Alliance
Rick Huddle, Cadeo Group
Courtney Dale, Cadeo Group
Ray Hartwell, Summit Conservation Strategies
Kristen Aramthanapon, Northwest Energy Efficiency Alliance
Nick Michel, Northwest Energy Efficiency Alliance
Nate Baker, Cadeo Group
Cory Luker, Cadeo Group

ABSTRACT

Utilities have offered variable frequency drive (VFD) programs for many years, yet their full savings are often not realized due to end-user overrides and improper setup. Current market research reveals that users override control strategies at an alarming rate and meta studies show a disheartening drop in energy savings persistence over a mere three years.

Enter smart pumps—a comprehensive solution integrating the drive, motor, pump, and control logic in a single device. This cohesive approach simplifies installation and minimizes potential points of failure. Furthermore, smart pumps streamline the balancing process and eliminate the need for downstream sensors while still providing valuable operational insights.

One notable regional midstream program has spearheaded efforts to raise awareness of smart pumps, yielding an increasing market share over the past four years. As manufacturers continue to expand their smart pump offerings, this growth is poised to continue.

This paper documents research that shows the imperative of securing long-term VFD savings and illuminates how smart pumps represent a breakthrough solution. Supported by compelling case studies, we showcase the tangible benefits, both in energy conservation and operational efficiency, that smart pumps deliver.

Introduction

Pumps play a critical role in basic operations within the commercial and industrial sectors. In commercial buildings, pumps are used for heating, ventilation, and air conditioning systems; domestic water distribution; and fire protection. In industrial settings they are indispensable for cooling water, pressure washing, process water, and boiler feedwater. In the United States, pumping accounts for 21% of electricity use by motors in industrial facilities and 10% in commercial buildings (Rao et al. 2021).

Controlling the speed of a pump with a variable frequency drive (VFD) offers a great opportunity to lower electrical consumption, but as we'll discuss, VFD energy savings may not be fully realized or may erode over time. Smart pumps, which embed the VFD and controls within the pump itself, provide a way to ensure savings that persist over many years.

To illustrate, think of traditional VFDs and pumps like a group of your friends helping you put together a new bike where each person brings their own, special-ordered components. If you order all the right parts, and all the friends work well together, you can build a great bike. But if some of the parts are the wrong size or you all get into a disagreement or you're assembling it outside in the rain, there's a good chance that the gear shifter will constantly need adjustments. Over time, you might get so frustrated that you take out the shifter and have to pedal around as a one-speed. This is what it's like installing a VFD with a traditional pump: working with several different engineers to design, several different contractors to install, and if things don't go well, the system won't work efficiently, and over time, the VFD may get set at a constant speed.

However, installing a smart pump is like buying a brand new, completely assembled bike. All of the components are *designed to work together* and are assembled by trained professionals in factory conditions. Much less coordination is required and much less potential exists for incorrect assembly. You can hop on and start riding your bike right away. Additionally, a factory-assembled smart pump, like the factory-assembled bike, helps ensure that you can change speeds and be more efficient for years to come.

The benefits of smart pumps over traditional VFDs are explored in the next sections. First, we explain the savings mechanisms and potential applications of variable speed pumping, along with how utility programs have incentivized VFDs and some of the shortcomings of VFD-based pumping. Then we provide an overview of smart pumps and the variety of benefits they can provide over VFDs. We provide three case studies that describe real-life savings from smart pump installations and explain how they could increase utility programs persistence of savings.

Savings Potential with Variable Speed Pumping

Variable frequency drives are electronic devices that control a motor's speed, and by controlling the speed of a motor with a VFD, power (energy) consumption is reduced. This is especially true for equipment like centrifugal pumps as well as centrifugal fans and compressors. All of this equipment follows the affinity laws: input power is roughly proportional to the cube of speed. This means that if you slow a pump down to 80% of it's rated speed, the power required is cut in half.

Save on Both Constant Load and Variable Load

VFDs can be beneficial for both variable load systems (see Figure 1) and constant load systems. For variable load systems where the required flow and head (or pressure)[1] varies with time (e.g., an HVAC pump serving a building's heating coils), a VFD can increase or decrease the speed of the motor to meet the changing needs of the system. The savings depends on the load profile: how many hours the pump operates at each speed.

[1] Pump systems generally use head (measured in feet) as an indication of the pressure provided. Head is fluid independent, meaning that the pump will lift any fluid to the same height, regardless of its density. Pressure, on the other hand, is fluid dependent.

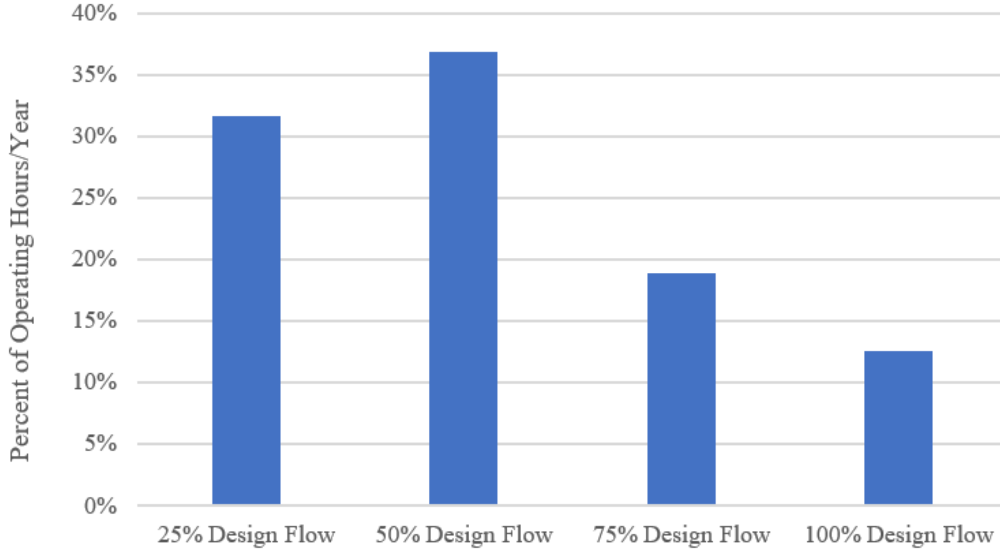

Figure 1. Example of a variable load system.

Research by NEEA and Cadeo Group also shows significant potential savings for constant-load systems like those shown in Figure 2 (e.g., constant-flow recirculation or primary flow pumps). These types of systems, which often have oversized motors, typically use a balancing valve to obtain the design flow. But a VFD can be used instead of the balancing valve and achieve significant savings (shown in Figure 3). The difference between the upper curve (balancing valve on a pump) and the lower curve (VFD) is the power savings.

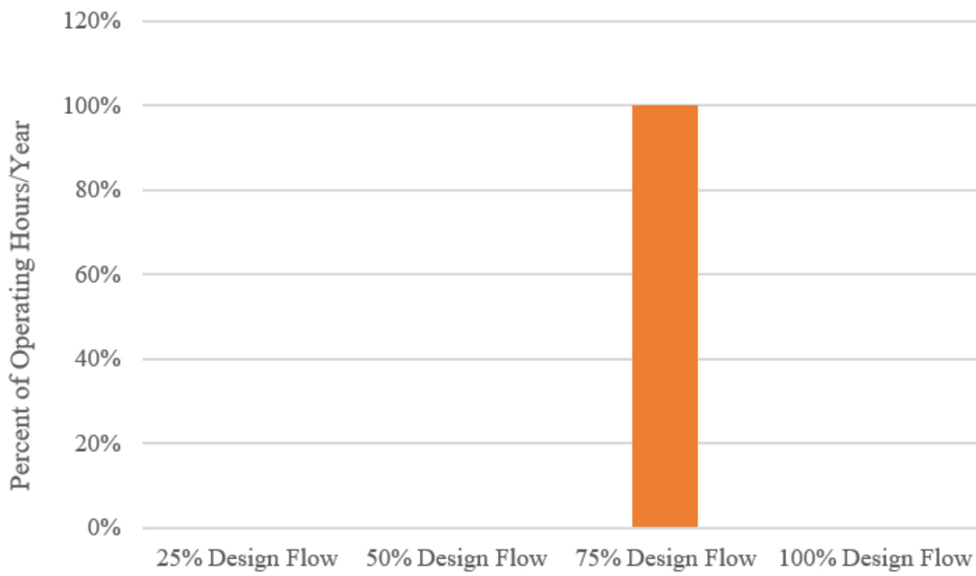

Figure 2. Example of a constant load system.

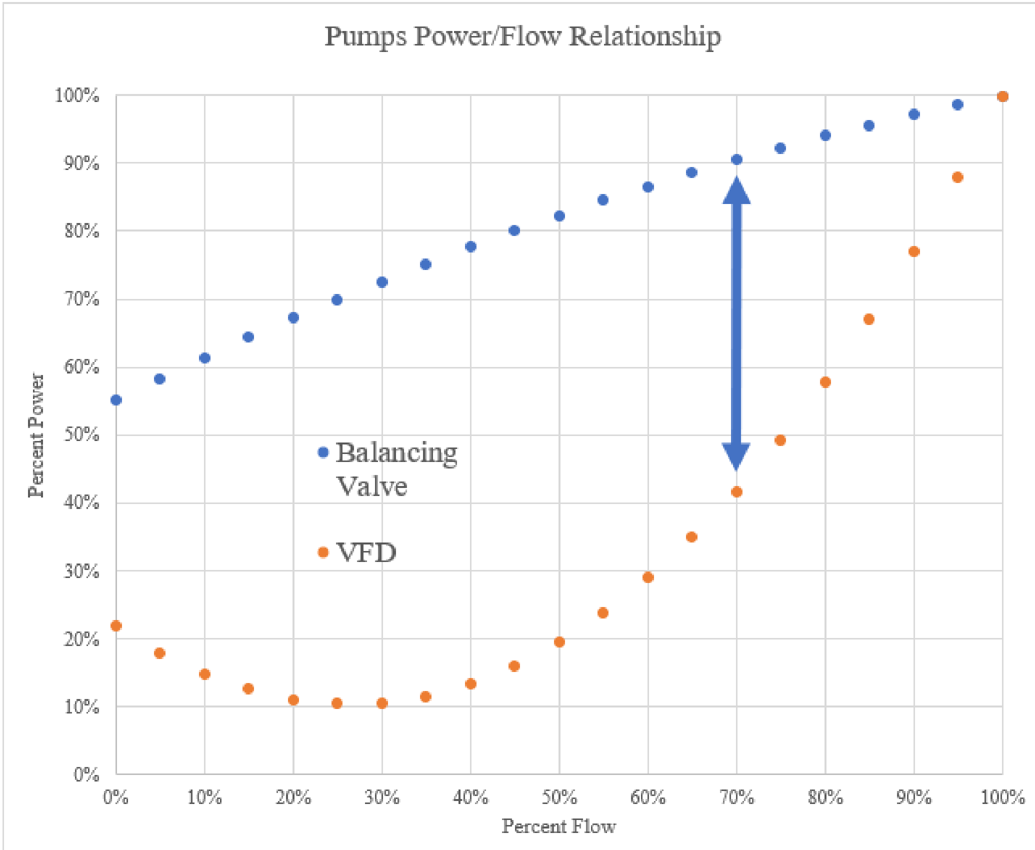

Figure 3. Required pump power versus flow for balancing valve and VFD control.

Utility Programs

As VFD technology matured and became more widely available during the 1990s and early 2000s, governments, utilities, and regional energy efficiency organizations started offering incentives and rebates to encourage the adoption of VFDs on fans and pumps in various industrial and commercial applications (Elliot and Nadel 2002). Currently, incentives are offered by approximately 700 utilities across the United States (Cham 2022).

Utility programs that incentivize VFDs have been largely successful with widespread market adoption—but some utilities have problems with low realization rates and there's a lack of certainty around persistence of savings. We explore this uncertainty in the next section.

Problems with VFD Savings Persistence

While VFDs are often used in new construction and retrofit projects, the desired energy savings are not always realized and may not persist even if they are initially achieved. A Massachusetts impact evaluation study of prescriptive VFD measures showed that failure to install controls or configure speeds drastically reduced energy savings (KEMA and DMI 2013) while the Connecticut Energy Efficiency Board (Hinsey and Pickard 2018) saw a realization rate of 54% for VFDs.

Studies also show energy savings do not always persist over time. Pumps with traditional VFDs have a multitude of potential failures or errors that cause facility managers to override them:

- Failed pressure sensors.
- Communication errors in the controls system.
- Failed controller.
- Improperly configured controls.[2]

In a series of interviews with controls market actors (BPA 2023), participants indicated that end users often override control strategies, which impacts the persistence of savings. Some interviewees stated that controls strategies are "changed right away," while others suggested that controls remain in place about half of the time. Researchers on this study theorized that packaged controls, like those found on smart pumps, may lead to less overrides.

A commercial building stock assessment shows that for commercial buildings in the Pacific Northwest, 19% of drives are operated in fixed-speed mode (NEEA 2020). An international persistence study showed that average savings drop by 25% and that the most dramatic degradations are caused by undetected mechanical or control component failures (IEA 2010). Another study (Gunasingh, Zhou, and Hackel 2018) shows persistence of 58% after six years specifically for VFD installations.

There's no question that VFDs *can* save significant energy, but the question is: how can we ensure that these potential savings are realized upon installation *and* persist over time? One potential solution is the smart pump: embedding the VFD and the controls programming into the pump to ensure that it is programmed correctly from the beginning and less likely to get bypassed in the future.

Smart Pump Basics

Just as a factory-assembled bike comes pre-packaged with parts designed to work together, a smart pump comes packaged as a pump, motor, and variable speed drive with built-in control strategies. Often called a "self-sensing" or "sensorless" pump, a smart pump integrates speed controls to automatically optimize pump operation based on system requirements. The on-board monitoring of power and motor speed can eliminate the need for downstream sensors.

Manufacturers take readings of smart pumps on a test bed. Each smart pump's power and speed are mapped to specific head and flow conditions (shown in Figure 4) which are programmed into the packaged controls. Manufacturers then program different control strategies into their equipment, so in the field a user only needs to provide design point conditions and then the smart pump varies its speed to use the lowest power.

---

[2] Retro-commissioning is a potential short-term way to address these issues, but installing a smart pump provides a long-term solution.

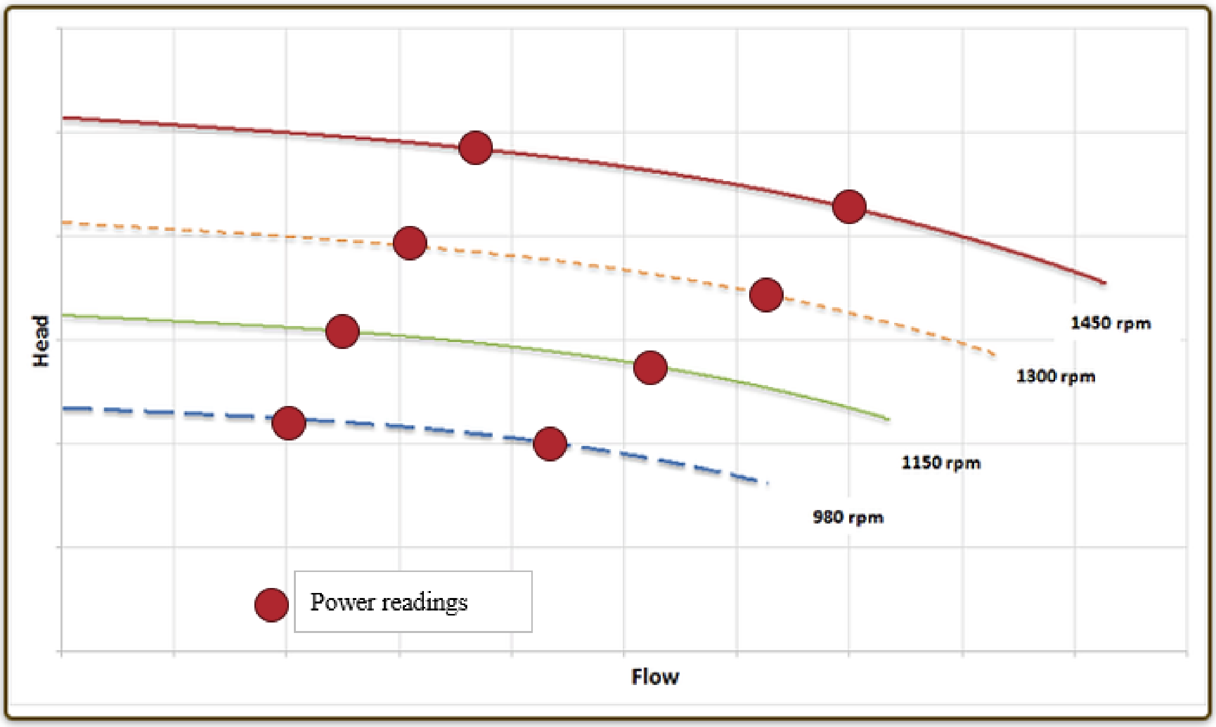

Figure 4. Illustrative example of a smart pump performance map.

All major pump manufacturers now offer smart pumps, which, until recently, have only been available in smaller sizes- below 3horesepower (hp). But over the past few years, manufacturers have continued to expand their offerings. Many manufacturers now offer a variety of sizes: from fractional hp circulators up to 5 or 10hp with some even up to 60hp, which cover a vast majority of commercial clean water pumps.[3]

Smart pumps offer several advantages over pumps with traditional controls. Some benefits increase efficiency, some make installation easier, and some help ensure long-term savings. Like traditional VFDs, smart pumps have open protocol controls (e.g., BACNet) that can connect with existing building management systems. Together, all of these benefits make smart pumps a compelling choice for market transformation.

XMP is currently researching a total installed cost comparison of smart pumps versus pumps plus a drive. While the purchase cost of a smart pump may be more expensive than a constant speed pump, when you compare against the total installed costs (added cost of VFD, conduit, pressure sensor, flow sensor, and labor to install), the incremental costs may be small.

Efficiency Benefits

Many smart pumps, particularly ones under 30hp, are often driven by ECMs. Traditional motors use an induced magnetic field to spin the wire-wound rotors. ECMs, on the other hand,

---

[3] Analyzing data from a Northwest commercial building stock assessment shows that 95% of commercial clean water pumps are 60hp and under (NEEA 2020).

use permanent magnets on the rotor. This design delivers the same horsepower using significantly less electricity, especially at reduced speeds.

Installation Benefits

Installing a smart pump instead of a standard variable speed pump with a VFD on the wall offers several benefits during installation. The integrated nature of smart pumps means that there are significant material and labor savings for the mechanical contractor, the electrical contractor, and the controls contractor. Smart pumps also reduce the potential "error points" and the need for timing coordination among trades during installation.

For example, smart pumps feature factory-aligned integrated motors, eliminating the need for specialized expertise and time-consuming steps associated with motor installation and laser alignment. Smart pumps include integrated VFDs, eliminating parts and labor associated with mounting the VFD and wiring it to the motor. The packaged design of smart pumps also addresses crucial wiring design considerations from the VFD to the motor such as cable sizing, routing, and electromagnetic interference (EMI) shielding. Furthermore, packaged VFDs guarantee appropriate sizing of the VFD to the pumping application, eliminating the possibility of incorrect VFD sizing.

With a traditional system, a controls contractor installs remote pressure and flow sensors, connects control and communication wiring, and programs the controls system. Performance mapping in smart pumps eliminates the need for downstream sensors and enables self-optimization[4].

As part of start-up, the testing, adjusting, and balancing (TAB) contractor optimizes the flow rates within the pump system. Many smart pump models offer self-balancing logic that greatly reduces the amount of time a TAB contractor spends on the job. The TAB contractor only needs to enter the required flow at design point and minimum flow conditions, and the smart pump will vary the motor speed and calculate the as-built system head at both conditions. This eliminates the need for labor-intensive pressure measurements.

Persistence Benefits

In addition to streamlining installation, many of the same features of smart pumps provide a greater likelihood of long-term savings. Being factory-assembled eliminates many of the potential errors and failure points:

- No pressure sensors to fail.
- No chance of communication errors in the controls system.
- No chance for improperly configured controls.

Traditional pumps paired with VFDs require downstream pressure sensors to control them. Mechanical fatigue, electrical issues, and poor installation can cause these sensors to fail or fall out of calibration.

Additionally, these sensors and other pump control logic must run through a building automation system (BAS). These systems often encounter communication issues due to a variety of factors. BAS communication problems can arise from network congestion, incompatible

[4] Some smart pump applications may still require sensors or may benefit from additional sensors.

protocols among devices, software bugs, or hardware malfunctions. Regular software updates and changes to system configurations can also introduce bugs or compatibility issues. As buildings incorporate more IoT devices, the complexity and potential for communication failures increase.

BAS can often be improperly configured by controls contractors due to several reasons. A lack of adequate training or experience among the contractors can lead to mistakes in setting up system parameters, interpreting sequences of operation, or integrating various components. Controls contractors need to be both good programmers as well as understand HVAC systems, which is a unique set of skills. Time constraints and project deadlines may also force contractors to rush through the configuration process, resulting in shortcuts or overlooked aspects. Inadequate documentation or communication from the design team can contribute to misinterpretations or oversights during the configuration stage. Additionally, limitations in the BAS software or hardware capabilities can sometimes hinder proper configuration, forcing contractors to make compromises or workarounds that lead to suboptimal settings.

The smart pump also comes completely assembled from the factory instead of the different components being connected on a job site under potentially difficult conditions. By increasing the likelihood of proper setup, there's a greater assurance that the system will work properly and less likelihood that operators will override the system, which is one of the greatest contributors to a degradation of savings (KEMA and DMI 2013).

Smart Pumps' Potential for Increased Persistence

The Northwest Energy Efficiency Alliance's (NEEA) Extended Motor Products (XMP) program aims to reshape the market of high efficiency pumps and circulators by collaborating closely with equipment distributors, manufacturers, and industry groups. While XMP incentivizes pump distributors to encourage sales and education of all efficient pumping systems, the program has a particular focus on smart pumps. The program, which started in 2019, promotes smart pumps through their partner distributors as well as dedicated outreach to a variety of market actors, including designers, facility managers, maintenance contractors, and energy service companies. Feedback from these market actors helps NEEA understand the barriers to adoption and value proposition, allowing XMP to adjust its message over time.

Case Studies

In the pursuit of validating the theoretical advantages of smart pumps, XMP conducts case studies. These empirical investigations serve to substantiate the benefits of embedded controls in real-world scenarios, providing tangible evidence of their efficacy. So far, three case studies have shown that smart pumps can offer a variety of benefits, depending on the application.

Smart Circulators for Independent Living

Providence Down Manor is the only independent retirement community in Hood River, Oregon. Large, multi-unit buildings like Down Manor use circulators to ensure that every apartment gets hot water quickly so residents don't have to wait while the tap runs. With long runs of plumbing to connect centralized water heaters with apartments at the end of the building, running the tap to draw a hot shower can waste considerable time and water. Hot water circulation solves the inconvenience, but it can also waste energy. When hot water is moved up multiple floors and along hundreds of feet of pipe, heat leaks out of the system. Plus, it requires the use of a pump that is continually running, and the return water must be reheated constantly.

To maintain the convenience of hot water circulation that residents were accustomed to, Down Manor installed new hot water pumps with smart circulators. These smart circulators adapt to pressure or flow requirements and reduce power when demand is lower. The energy-efficient ECM saves energy no matter how the circulator pump is operating. Overall, the smart pumps reduced the motor power draw by an average of 83% compared to the existing circulators (BetterBricks 2023a).

The building manager reported the installation went smoothly and noted that he heard no complaints about the process. Four years after installation, XMP followed up with facility staff who haven't changed the controls and have no complaints about the pump operation, suggesting that there has been no decrease in savings.

Smart Circulators for Multifamily Housing

Similarly, Bellwether Housing's experience with domestic hot water circulators in affordable multi-family buildings in Seattle showcased the adaptability and efficiency of embedded control strategies. Bellwether installed smart circulators in four of its buildings across the city. Each facility chose the most efficient controls strategy, adaptive pressure, and saw a 90% decrease in power consumption compared to the existing circulators (BetterBricks 2023b). Maintenance staff reported no issues regarding reduced service quality, temperature fluctuations, or prolonged wait times. Staff expressed confidence in the system's reliability, noting its flawless performance six months post-installation. "If anything had gone wrong, I would have known about it, but these pumps have been operating flawlessly."

Smart Pumps for Class A Offices

Built in 2008, Tower 333 is a 20-story office tower in Bellevue, Washington, featuring more than 400,000 sq. ft. of rentable space. LEED- and ENERGY STAR®-certified, this office building also includes a half-acre outdoor plaza and a ground-floor restaurant.

Due to its height, Tower 333 requires a domestic water-booster system to deliver reliable water pressure all the way to the top floor. The original system consisted of three 20hp constant-speed booster pumps that operated in a staged sequence, bringing on successive pumps as demand changed.

Even though the building is relatively new, these booster pumps were creating a lot of complaints. The pumps were loud enough to bother occupants in the conference room above. Maintenance staff also had to constantly rebuild the pumps due to failed components.

The facility staff worked with one of XMP's partner distributors to design and install a smart-pump booster skid. Featuring four 5hp pumps, the new skid is powered by ECMs and came with a factory-built sequencer. This sequencer optimizes pump selection for maximum efficiency. Calculations estimate that the new skid will save 87% over the previous pumps. Some of this savings comes from a reduction in horsepower, but some of it initiates from better control. This solution not only saves energy, but also improves system reliability and reduces maintenance. The chief facilities engineer was pleased with the installation, "I'd have to say the biggest benefit for me and my staff is the reduced amount of time needed to troubleshoot failed sensors, rebuilding pumps, and responding to noise complaints. That peace of mind is worth a lot." Since facility managers are often the users who override controls (BPA 2023), these smart pumps are expected to continuously save.

Conclusion

While VFDs offer great potential for energy savings, studies show that initial savings can fall short and VFD overrides can eliminate them altogether. Smart pumps provide a logical path that may increase the persistence of savings by reducing the potential for installation errors and long-term failures.

The XMP program is working to prove-out these long-term savings through case studies. XMP continues to promote smart pumps within the program and the program's connections with pump distributors enables us to understand the barriers, solutions, and value propositions relevant to different market actors. In 2024, XMP is expanding its outreach to designers, energy service contractors, service contractors, facility staff, technical schools, and multi-cultural chambers of commerce. We hope to continue to build a repository of case studies and publish them.

While we have many competent and capable friends in design and construction, the truth is that being human, there's always the potential for errors and miscommunication. A drive and pump specified and ordered from separate individuals opens the door to misalignment, and a construction site virtually never matches the optimal assembly conditions of a factory. With smart pumps, utilities can offer their clients a pre-assembled system that will keep the client efficiently pedaling down the road for years to come.

References

BetterBricks. 2023a. *Smart Pumps Help Keep Costs Down at Providence Down Manor*. Portland, OR.

BetterBricks. 2023b. *Smart Circulators Provide Convenience and Savings for Bellwether Housing*. Portland, OR

BetterBricks. 2023c. *Class-A Office Building Finds Grade-A Booster Pump*. Portland, OR

Bonneville Power Administration (BPA). 2023. *Market Research and Momentum Savings Team Quarterly Call: Controls Market Characterization Research Findings*. Portland, OR

Cham, M. "VFDs: Rebates and What's Changing". 2022. Pittsburgh, PA.

Elliot, R., and S. Nadel. 2002. *Fan and Pump Systems: Markets and Programs*. American Council for an Energy Efficient Economy.

Gunasingh, S., J. Zhou, and S. Hackel. 2018. *Persistence of Savings from Retro-Commissioning Measures: A field study of past ComEd Retro-commissioning projects*. Madison, WI. Seventhwave

International Energy Agency (IEA). 2010. *Commissioning Cost-Benefit and Persistence of Savings.*

KEMA and DMI. 2013. *Impact Evaluation of 2011-2012 Prescriptive VSDs*. MA. DNV. Massachusetts Program Administrators, Massachusetts Energy Efficiency Advisory Council

NEEA (Northwest Energy Efficiency Alliance). 2020. *Commercial Building Stock Assessment*. Portland, OR.

Hinsey, J. and N. Pickard. 2018. *C1630 Largest Savers Evaluation Final Report*. CT. Nexant. Submitted to the Connecticut Energy Efficiency Board in partnership with Warren Energy Engineering

Rao, P., P. Sheaffer, Y. Chen, M. Goldberg, B. Jones, F. Cropp, and J. Hester. 2021. *U.S. Industrial and Commercial Motor System Market Assessment Report Volume 1: Characteristics of the Installed Base*. Lawrence Berkeley National Lab, Berkeley, CA.