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Retrofitting Primary Chilled Water Pumps With VFDs

By Eric O'Neill
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How much of what you "know" do you actually know, and how much have you learned secondhand? Most of us probably pick up a large portion of our "knowledge" from secondhand sources (much like this article or the people we work with). This is particularly true of what-not-to-do knowledge. And that's great, because if we had to learn every lesson firsthand, we'd go out of business, pronto.

However, no one has gone out of business for asking the question, "Why?" Human learning thrives on our ability to dig into a subject and build connections between areas of understanding we have well developed. Asking why is an excellent way to do that. It's also an excellent way of discovering whether some of that knowledge really holds or if it is based on an assumption that is no longer true.

As an example of this, Alliant Energy sponsored a retrocommissioning study on an 800,000-sq-ft, full-service hospital in the heartland of America. Its chilled water system, like the rest of the building, is a conglomeration of several decades' worth of construction projects. Based upon that description, I bet you probably know exactly which hospital I'm talking about. Go on. Take a guess.

Well, maybe not, but that building is Mercy Medical's hospital in Dubuque, IA. Despite the nearly-generic, high-level description, the project gets more interesting once you're inside the facility. The Energy Star plaque near the elevator sets the stage: the facilities staff is on a mission to reduce energy costs, and they're no slouches. At some point, they harvested most of the low-hanging fruit, and they wanted outside expertise about their more complicated systems for those harder to reach problems.

Their chilled water system consisted of two constant-flow primary loops (the ’70s building plant and the Energy Center plant), connected to three variable-flow secondary loops (Figure 1). To make matters worse, these two primary loops are on opposite sides of the building. The secondary loops primarily use two-way valves, with most of the remaining three-way valves slated for replacement with two-way valves in the next budget year. An initial review of the project would likely suggest tweaking some setpoints or making a few controls changes, which are excellent starting points. However, whenever there’s a constant speed system controlling a variable load, there’s bound to be more energy savings.

‘YOU’VE GOTTA HAVE FULL FLOW THROUGH THE CHILLER, OR IT WON’T LIKE IT.’

You can probably hear one of the engineers from your past saying that — or maybe you’ve said it yourself. But is it still true today? Why did that become such common knowledge, so much so that it is nearly ubiquitous to have constant-flow primary pumps in this type of building?

This is one of the times when it’s useful to understand why that’s true. Because here’s another old saying that does turn out to be true: Only when you really understand the rules can you break them.

Historically, chillers responded relatively slowly to load changes, whether that was due to flow or temperature changes. Water temperatures change pretty slowly, as you would expect because buildings are thermally sluggish. But water flow? That can change quickly if you’re not careful. If water flow decreases rapidly while the chiller is still flooding the evaporator with no heat to vaporize the refrigerant, the chiller will fault off on low-suction pressure (or worse, like freezing the water in the evaporator). That’s when the chiller doesn’t “like it,” and neither do the facilities staff who bear the brunt of the fallout when the building starts getting too warm.

Microprocessor control systems have come a long way and help the chiller manage these variables, but things haven’t always been that way. This may explain why many engineers believe a constant flow through chiller is needed. The technology in days past just wasn’t up to the task.

However, even some relatively old chillers by today’s standards have controls that help them respond properly to load changes. Two of the three chillers for this particular project are nearly 20 years old, so the following strategies can be applied to many of today’s operating chillers (consult the manufacturer). And most modern controls systems are fully capable of giving up-to-the-second feedback on a number of controls points. Often, the only thing stopping many of these systems from moving forward is the outdated mentality that you must have constant flow through a chiller.

WHAT TO DO?

The first chilled water plant, the ’70s building, has three 50-hp primary chilled water pumps. The second chilled water plant, the Energy Center, has two 50-hp primary chilled water pumps. The ’70s building plant operates up to two pumps with the third serving as backup. The Energy Center operates one pump with the other serving as a backup. The plants can work separately or together to meet the building loads, depending on the required capacity (Figure 1).

These chiller plants are separated by a decoupling bridge (aka primary-secondary bypass), which allows excess primary flow to return to the chiller. Prior to this project, this bridge was used to maintain a constant flow through the chillers, independent of the flow in the secondary loop.

Flow in this bridge consists of primary water that's not being used in the secondary system (where all the loads are attached). In other words, it's wasted flow. Luckily, the bridge had an existing flowmeter, and logged data from this project indicated bridge flow that was substantially higher than necessary, even during peak demand periods.

This unnecessary flow wastes significant energy, so we proposed a project that would add VFDs to each pump. We could then properly control the system to reduce the primary flow to only what was necessary to meet loads. Based on our original calculations, the payback on this project was just over three years, including all engineering and project management. The owner agreed to this proposed system and hired us to help them implement the project.

While deciding how best to proceed with the controls upgrade, we had a number of things to consider. First, we needed to get the greatest energy savings at the lowest cost. All incremental energy savings needed to be evaluated against their incremental cost to ensure the cost effectiveness reflected our original analysis to which the owner agreed. Second, we needed to be sure the accuracy of any equipment used is sufficient for their respective tasks. You can only control things as well as you can measure them. Finally, and most importantly, we needed to be particularly careful about avoiding chiller shutdowns. That's important in all buildings, but especially in a hospital. Maintenance calls dramatically overwhelm saving energy, so the project will get quickly dismantled if shutdowns becomes a problem.

MINIMIZING FLOW

The savings is achieved by installing the VFDs on the primary pumps, and modulating primary flow as closely as was reasonable to the secondary flow. While this could be done in a number of ways, we decided on a minimally invasive approach using as much existing equipment as possible.

The existing bridge flow sensor is reasonably accurate down to approximately 200 gpm. By controlling the primary pumps to provide this 200 gpm, we're able to get a large portion of the energy savings while avoiding invasive piping modifications, such as adding check valves or control valves. This option may not achieve 100% of the savings available, but it will be close because there are low-flow limits through the evaporator that limit the potential savings. The additional modifications and controls necessary to achieve every last drop of savings weren't cost-justified for the project.

As a safety precaution, temperature sensors were added around the bridge to sense whether flow had reversed (secondary flow returning directly to the supply). For a minimal price, this gave some redundancy in an event where the bridge flow sensor experiences technical difficulties and a reversed flow condition isn't sensed. One comforting fact of the project is that if any issues are identified or any faults are issued, the system can simply be reverted temporarily to the previous setup by setting all primary pumps to 100% speed.

PREVENTING CHILLER FAULTS

As discussed before, chiller faults are the primary concern with this system modification, and rapid flow variation through the chiller is the primary culprit. Keep in mind that no matter what technology you install in a chiller, once refrigerant is in the evaporator, no amount of technology is going to remove it. We can't fight the laws of thermodynamics. We still need heat, and proper flow control is our only tool for that challenge.

There are two ways for flow to change rapidly in a piping system. One is to increase the hydraulic power delivered by the pump, either by staging on/off pumps or increasing the speed of the operating pumps. The second is to change system flow resistance.

Minimizing changes to the hydraulic pumping power is fairly simple. Pumps are directly controlled by the control system, and control gains can be used to slow down pump reactions to a safe rate. During periods of time when pumps need to be staged on or off, they can be sped up or down at a rate that allows the other pump(s) and chiller to compensate.

Changes in system flow resistance, however, are the hidden danger in variable-speed primary pumping modifications. Consider the example shown in Figure 2. Each chiller has an isolation valve (V-1 and V-2) to prevent flow through a chiller when it is off, essentially closing a bypass around the active chiller. However, what happens when chiller 1 is operating and chiller 2 is called to stage on? V-2 will have to open before flow can be proven through chiller 2. When it does, the flow through chiller 1 will begin to drop as flow increases through V-2 until additional flow is added by the pumps (either by engaging additional pumps or increasing their speed). And if you're controlling your pumps to a constant flow through the bridge, the flow path between the pumps and bridge will have no effect on the overall flow provided by the pumps. This reduction in flow, if too sudden, will shut down the active chiller on faults, so proper control of these transition periods is essential.

In either situation, the key is to go slow, especially on two-way valves and pump speeds. The space temperatures aren't going to respond quickly to changes in the plant, so why risk a fault by moving too fast?

SYSTEM TESTING

The Alliant Energy retrocommisisoning program also funds functional performance testing and bill monitoring to ensure the project is completed properly and the client has hard evidence of the results from their investment.

As part of this testing, one of our final steps was to collect data on bridge flow, which can be compared to the data prior to implementation. Figure 3 displays the before (red) and after (blue) bridge flow as a function of chiller load. As we expect, prior to project implementation, and as chilled water load increases, the secondary pumps divert flow away from the bridge. It even appears that near high loads there is excess flow, which just means the system was overdesigned and this proposed measure will save energy during most operating conditions.

The pump savings are, essentially, coming from the difference in flow rates between the two cases. The larger the flow reduction, the greater the energy savings. But in most cases, we expect some reduction in flow. And remember the affinity laws: even small reductions in flow near full flow can have significant energy impacts because pump power consumption is proportional to the flow rate cubed.

RESULTS

We verified all energy savings using a combination of both the on board kWh readings from the VFD as well as using calculations based on the trended pump speed. There are additional savings to be had now from optimizing the chiller and condenser pumps in conjunction with the chilled water pumps, but that's a project for another day. This project is already seeing signfigant energy savings with no operational issues, and its helpful to get facilities staff comfortable with incremental system measures.

Overall, the cost of this project was primarily for new VFDs and engineering, with an overall payback of just over three years. And that's just considering pump savings. There are additional savings due to the improved chiller efficiency with higher return water temperatures. So remember to constantly question what you have or why you're doing the things you do. There are plenty of projects out there that are very cost-effective and right under your nose. You just have to be willing to challenge yourself, but the results are worth it. ES

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