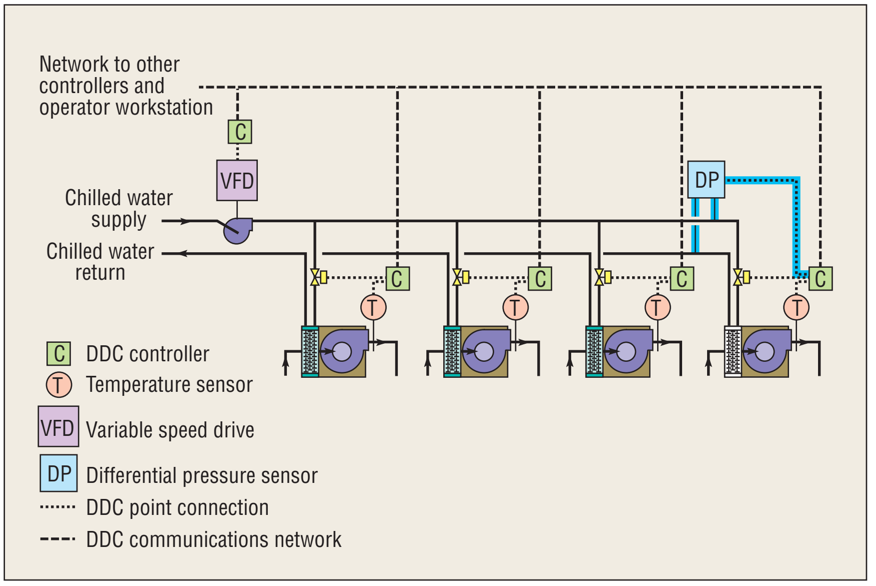
Packaging DDC Networks with Variable Speed Drives

By designating complex network-based control sequences as packaged products with responsibility for their performance vested to manufacturers, it may be possible to simplify designs and increase the utilization of VFDs and other advanced control technologies in the field



1 Typical variable flow chilled water distribution system.

By THOMAS HARTMAN, PE,
Principal,
The Hartman Co.,
Marysville, Wash.

Two of the greatest recent technological breakthroughs in our industry have been variable frequency drives (VFDs) for AC motors and direct digital control (DDC) networks. But if there were a law against under utilizing either of these technologies, I fear all HVAC engineers would be in jail today; VFDs and DDC networks are the least effectively applied technological tools in our industry. Difficult as it may seem, many designers are still questioning whether these two technologies are even useful in projects where their proper application could reduce energy use and improve overall system performance by an order of magnitude or more.

Variable speed drives and network-based DDC controls can be applied to nearly all of the major HVAC components—from fans to pumps to chillers. In fact, an increasing number of these are being installed with VFD speed regulation and DDC control. But, make no mistake about it, even though variable speed drives and DDC controls are becoming widely employed, the technology is overwhelmingly underutilized. To show why and offer suggestions for improving the situation, this article uses the example of a chilled water distribution pumping system in which a variable flow chilled water pump serves multiple loads with modulating, two-way control valves (Fig. 1).

Here, a variable speed pump is operated to maintain a differential pressure setpoint for a distribution system that serves a number of loads. Each load has a modulating valve operated by a DDC controller. Fig. 1 also shows the DDC network that connects all controllers together such that the value and status of all connected points are accessible from an operator workstation. Note that the network is used to transmit the differential pressure value to the controller operating the pump. So, we have a variable speed pump and networked controls operating the system.

What's wrong with this picture?

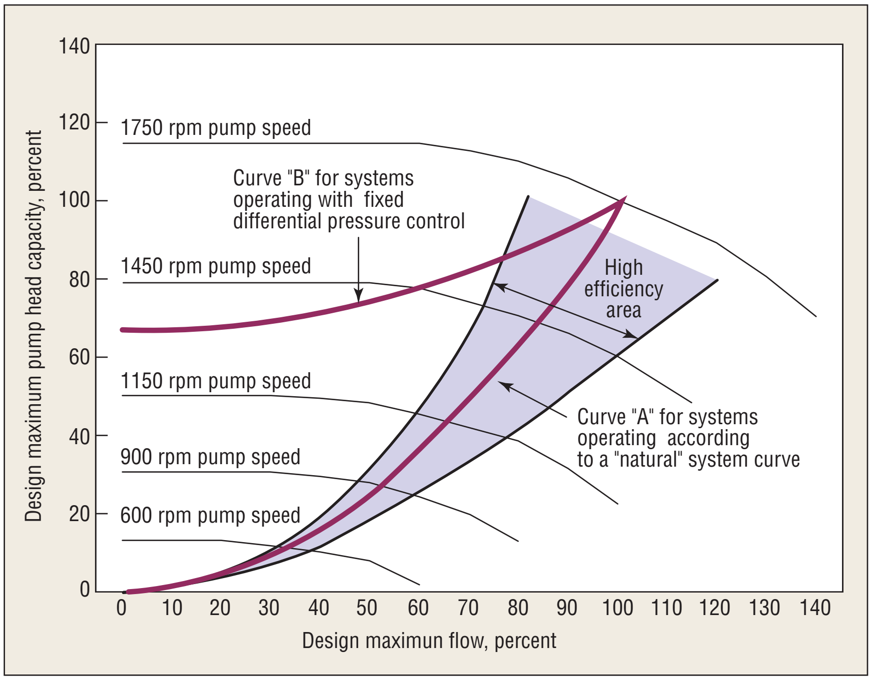
Pump and fan laws

Fan and pump laws dictate that a centrifugal pump can supply 50 percent of design flow at 50 percent speed and require only 12½ percent (0.5 cu) of the full flow power, but only if the pressure at which the fluid is supplied is permitted to fall to 25 percent (0.5 sq) of the full flow pressure. If the supply pressure does not fall with the square of the flow requirements, then the pump speed cannot be reduced as the law permits. This results in a reduction in pump efficiency. These relationships are shown in Fig. 2.

A zone of highest pumping efficiency throughout the speed range of the pump is highlighted in blue. If the system curve approximates that of a simple circulating system (*e.g.*, the head pressure requirements fall with the square of the flow), the system curve is approximated by Curve A. Such a system curve ensures that the pump operates at the highest pumping efficiency through all flows and that the power required falls with the cube of the flow requirements. The system curve for a typical variable flow distribution system, as represented in Fig. 1, is shown by Curve B. In Curve B, the pumping efficiency quickly falls as flow requirements are reduced.

Part load operation

There are actually two costly energy penalties for systems that follow Curve B. Loss of pump efficiency is one of them. The second is the high pump-head pressure required at decreased loads. Because the majority of variable flow pumping systems are operated to maintain a fixed differential pressure between the supply and return distribution lines, the pumping pressure is not permitted to fall significantly as the load decreases, and a substantial energy penalty is the result. This combination of reduced pump efficiency and a higher head pressure limits opportunities for reducing pump power at part-load conditions.



2 Pump/system curves for pressure and network pump controls.

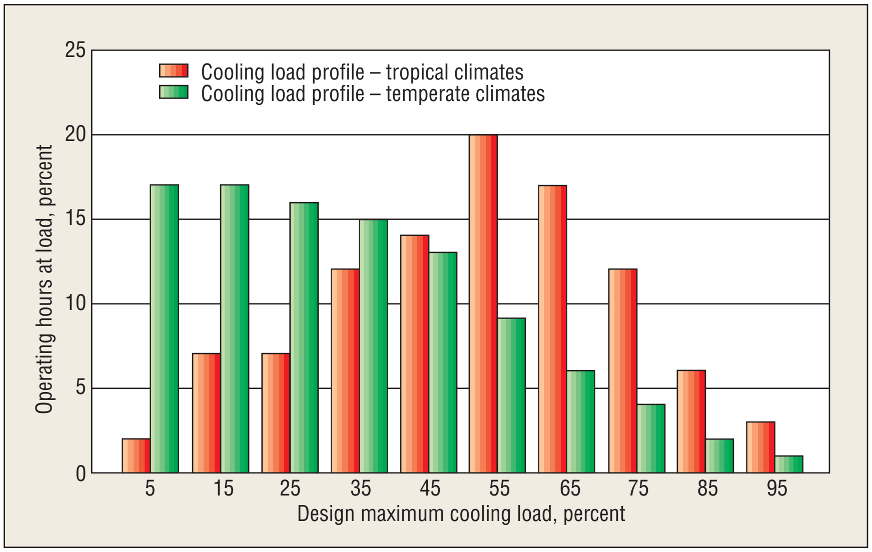
Regarding chillers, manufacturers try to remedy this loss by offering screw compressors or other positive displacement-type compressors that do not lose efficiency under such conditions.

Multiple units are often employed to reduce part-load inefficiencies. But these approaches do not attack the second penalty, which is the extra power requirement due to the high head requirements (that are unnecessary) at low flows.

Centrifugal fans, pumps, and compressors are simple devices that are very efficient at their sweet spots (the high-efficiency zone in Fig. 2). It is reasonable to find ways to accommodate limitations of these devices with system concepts permitting the pressure to decrease as flow decreases to operate at the highest possible efficiencies throughout all flow conditions.

The value of such an approach

continued on page 83



3 Cooling load profile for comfort conditioning in two major climates.

continued from page 81

is illustrated in Fig. 3, which shows the expected load profiles for chilled water plants employed for comfort conditioning. Fig. 3 also shows the percent of total operating hours the system spends at various load capacities for two basic climates. Assuming the chilled water flow is proportional to the load, Fig. 3 approximates the flow requirements for a distribution system to the loads served. Note that the overwhelming majority of pumping hours is spent at reduced flows in both climate types. Systems operating according to Curve A in Fig. 2 can achieve enormous energy savings over Curve B systems at these flow conditions.

Change is needed

Rules for sizing valves and certain pump control features predate the availability of variable speed drives. To achieve good control, it is still recommended that control valves be sized so that 25 to 50 percent of the full flow system pressure drop occurs across the valve.

Rules of thumb in hydronic systems vary, but it is common to see systems configured so that at full flow the control valve pressure drop is one-third of the total system head; the pressure drop through each load is one-third of the total head; and the remaining one-third consists of piping and all other pressure drops. This is the criterion employed for Curve B in Fig. 2 wherein the differential pressure setpoint is about two-thirds of the total full flow system head. While these rules did provide successful control for many applications back in the days of simple pneumatic controls, the solution is energy intensive and also has negative side effects.

For example, consider the Fig. 1 system operating at low loads. Because the flow through the coil is low, the pressure drop across the coil approaches zero. However, the pump operates to maintain a constant pressure across the valve and coil, so the pressure drop across the valve increases. This increase in pressure across the valve at low flows reduces "controllability" and is one reason why control instability is more likely to occur at low load conditions.

New rules are needed

The old valve-sizing rule of thumb served an important purpose when linear pneumatic controllers were prevalent, but it has always had significant limitations, and it is not an energy-efficient approach in the era of variable speed pumping. Knowledgeable designers recognize immediately the two questions that have to be answered to move beyond this reliable, but less efficient, approach. The first question is "What is the most effective design direction to take?" and the second is "How can I be sure it will be implemented smoothly without wreaking havoc on my projects?"

While the industry employs both variable speed drives and networked DDC technologies with increasing regularity, the full energy savings and performance capacities of these remarkable developments are rarely achieved.

The answer to the first question is to employ the DDC network rather than differential pressure to operate the pump speed. Such an approach would permit the pump to slow, so long as all the loads are satisfied, without regard to a differential pressure. Such control is now possible because DDC technologies are maturing and developing more sophisticated software controllers.

Control manufacturers have had sufficient experience with software loop control to add features like variable gains, anti-windup, and self-tuning capabilities. Perhaps the most important feature that is evolving with DDC systems is their ability to "network" points among various controllers. It may be time to consider putting these features to work.

The two primary reasons the rule of thumb concerning valve selection seeks a relatively high pressure drop across control valves are 1) to ensure linear control response, and 2) to ensure that the operation of each valve is undisturbed by the action of adjacent valves. If the full flow pressure drop across the valve is low, then linear response is lost. One valve suddenly opening or closing as its load changes state could change conditions at an adjacent load.

It is not difficult to imagine that instabilities could occur as two or more adjacent valves each *correct themselves* in response to changes of the other. This type of instability would have been enormously troublesome in the days of pneumatic controllers, but networked DDC systems can accommodate such changing conditions smoothly and easily.

Imagine that the communications network in Fig. 1 is used to control the variable speed pump and valves instead of the differential pressure sensor. Each valve could be modulated not only according to local load changes but also in response to system changes as communicated over the network. The pump could be operated to meet flow requirements as efficiently as possible. A system schematic that provides such control is shown in Fig. 1—

just remove the differential pressure sensor. Properly programmed, such a configuration can permit the chilled water distribution pump to operate in the high-efficiency zone of Fig. 2 at nearly all conditions. The control valves for each load can be sized for a significantly lower pressure drop, thus reducing the total system head at all loads and reducing the size of the pump.

In simulations and field tests, such chilled water distribution system configurations have been shown to cut the required annual pumping power by one-half to two-thirds below that of a traditional system. This is exciting. These designs provide savings in both first costs and annual energy costs, resulting in energy savings in the range of $1 to more than $3 annually per gpm of chilled water pump capacity.

A change worth pursuing

Such an advance in pumping control technology is an exciting prospect, but the second question still begs an answer. How can the designer be sure the new approach will be implemented effectively and without hassles? It is not too difficult to envision the basic changes in controls and operation required to capture these substantial pumping energy savings; however, designers cringe at the prospect of trying to describe networked solutions in a sequence of operations. Most designers will dismiss entirely the chances that a controls contractor will provide a trouble-free implementation of a network-based sequence no matter how well it is described.

The unhappy truth seems to be that the *process* by which control sequences are implemented is an enormous part of the problem in raising the level of DDC technology applied in the HVAC industry today. Most designers realize that the valve sizing rules result in a premium for pump-power costs, but they are reluctant to change a design approach they know can be implemented without troublesome startup problems.

Productization

To try to develop a solution to this dilemma, imagine that the pump applications technology outlined in this article was a *product* that designers could specify, such as air handlers or VAV boxes. In these products, it is the product supplier and not the designer who assumes ultimate responsibility for the performance of the product. That performance is based on sizing and other general information provided by the designer in the construction documents.

Software "products" are widely used today but not as elements in design documents for the building construction industry. However, by designating certain more complex network-based sequences as products whose basic features are generally understood by a wide segment of our industry, it may be possible to develop an implementation path that is similar to that of other products. This process of "productization" is a promising model for successfully implementing new network-based application controls.

Manufacturers of related HVAC components and controls manufacturers are both logical choices for delivering network-based software applications. My company is working with interested firms in these two categories to try to define and modularize reasonable networking technology "packages" such as the example of low power pumping outlined in this article.

Other network application technologies that can be modularized in similar fashion are chiller plant control, VAV system control, and comfort controls operated by individual tenants. The improvement in performance and reduction in energy available by implementing such networked controls are substantial. We in the industry should consider working together to package specific networked technologies so they can be employed efficiently and effectively as applications arise.

To get the benefit of all voices in our industry, I urge interested readers to visit our Website frequently over the next year to get a better understanding of and provide comments to a developing vision as to how networking technologies can be packaged most effectively. I also urge readers to write to *HPAC* to voice your opinions on this important topic.

Summary and conclusion

While the industry employs both variable speed drives and networked DDC technologies with increasing regularity, the full energy savings and performance capacities of these remarkable developments are rarely achieved. The present design and implementation process that places complete responsibility for the implementation of such technologies on the designer is effectively blocking such advancements in our industry.

A promising prospect that could change this situation is the development of DDC network "products." To undertake this challenge, the industry needs to hear all interested voices to determine if and how such packaged products can be developed and implemented in systems to achieve higher performance. **HPAC**

Mr. Hartman is a member of HPAC's Board of Consulting and Contributing Editors. Additional information on technologies discussed in this article is available at www.hartmanco.com. Any questions or comments about the article may be addressed to Mr. Hartman at tomh@hartmanco.com. See pg. 7 for contact information.

Circle 504 on reader service card if this article was useful; circle 505 if it was not.