Variable-flow chilled water plants became a practical reality when chiller equipment and system controls capable of handling variable primary (chilled water) flow (VPF) were introduced in the early 2000s.

The idea of varying chilled water flows in the plant at part-load has been applied for decades. After all, if the coils in the field do not require full flow (load), why should we supply the full design flow? The advent of two-way valves in cooling coils reduces the water flow rate at part-load conditions. However, for many years chiller manufacturers have mandated constant flow through the chillers, especially at the evaporator. This was largely driven by the fear of catastrophic failures caused by water flow rate changing quicker than the ability of the chiller controller to safely run the chiller.

Figure 1 shows a typical constant-flow chilled water plant with two-way valve control at the coils. In these designs, the primary chilled water pump pumps a constant flow into the chillers’ evaporators when the chillers are switched on. The bypass line circumvents excess water that is not required in the field. However, for many years chiller manufacturers have mandated constant flow through the chillers, especially at the evaporator. This was largely driven by the fear of catastrophic failures caused by water flow rate changing quicker than the ability of the chiller controller to safely run the chiller.

With both the primary-only and the primary-secondary systems, chilled water plant designers had to be content with designs that employed chilled water bypasses, decoupler pipes and even three-way valves to enforce the constant flow requirement at the chillers. Old habits die hard, and such is still the case in many chilled water plants today. As most chilled water plants run predominantly at part-load, this constant flow requirement at the chillers consumed more energy than is necessary, degrading the overall chilled water plant efficiency defined in the first part of this series (see HVAC&R Nation May, issue 61).

Since the early 2000s, a number of chilled water plants have been installed with variable-flow operation. Understanding the key requirements of such a system is critical to reaping the benefits of a cost-effective, reliable and efficient installation.

Figure 3 (p16), shows a chilled water plant running with VPF conditions. Primary variable speed pumps vary the chilled water flow through the operating chiller to meet field demand. Chillers are sequenced as necessary to achieve the capacity and hold the system temperature set-point.

This creates chilled water pump power savings across the entire system, from design flow down to the minimum flow of the last operating chiller. The extent of pump power savings is dependent on the modulation range (also called “range-ability”) of the chiller flow and the chilled water plant control differential pressure set-point. Good designs have good modulation and relatively lower control set-point for pump controls. Such designs will mimic the power savings close to those shown in the theoretical cube-law savings for variable speed driven pumps.

The VPF systems is an improvement over primary-secondary systems as the design does away with the secondary pumps and replaces the constant primary pumps with variable-flow pumps. Not only is it more efficient but the installation also benefits from having fewer pumps and less electrical installation in the plant room.

So, what types of chillers are suitable for variable-flow plants? The answer depends on the chiller compressor and the controllers employed. The key here lies in the advice from the manufacturers and

**Primary–only CV**

1. 11.7°C 100 L/s
2. 11.7°C 100 L/s
3. 11.7°C 100 L/s

**Part Load**

1. 11.7°C 50 L/s
2. 11.7°C 100 L/s
3. 11.7°C 100 L/s

**Bypass**

- 13.0°C 250 L/s
- 5.0°C 250 L/s

**Primary CV pumps**

- 5.0°C 50 L/s

**Figure 1: A typical constant flow primary-only chilled water plant.**
the selection of experienced installers and controls companies. In general, the current generation of chillers are capable of VPF. Some scroll chillers are also capable of VPF. Older generation chillers may also be capable of VPF operation, but once again consult the manufacturer on the limitations. Key questions to ask the manufacturer are:

- What are the design, minimum and maximum flow rates of the chiller and their corresponding water-pressure drops?
- What is the maximum rate of change of flow rate that I can run these chillers at?

The first question allows the designer to assess the range-ability of the chiller. As a guide, a minimum ratio of 1:2 between minimum and design flow is recommended for VPF plants. This is more critical in the case of multiple chillers to ensure smooth chiller sequencing. The maximum flow is for VPF plant designs that intend to over-pump operating chillers beyond their design flows to maximise plant efficiency before engaging the next stage of chiller plant loading.

The minimum rate-of-change of flow rates ensures that the chiller can respond to flow changes without endangering chiller safety, while at the same time avoiding any nuisance trips when flows are varied for the chiller(s). Here, a minimum tolerance of 20–30 per cent rate-of-change of flow per minute in chillers is recommended for VPF plants. Chillers that have a lower rate-of-change tolerance, or do not have this information readily available, are generally not recommended for VPF designs. Chillers with advanced variable flow control can tolerate up to a 50 per cent rate-of-change per minute.

In general, larger chillers have a multitude of heat exchanger types, sizes and water passes to achieve these VPF selection criteria. And, therefore, chiller specifications for VPF plants should include the range-ability and rate-of-change of flow capability of chillers.

When chilled water flow is reduced while maintaining chilled water set-point, there is little difference in chiller efficiency at the part-load condition. This is due to the same chilled water set-point at the chiller and similar condenser water temperatures at design flows, therefore, the chillers work at a similar lift to a constant-volume system. The chilled water VPF works well with nearly no penalty on chiller power input.

A comparison of part-load relative chilled water plant power input of various designs is shown in graphs in Figures 4 and 5. The left bar is the baseline “Parallel AHRI”, which is based on standard AHRI temperatures and constant flow rates* The second bar is the same design with VPF on the chilled water side. The third and fourth bars are constant flow rates at low-flow low-temperature (LFLT) design (see Chiller Plant Technology – Part one in HVAC&R Nation May, issue 61).
As the chilled water plant operates at part-load conditions, reduction in chilled water flow-rate in a VPF system improves overall chilled water plant efficiency.

WHAT ABOUT THE CONDENSER?

Variation in condenser flow as a function of load is not as easily implemented as that of chilled water.

Definitions

* AHRI is the Air Conditioning, Heating and Refrigeration Institute and publishes the AHRI 551/591 Standard for Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle. It defines the standard rating conditions for full and part load operation of chillers and heat pumps. Our local MEPS standard has adopted standard rating conditions for chillers, which are: 6.7°C leaving chilled water at 43 L/s/MW and 29.4°C entering the condenser at 54 L/s/MW.

** Surge occurs in a chiller when the pressure difference between the condenser and evaporator exceeds the capability of the centrifugal chiller compressor to overcome this pressure difference. Surge generally happens at partial load with high lift, such as warm condenser water temperature, but can also happen at or near full load. Surge causes extreme stresses on the chiller mechanical components, and if left unchecked can eventually damage the compressor. It is good practice to check the chilled part-load selection at both cooler condenser water conditions as well as warm conditions to verify the operating envelope of the chiller. For variable-flow designs, these data points need to be checked at the specific reduced flow rates as well.

As condenser water flows are reduced, there is a corresponding increase in chiller power due to the higher lift that the chiller now needs to reject heat. Furthermore, if the condenser connects to an open cooling tower water system, the static lift of the tower will be fixed and not provide any pump power savings resulting from a reduction of flow. These factors negate some of the condenser pumping power savings in such systems.

Condenser water variation through the chiller requires the same variable flow limitation parameters from the chiller manufacturer as with VPF. Additionally, the part-load operation and data with variable condenser flow needs to be verified with chiller manufacturers to ensure stable operation. Certain types of centrifugal chillers are more susceptible to surge** under these conditions, hence the need for this verification.

More information

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