

■ Engineering ■ REPORT

Published by Kele, Inc.

January 2008 #18

CONVERTING PRIMARY/SECONDARY CHILLED WATER SYSTEMS TO ALL VARIABLE FLOW



by
Gil Avery

There is a perception in our industry that the control of variable flow chilled water systems is so complicated that it is difficult for the operators to understand. Thus, many engineers and designers have hesitated in converting primary/secondary systems to all variable flow, even though the return on investment is measured in weeks rather than years. The conversion, when controlled correctly, may reduce the chilled water plant energy consumption at least 15%, and often 20% or more (ref.#1). This reduction occurs primarily because the chillers can operate in what has become known as the "Max-Cap" range. This range is typically available 98% of the time. For chillers with water-cooled condensers and cooling towers, it occurs whenever the outdoor wet bulb temperature is below design. Seventy-eight degrees Fahrenheit wet bulb is the design in much of

the country. For air cooled chillers, the Max-Cap range occurs any time the outdoor dry bulb temperature is below the design dry bulb temperature, for example below 95°F. Chillers, with halo-carbon compressors, depending on the make and model, can often produce from 10% to 40% more cooling capacity than their nominal rating with colder condensing temperatures. Operation in this range is a win-win event; the cooling capacity goes up and the kw/per ton (total energy used) goes down. In order to utilize this additional capacity, the flow and/or the delta T between the supply and return chilled water must increase. The flow through chillers in primary/secondary systems is generally constant and therefore they cannot utilize much of the benefit of operating in the Max-Cap range. The control and staging of the chillers is actually much simpler than for a primary/secondary system. It is not necessary to measure or determine the direction of flow in the crossover, and the flow through the on-line chiller(s) is always equal to or greater than design flow.

These are the steps necessary to make this conversion:

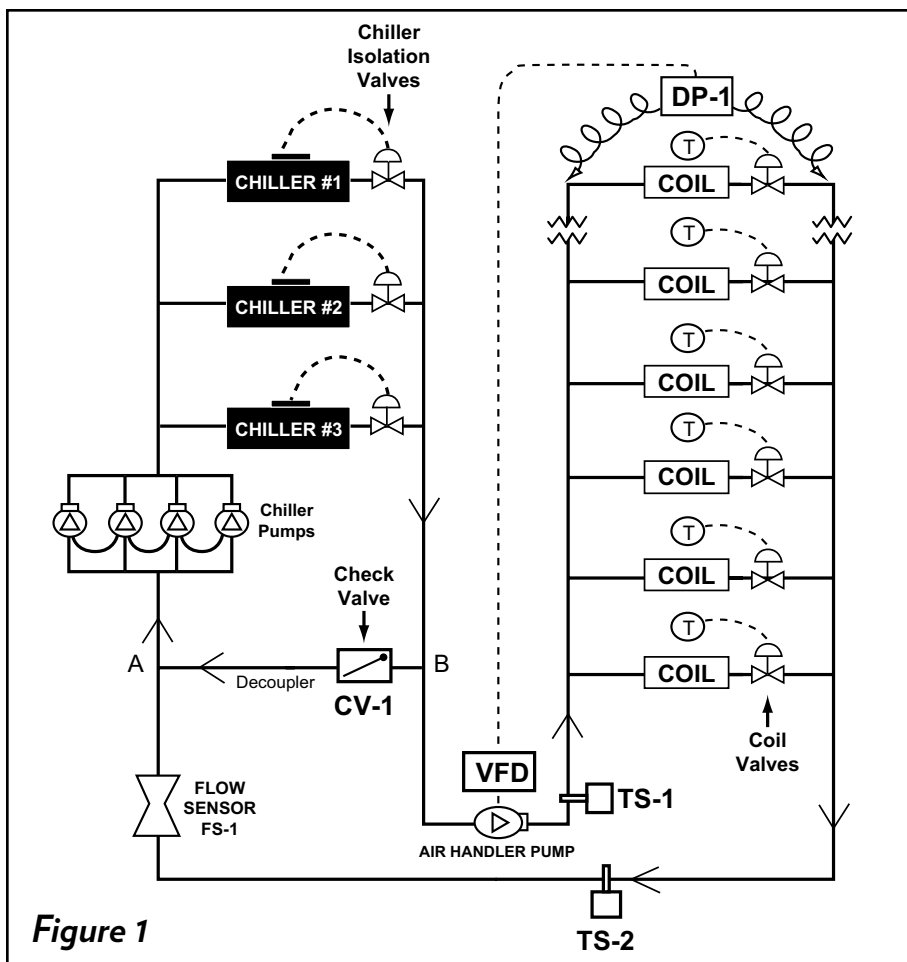
1. Replace all air handling unit 3-way valves and/or 2-way modulating valves that do not close tightly. The replacement valves must close tight at one and one half times the total system head. The dynamic rating (maximum differential that the valve wetted parts will withstand) must also meet this differential rating. All modulating valves must have a rangeability of at least 200 to 1 and meet ANSI Class VI leakage rating. Converting to all variable flow places the chiller pumps in series with the variable speed air handler (secondary) pump and therefore the differential pressure across the air handler valves will be greater than in a primary/secondary system where only the secondary pump determines the differential pressure.
2. Remove all balancing valves that do not serve as isolation or service valves. Those left in for service should be opened fully. Close or remove all bypasses between the chilled water supply and return lines. Open 100% all triple-duty valves.

3. Control valves must be closed when the AHU they serve is off unless water is circulated in the coils in cold weather to prevent freezing, when the chillers are off.
4. Interlock the chiller (primary) pumps to run with the chiller they serve. These pumps may be manifolded together, as shown in Fig.1 or each pump may be piped to a chiller. When operating in the Max-Cap range the chiller pumps are in series with the air handler pump and flow through the chiller pumps may increase above the design flow of a primary/secondary system.
5. Control the VFD on the air handler pump from a differential pressure sensor (DP-1) across the branch serving the most remote AHU. If the air handler valve positions are known, reset DP-1 from the most demanding air handling unit valve. This will keep the pump head as low as possible.
6. Install a check valve, CV-1, in the existing decoupler connecting the chilled water supply and return mains (points A-B), to prevent return water from mixing with supply water. The check valve may be line size and may have a manual or automatic opening mechanism so that the valve can be opened and

water circulated to the AHUs in cold weather when the chillers are off. A modulating two-way control valve may be used instead of a check valve. Control this valve from a differential pressure sensor across the chiller evaporators. The valve must be sized for the minimum flow of the largest chiller, a close-off rating at least as high as the air handler pump cut-off head and for a pressure drop at or less than the setting of differential pressure sensor DP-1. The differential pressure across points A-B will never be less than the setting of DP-1.

7. Install a two position chilled water isolation valve in the branch to each chiller. These valves may be line size, metal seated butterfly valves unless they will also be used as a service valve. If they are used for servicing, then tight shut-off valves must be used.

8. Stage the chillers "on" from temperature sensor TS-1 with the set point at the design supply water temperature to the air handlers. Staging the chillers on from supply temperature enables the chillers to operate in the Max-Cap variable flow range to produce their maximum capacity depending on the entering condenser water temperature. The on-line chiller(s) will load fully (above rated capacity whenever the outdoor Wet bulb temperature is below design) before the next chiller is brought on-line. The chart in Figure 2 depicts the typical performance of a 1,000-ton chiller as the evaporator flow



**Typical Performance of a 1,000-ton Chiller Operating
in the “Max-Cap” Range with a Constant Evaporator
 ΔT of 12°F and an Increasing Evaporator Flow**

CDS Deg. F	Tons	CW GPM	Evaporator PD (FT)	Increase in “EPTE”	Total kW	Net kW/TON
85	1,000	2,000	20.6	--	580.0	.58
80	1,090	2,178	24.0	2.1	601.6	.55
75	1,130	2,258	25.7	3.2	602.1	.53
70	1,156	2,310	26.8	3.9	605.0	.52
65	1,182	2,362	27.9	4.6	595.6	.50
60	1,207	2,412	29.0	5.3	596.7	.49
55	1,233	2,464	30.0	6.0	597.8	.48

Notes:

CDS = Condenser Water Supply

CW = Chilled Water

EPTE = Evaporator Pump Transport Energy (kW)

Figure 2

increased from 2,000 to 2,464 GPM and the condenser water supply temperature decreased from 85°F to 55°F. The increase in evaporator pump water transport energy (EPTE) is added to the chiller KW to arrive at the total and net KW per ton. The net kw/ton for this machine has decreased from 0.58 to 0.48 and the cooling capacity has increased from 1,000 to 1,233 tons (23.3%). (See Figure 2.)

9. For each chiller, set the control point for the temperature sensor in the supply water off the chiller 3° below design. If the design is 44°F, set the chiller sensors at 41°F. This will enable the chillers to operate in the more efficient Max-Cap variable temperature range. The chart in figure 3 depicts the performance of a typical 1,000 ton chiller as the delta T increased from 12 to 14 degrees. The kw/ton for this machine decreased from

0.58 to 0.49 and the capacity increased 11.6% from 1,000 to 1,166 tons. (See Figure 3.)

10. Since both the chilled water flow and the delta T vary, the actual kw/ton may be less than that shown in Figures 2 and 3.
11. To stage a chiller off, close the

chiller isolation valve and stop the chiller pump when the building load drops far enough below the capacity of an on-line chiller to avoid cycling the chiller back on too quickly. Load is proportional to flow times delta “T”. Flow can be measured by flow sensor “FS-1” and delta “T” from temperature sensors “TS-1” and “TS-2”. Flow can also be measured with a differential pressure sensor across the chiller evaporator if dependable flow characteristics of the chillers are known.

12. Vary the speed and cycle the cooling tower fans (and tower bypass valve if used) from a temperature sensor in the condenser water supply to the chillers.
13. Reset the condenser water supply temperature with the outdoor wet bulb temperature. Do not reset below that recommended by the chiller manufacturer.

**Typical Performance of a 1,000-ton Chiller Operating
in the “Max-Cap” Range with a Variable Evaporator
DT and a Constant Evaporator Flow of 2,000 GPM**

CDS Deg. F	Total kW	Tons	CWR Deg. F	CWS Deg. F	Delta T	KW per Ton
85.0	580.0	1,000	56.0	44.0	12.0	.58
80.0	592.9	1,078	56.4	43.5	12.9	.55
75.0	587.8	1,109	56.3	43.0	13.3	.53
70.0	585.0	1,125	56.0	42.5	13.5	.52
65.0	569.5	1,139	55.7	42.0	13.7	.50
60.0	565.0	1,153	55.3	41.5	13.8	.49
55.0	571.3	1,166	55.0	41.0	14.0	.49

Notes:

CDS = Condenser Water Supply

CWR = Chilled Water Return

CWS = Chilled Water Supply

Figure 3

- 14.** All equipment interlocks, flow and temperature stabilization time delays, chiller isolation valve timing, condenser water controls, etc., must be specified as recommended by the chiller manufacturers, to complete the sequence of control for an all variable flow chilled water system.

Ref.#1 - "Controlling Chillers in Variable Flow Systems" Gil Avery
February 1998 *ASHRAE Journal*

Gil Avery, PE
Kele, Inc.
12/31/08
gil.avery@kele.com