CONTINUOUS COMMISSIONING^{SM} OF A THERMAL STORAGE SYSTEM

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ABSTRACT

Chilled water thermal storage systems can reduce the electrical demand charge during the on-peak months. However, operational problems such as the inability to fully charge the system or premature discharge of the stored cooling capacity can be costly, which can result in turning on chillers during on-peak hours in order to provide cooling to the buildings. In this paper the optimization of a thermal storage system operation through Continuous Commissioning^{SM} is presented. Detailed building and chilled water loop commissioning activities are discussed.

INTRODUCTION

A thermal storage system stores chilled water or ice during periods of off-peak electrical demand. The system is designed to provide either partial or complete building cooling needs during on-peak hours when most or all chillers are shut down. The objective is to minimize the demand charge during on-peak periods. However, operational problems such as the inability to fully charge the system or premature discharge of the stored cooling capacity often force the chillers to be turned on during on-peak periods, which can be very costly (Liu et al. 1999).

Various control strategies which optimize the operation of thermal storage systems have been developed in recent years (Rawlings 1985, Ferrano and Wong 1990, Spethmann 1993, Kawashima et al. 1995, Krarti et al. 1999). However, most of these works are performed under a simulation environment and concentrate on development of accurate load predicting models. There are some performance evaluations of ice or chilled water storage system (Shavit and Goodman 1985, Moore and Harmon 1998, Sohn et al. 1999, Gillespie et al. 1999). Only one deals with overall optimal operation of thermal storage systems through Continuous Commissioning process (Liu et al. 1999).

In this paper, the optimization of a thermal storage system operation through Continuous Commissioning is presented. Detailed building and chilled water loop commissioning activities are discussed. The case study presented here shows that commissioning of the thermal storage system is not limited to the storage tank itself, but is closely related to successful commissioning of building air handling units (AHUs) and chilled water loops. The full benefit of a thermal storage system cannot be realized without the optimization of the AHUs and chilled water pumps operation.

SYSTEM INFORMATION

The thermal storage system in this case study serves a mental health campus with over 600,000 square feet of conditioned space in more than a dozen major buildings. The storage system was installed after a campus-wide energy efficiency retrofit. It is designed to store 42°F chilled water with a return water temperature of 56°F. Total storage capacity is 7000 ton-hours. The tank is designed to provide all the cooling needs of the campus during the on-peak hours (from noon to 8:00 PM weekday, June through September) in order to keep the electric demand below 1400 kW. There are four major chillers located in 3 different chiller plants, with total cooling capacities of 1325 tons (two 425 ton, one 275 ton, and one 200 ton). The chiller plants and the thermal storage tank are connected through the campus chilled water loop. The storage tank is in parallel with the chillers. Figure 1 is a piping schematic of the chilled water system. Tank pump and building chilled water pump motors are equipped with variable frequency drives (VFDs).

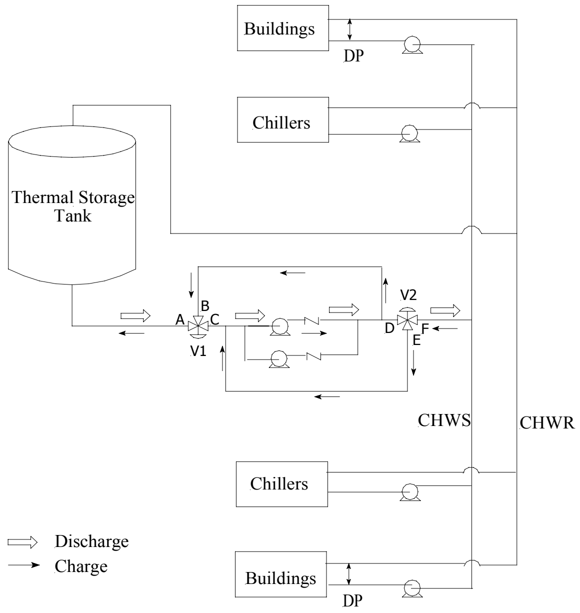

Figure 1. Piping Schematic of the Thermal Storage Tank and the Chilled Water System

In the charging mode, chilled water produced by the chillers enters the bottom of the storage tank (Port F→ Port E → Pump → Port B → Port A). In the discharge mode, 3-way control valves V1 and V2 move together to opposite positions, causing the chilled water to reverse its flow direction. It is now pumped out of the bottom of the tank and supplied to the campus chilled water loop (Port A→ Port C → Pump → Port D → Port F).

There are 14 temperature sensors at different levels of the storage tank that monitor the temperature profile of the tank. Differential pressure of the chilled water loop was monitored at two locations close to the end of the chilled water loop.

PROBLEMS DURING ON-PEAK MONTHS

During on-peak months, the tank operating mode was based on time of the day. It discharged from 11:30 AM to 8:00 PM. After 8:00 PM, all the chillers were turned on to charge the tank as well as to supply chilled water to the buildings. The chillers were shut down the following day at 11:30 AM before the storage system switched over to discharge mode.

The first year of operation revealed several problems during on-peak months. (1) One or two main chillers sometimes went into alarm and shut down automatically during the off-peak hours. However, no one was on site to monitor the system operation, hence, the chillers were not being reset by the operators. This resulted in the tank being severely under-charged, and the operators had to run the chillers during on-peak hours. (2) The charging process was extremely slow. The tank was not fully charged before it was switched to the discharge mode, which sometimes forced the chillers to be turned on during hot weather conditions to provide adequate cooling to the buildings. (3) The chilled water differential temperature (DT) across the tank was only 8 to 10°F, far below the design DT of 14°F, which caused the tank to be depleted prematurely.

Figure 2 shows the weekday whole campus electrical demand profile for the summer of 1997 from June 18 to September 30. It can be seen that on-peak demand was considerably higher on several occasions because of the problems mentioned above. An on-peak demand of 1731 kW was set in July 2, 1997, which cost the facility more than $10,000 in the following 12 months due to a clause in the rate schedule. This penalty could have been avoided if the on-peak demand was controlled below 1400 kW. Also note that the off-peak demand normally peaked at late morning as the campus electrical load picked up. Meanwhile, the operator also tried to charge the storage tank as much as possible by running several chillers until just before the on-peak hours began, which compounded the problem. The off-peak demand went up to over 2700 kW during that summer.

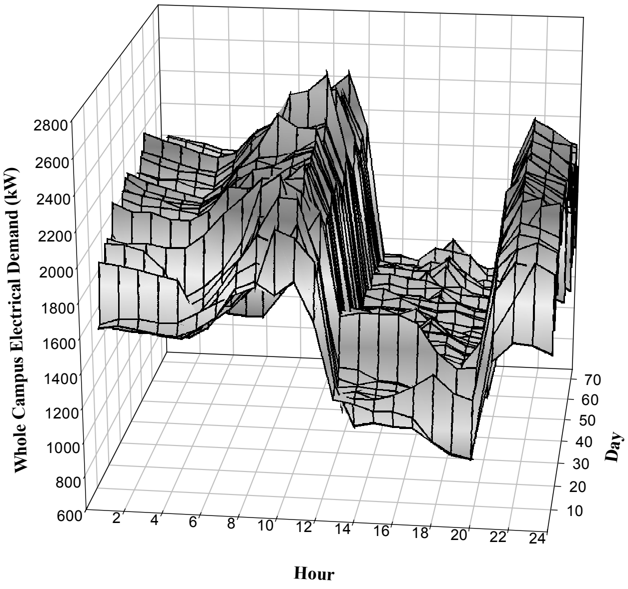

Figure 2. Weekday Whole Campus Electrical Demand Profile From June 18 To September 30, 1997

ANALYSIS

The commissioning team investigated these problems, reviewed the existing operating sequence, retrieved the trend data from the EMCS, and analyzed the problems experienced. The causes are summarized and discussed below.

Insufficient Alarm Generating and Reporting Capability

Nobody is in the control room to monitor the system operation after 5:00 PM everyday. However, chillers sometimes go into the self-protection mode and shut themselves down due to various faults such as high condenser pressure, low refrigerant temperature, or motor overload, etc. On one occasion, the maintenance staff forgot to reopen the cooling tower make up water supply valve after some repair work was performed at the cooling tower. The cooling tower eventually ran out of water and caused two main chillers to shut down at night. The operator walked into the control room the next morning only to find that the tank was not charged at all. He had no choice but to turn on the chillers during the on-peak hours.

The control system actually has the capability of paging the operator whenever an emergency like this occurs. However, this function was not programmed into the EMCS. This was corrected immediately by defining various emergency conditions and setting up dial out procedures. Recommendations were made to provide a laptop computer for the operator so that he could monitor the system operation remotely. The operator eventually obtained a laptop computer so that he could monitor the operation at home.

Water Balance Problem at the Two Main Chillers

There was no chilled water flow regulation at the two main chillers. Chilled water flow rates were measured to be 20 - 30% higher than the design chilled water flow rates. These high chilled water flow rates caused a low temperature difference across the chillers, and the chillers could only produce 45°F chilled water during the first pass of the charging process, which normally took 7 to 9 hours. In order to fully charge the tank, this low temperature chilled water had to be passed through the chillers again to produce 42°F chilled water, causing extended chiller operating hours and poor chiller efficiency.

Actions were taken to resolve the high chilled water flow problem at the chillers. To balance the system, manual control valves at the discharge side of the chilled water pumps were throttled at first to reduce the water flow. VFDs were recommended and later installed on the chilled water pumps to improve the flow control. Manual control valves were then fully opened when the VFDs were installed and operational.

Low Cold Deck Temperature Settings at the AHUs

The investigation found that most of the AHU cold deck temperature set points were very low, ranging from the upper 40s to the lower 50s. The low set points inevitably resulted in chilled water control valves that were wide open almost all the time, contributing to low return chilled water temperatures.

Operational problems that called for lower cold deck temperature set points included leaky mixing dampers for multi-zone units, higher than necessary hot deck temperature set points, and leaky steam or hot water control valves, etc. These problems were identified and addressed during the building Continuous Commissioning process. Every AHUs cold deck temperature set point was optimized and reset based on outside air temperature. Subsequently, the chilled water control valves started to modulate in order to control the cold deck temperature at the set points. Comfort levels at the buildings were improved and we observed increased chilled water return temperature.

Existence of 3-Way Control Valves at Some AHUs

One obvious factor for the low return chilled water temperature was the existence of 3-way control valves in a number of AHUs. These valves caused bypass of supply chilled water into return pipes under part load conditions, resulting in low return water temperature. The need for each 3-way control valve was evaluated and recommendations were made to remove or cap off most of the bypasses at the 3-way control valves.

Poor Pump Speed Control Algorithm at the Storage Tank

In the charging mode, tank pump speed was modulated by controlling the chilled water temperature entering the bottom of the tank at 42°F. The VFD would slow down when the chilled water temperature was higher than 42°F, it would speed up when the chilled water temperature was lower than 42°F. There were two major problems with this control scheme: first, because of the water balance problems at the two main chillers, chilled water temperature entering the storage tank was relatively high during the first round of charging. This directly resulted in a slow charging process due to low pump speed. Second, this control scheme sometimes caused other buildings to "fight" with the tank in order to get chilled water during charging periods when the tank was running at high speed, resulting in comfort problems in those buildings. Because of this, the control sequence was modified to control the tank pump speed by maintaining a slightly negative loop differential pressure at the end of the chilled water loop.

In the discharging mode, tank pump speed was modulated by controlling the chilled water loop DP at a set point of 6 psi. This set point was unnecessarily high since the DP sensor is located close to the end of the chilled water loop, and each building has its own chilled water pump to provide additional pressure. Excessive differential pressure caused high flow and low return chilled water temperature. As a result, the tank chilled water was almost depleted by 6:00 PM on a typical warm day. To correct this problem, the DP set point was adjusted from 6 psi down to -6 psi. Storage tank pump speed dropped dramatically and the differential temperature at the tank improved.

Non-Optimal Pump Speed Control Algorithm at the Buildings

Building chilled water pump speed was modulated to maintain either constant building chilled water DP or constant building chilled water return temperature of 55°F. Some of these DP setpoints were also found to be very high, causing excessive chilled water flow at the cooling coils and resulting in low return water temperature. Further more, some coils have a higher design DT and can return chilled water at temperatures higher than 55°F.

The control schemes were modified. For large buildings with multiple AHUs, the building pumps still controlled the building chilled water DP, which was reset based on outside air temperature. For smaller buildings with one or two AHUs, building pumps speed control were modified to provide cascade control for cold deck temperature. A typical control logic diagram is shown in Figure 3.

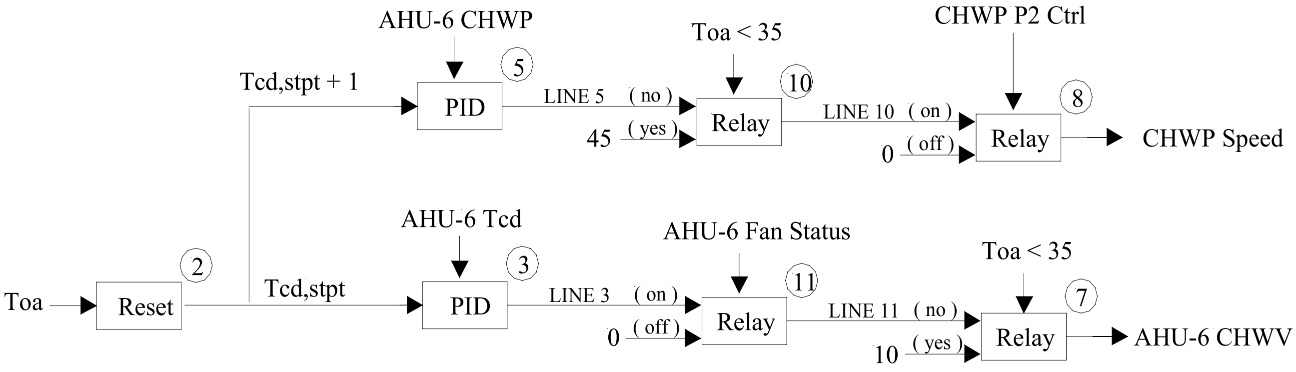

Figure 3. Schematic of the Control Logic for Building Chilled Water Pump

Turning off office AHUs during unoccupied periods, resetting the hot deck temperature set points, and other Continuous Commissioning measures all helped reduce the cooling loads on the buildings. The system operating condition improved significantly after most of the identified problems were resolved during the Continuous Commissioning process. The storage tank is being charged at a faster rate. It is considered fully charged if the temperature sensor reading at the top of the tank reaches 42°F and the stored cooling tonnage is over 7200 ton-hr. Once the storage tank is fully charged, control valves V1 and V2 move to different positions to lock the tank. One of the 425-ton chillers can be turned off to reduce the whole campus electrical demand, which normally occurs during late morning.

Since the completion of the Continuous Commissioning process, electrical demand has been kept below 1400 kW during the on-peak periods. Off-peak demand during on-peak months also dropped. Figure 4 shows a typical summer month (June 2000) whole campus electrical demand profile after the Continuous Commissioning activities. Since the whole campus electrical demand dropped rapidly after 4:30 PM, the control sequence was modified to turn on one small 200-ton chiller after 5:00 PM if the thermal storage tank is about to run out of chilled water and the electrical demand is below 1200 kW. This situation normally occurs during hot weather conditions. As a result, building comfort level was improved without incurring additional demand charges. Also note that off-peak demand during this month is below 2200 kW, as compared to over 2700 kW in Figure 2 prior to the Continuous Commissioning process.

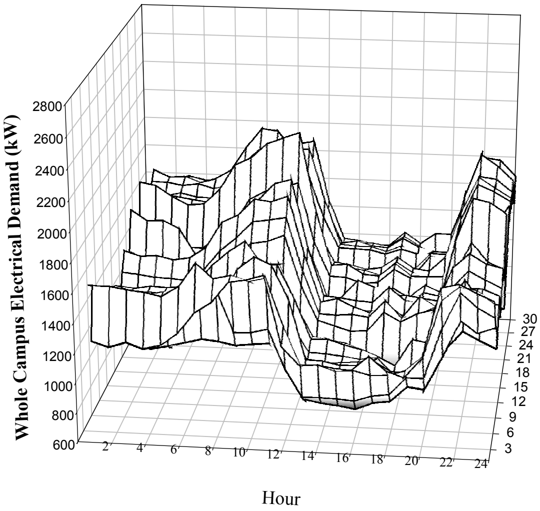

Figure 4. Typical On-Peak Months Electrical Demand Profile After Continuous Commissioning

OPPORTUNITIES DURING OFF-PEAK MONTHS

The existing operating sequence during the off-peak months also showed room for improvement. The operators usually kept the same operating sequence used in the on-peak months for off-peak season operation. Several chillers would be turned on during winter days to fully charge the tank. Unfortunately, high electrical demand was set during those months under this operating sequence. Although these electrical demands do not carry over to the next twelve months, they still represent thousands of dollars of extra charges that can be avoided.

The control sequence was modified to optimize the operation of the thermal storage tank and chillers during off-peak months. Whole campus cooling load was forecasted 24 hours ahead of time to determine the cooling tonnage to be charged (Wei et al. 2000). The control strategy takes advantage of cooler ambient temperatures by charging the thermal storage tank at nighttime. The key for this control strategy is to make the electrical demand profile as flat as possible. To cope with the warm spells during early spring, only the small 200 ton chiller is turned on when the outside air temperature is above 55°F and there is not enough cooling capacity in the storage tank.

Figure 5 compares the monthly billed electrical demand for the base year (1997-1998), the year when the Continuous Commissioning was in process (1998-1999), and the year after Continuous Commissioning was completed (1999-2000). It can be seen that considerable demand reduction was achieved after the Continuous Commissioning process. Cumulative demand savings are $57,800 from February 1999 to November 2000. The cumulative savings from Continuous Commissioning, including natural gas, electricity, and demand are $326,712 for the same period. The commissioning costs were $140,000, which resulted in a 10-month payback to the mental health facility.

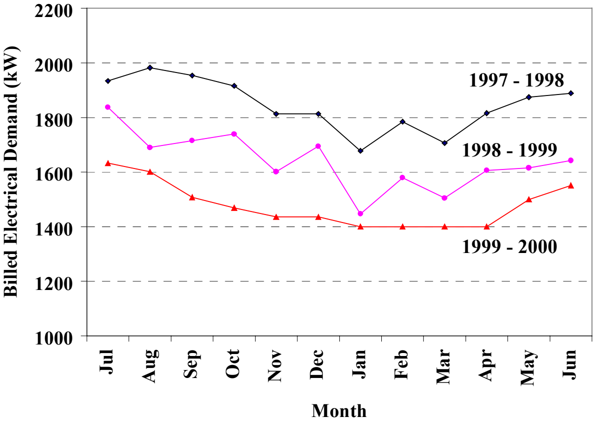

Figure 5. Comparison of Billed Electrical Demand Before and After Continuous Commissioning

SUMMARY AND CONCLUSIONS

The commissioning of a chilled water storage system at a mental health facility has been discussed. Electrical demand has been reduced through the Continuous Commissioning process, and the building comfort levels are improved due to an enhanced operating strategy of the thermal storage system. It is important to point out that successful commissioning of the thermal storage tank requires a thorough understanding of the interactions among all the systems involved. Building and water loop commissioning need to be performed prior to the storage system commissioning.

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