Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

A virtual prototyping approach to the design of advanced chiller control systems

Michele Albieri [*] **Alessandro Beghi** [**] **Cristian Bodo** [***]
Luca Cecchinato [****]

[*] *Rhoss S.p.A., via Oltre Ferrovia, 1, I-33033 Codroipo, Italy, (e-mail: Michele.Albieri@rhoss.com)*
[**] *Dipartimento di Ingegneria dell'Informazione, Università di Padova, via Gradenigo 6/B, I-35131 Padova, Italy, (e-mail: beghi@dei.unipd.it)*
[***] *Dipartimento di Ingegneria dell'Informazione, Università di Padova, via Gradenigo 6/B, I-35131 Padova, Italy*
[****] *Dipartimento di Fisica Tecnica, Università di Padova, via Venezia 1, I-35131 Padova, Italy, (e-mail: ceck@unipd.it)*

Extended abstract

The requirement of primary energy to cool and to heat buildings is an important part of the overall energy consumption in Western countries, summing up to about 30% of the U.S. and Europen global energy consumption, due to the increasing use of air conditioning units for cooling residential and office buildings during summer. It is generally agreed that in spite of the advancements made in computer technology and its impact on the development of new control methodologies for Heating, Ventilation, and Air Conditioning (HVAC) systems aiming at improving their energy efficiencies, the process of operating HVAC equipment in commercial and industrial buildings is still a low-efficient and high-energy consumption process (Yaqub and Zubair [2001]). Classical HVAC control techniques such as ON/OFF controllers (thermostats) and proportional-integral-derivative (PID) controllers are still very popular, due to their their low cost and ease of tuning and operation. However, these simple controllers do not grant a sufficient energy efficiency and therefore plants operating with such control architectures prove to be inadequate to meet the challenge of reducing the overall energy consumption for building cooling.

In this brief paper we report some results on the design of an advanced chiller control system. We consider in particular the control of a single scroll compressor, packaged air-cooled water chiller. Such an equipment is a very common one, and as such, it is particularly relevant to improve its performance by acting on the control system only. However, the control problem presents some particular challenges, since the system is poorly actuated. In fact, the regulation of the supply water temperature is basically achieved by a simple relay control, on the basis of the inlet or supply water temperature.

The approach we use to develop the control algorithms is that of Virtual Prototyping (VP), which makes extensive use of simulation tools. In particular, for the application at hand a simulation environment based on Matlab/Simulink has been developed and validated on a state-of-the-art experimental facility, as described in Albieri *et al.* [2007].

Typically, a chiller without capacity control can be regulated in two different ways, namely by controlling the chiller evaporator water temperature either at the inlet or at the outlet. In both cases, a relay control law is used, where the compressor is switched on and off when the controlled temperature reaches given threshold values. The difference between the upper and lower threshold values is called *water temperature differential*, and its value clearly affects the width of the oscillations of the supply water temperature as well as the number of start-ups of the compressor. A low value of the water temperature differential grants a higher control bandwidth and allows to obtain a more constant water temperature. On the other hand, there is an upper bound to the the number of compressor start-ups per hour, which is fixed by the compressor manufacturer. As a consequence, there is a limitation to the achievable control bandwith. Also, the value of differential cannot be decreased arbitrarily, but there is a lower limit value which depends on the plant water content.

While both control strategies maintain constant the user supply water temperature in full load conditions, outlet water temperature control grants better performance in chiller part load conditions since it maintains the mean outlet water temperature fairly constant during on/off operations. The performance of such control scheme can be further improved by implementing advanced strategies aimed at increasing the energy efficiency of the chiller and/or its accuracy in maintaining a given set point value of the supply temperature. We report here the main characteristics of an adaptive control algorithm, named AdaptiveFunction Plus [1], that has been recently implemented on board of commercial chiller units, presently on the market.

At the core of the algorithm there is a load estimation scheme which is based on a Kalman filter. The filter is designed on the basis of a model of the energy equation for the hydraulic circuits, which has been derived under the assumption that the mean value of the water inside the pipings and in the water tanks is equal to the inlet water temperature as seen from the chiller. The knowledge of the

[1] Patent pending

978-1-1234-7890-2/08/$20.00 © 2008 IFAC

10.3182/20080706-5-KR-1001.1612

(estimated) value of the load allows to adapt the controller parametrs in order to achive a desired objective, that can be a performance objective, or an energetic one.

As far as the regulation of the supply water temperature is concerned, it is possible to achieve as little oscillation as possible at part load conditions, both in terms of the average set-point water temperature delivered to the users and of standard deviation from the set-point temperature, by adapting the values of the temperature differential to the actual load conditions in order to obtain the highest possible number of compressor start-ups. If instead low energy consumption is sought for, the adaptive algorithm acts by adjusting the supply water temperature set-point value and optimizing compressor efficiency on the basis of the actual load conditions. It is thus possible to achieve significant seasonal energy savings compared to water chillers and heat pumps of an equivalent power with traditional control logic. Furthermore, the characteristics of the plant thermal inertia are estimated in order to adapt the control parameters to changes in the water circuit and thus in the system water contents.

A wide validation test campaign for the developed simulation environment has been carried out on a dedicated test facility. The test results, reported in Albieri *et al.* [2007], fully confirm that the simulation environment is able to reproduce all the system transient and steady state behaviors that are crucial to assess the performance of the control system.

Following the VP paradigm, a first assessment of the performance of the AdaptiveFunction Plus control algorithm has been performed in the simulation environment, by studying the time behavior of some key quantities, such as the accuracy in keeping the mean supply water temperature close to the set-point value, as well as an indication of its energy performance given in terms of the European Seasonal Energy Efficiency Rating (ESEER) (EECCAC [2003]). The indications obtained in the virtual environment have then been confirmed by a test campaign on the test facility. In Figs. 1 and 2, the performance of a standard inlet and outlet water temperature controller (Inlet_FB, Outlet_FB, respectively) are compared with that of the the AdaptivePlus controller, with and without set-point adaptation (Outlet_MABFS, Outlet_MAB, respectively), to illustrate the performance in terms of both accuracy and energy efficiency. In Fig. 1, the mean supply water temperature over a compressor cycle is reported, showing that the adaptive algorithm grants better regulation performance. In Fig. 2 the energy efficiency performance is analysed. Again, it can be seen that the Outlet_MABFS algorithm achieves the best energetic performance. We remark that the inlet water temperature control has better energetic performance with respect to the adaptive control law without set-point adaptation since it fails to accurately regulate the outlet water temperature, that reaches higher values at low Part Load Ratio values. Finally, it is worth noticing that for the Outlet_MABFS algorithm, the experimental average EER is 2.3 % higher than the virtual one. This fact can be ascribed to the chiller absorbed power model obtained from the manufacturer data, that are not accurate at high evaporation temperature.

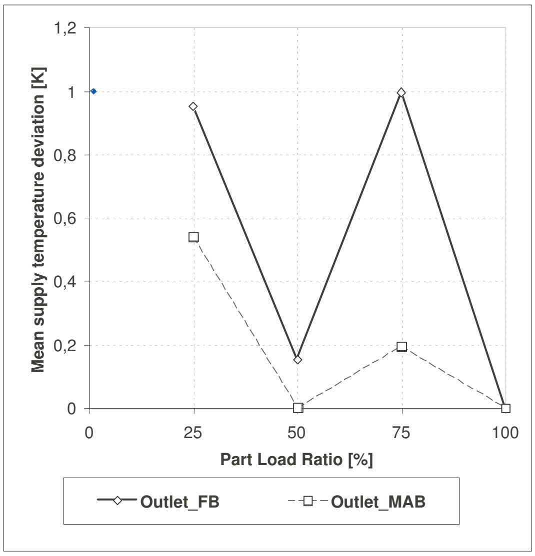

Fig. 1. Average (on+off period) chiller water outlet temperature for a standard (Outlet_FB) and the adaptive (Outlet_MB) controllers.

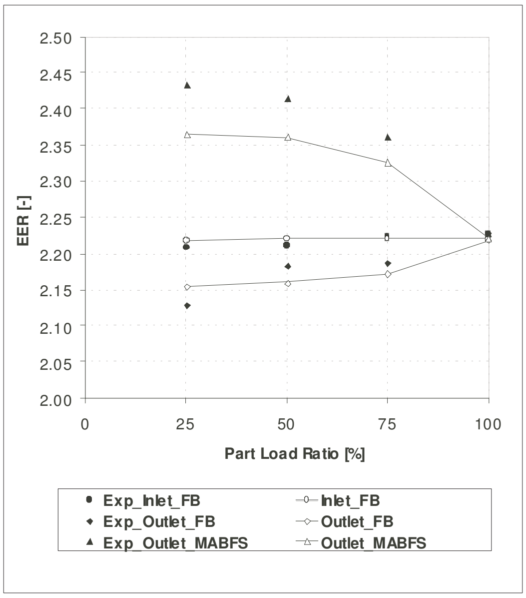

Fig. 2. Chiller Energy Efficiency Rating for different controllers. Curves denoted with "Exp" correspond to experimental data.

REFERENCES

M. Yaqub and S. M. Zubair, "Capacity control for refrigeration and air conditioning systems: A comparative study," *Int. J. Energy Res. Tech.*, vol. 123, pp. 9–99, Apr. 2001.

M. Albieri, A. Beghi, C. Bodo, and L. Cecchinato, "A simulation environment for the design of advanced chiller control systems," in *Proc. of CASE 2007*, pp. 962–967, 2007.

AA.VV., "Energy Efficiency and Certification of Central Air Conditioners (EECCAC)," Ed:Armines, vol. 3, April 2003.