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Advanced control systems for single compressor chiller units

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ABSTRACT

In this paper the problem of designing advanced control systems for increasing the performances of low capacity HVAC system with single scroll compressor is addressed. In particular, a simulation environment based on Matlab/Simulink that has been validated on a state-of-the-art experimental facility and used to design an adaptive controller for single scroll compressor, packaged air-cooled water chillers is presented. The capability of the controller to substantially increase the energy performance of the system, as well as to achieve excellent regulation performances in process applications is demonstrated.

Refroidisseurs de liquide à un compresseur : systèmes de régulation de pointe

Mots clés : Conditionnement d'air ; Refroidisseur de liquide ; Compresseur à spirale ; Conception ; Régulation ; Amélioration ; Performance

1. Introduction

Efficient use of energy is one of the main strategic measures not only for the conservation of fossil resources but also for the abatement of air pollution and the slowing down of anthropogenic climate change. 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 European global energy consumption, and reaching even higher percentages in countries such as Italy (up to 50%), due to the increasing use of air conditioning units for cooling residential and office buildings during summer. In fact, in the last years split -system air conditioners are being increasingly installed for cooling residential buildings, offices, and shops during the summer period. Such devices are clearly less expensive than other

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Nomenclature

A	flow section [m^2]
c_p	specific heat at constant pressure [J kg^{-1} K^{-1}]
e	specific system energy [J kg^{-1}]
e_c	specific kinetic system energy [J kg^{-1}]
e_p	specific potential system energy [J kg^{-1}]
f	well-mixed volume fraction [–]
L	mechanical energy [J]
$\dot{m}$	mass flow rate [kg s^{-1}]
min	minimum function [–]
M	mass [kg]
Q	thermal energy [J]
RHS	right hand side
s	Laplace variable [–]
t	time variable [s]
t_c	water tank or piping time constant [s]
T	temperature [°C]
υ	volumetric coordinate in the flow direction [m^3]
V	volume [m^3]
W	transfer function
ρ	density [kg m^{-3}]
τ	integration time [s]

Subscripts

f	water tank or piping well-mixed section outlet
H	hydraulic section
i	inlet
k	block index
L	load section
o	outlet

HVAC (Heating Ventilation and Air Conditioning) solutions, but they often lack in efficiency; as a direct consequence, the derived pollution effects on the environment are steadily increasing. These facts motivated the European Commission to deliberate on the energy performance of buildings (EPBD), with the Directive 2002/91/EC which imposes several actions to achieve prudent and rational use of energy resources and to reduce the environmental impact of the energy use in buildings. This can be accomplished by increasing both the energy performance of new and existing buildings and the efficiency of cooling/heating systems. 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 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 (Astrom and Hagglund, 1995; ASHRAE, 2003), due to their low cost and ease of tuning and operation. Such simple control architectures can be easily tuned to operate the system at given design thermal loads. However, to achieve a satisfactory energy performance, more advanced strategies have to be employed. In fact, the actual thermal loads affecting the system vary in time and, therefore, the controller parameters have to be adjusted accordingly to prevent the production of thermal energy when there is no request from the user. Different authors demonstrated the applicability of advanced control methodologies to HVAC system management in order to improve its energy efficiency, mainly focusing on large capacity multi-chiller plants (Chang et al., 2005; Huguang and Cai, 2002; Shoureshi, 1993; Braun et al., 1989a,b).

In this paper we address the problem of designing advanced control systems for increasing the performances of low capacity HVAC system with single scroll chiller unit. In particular, we present a simulation environment based on Matlab/Simulink that has been validated on a state-of-the-art experimental facility and used to design an adaptive chiller controller that allows to substantially increase the energy performance of the system, as well as to achieve excellent regulation performances in process applications. The control algorithm is presently patent pending and will be described in detail in a forthcoming paper (Albieri et al., submitted for publication). The paper is organized as follows. In Section 2 we present the plant/chiller model, and discuss in particular the chosen representation for the piping and water tanks, as well as the chiller unit. The control algorithm is synthetically described. In Section 3 we describe the experimental test facility that has been used to validate the model, and we present some results from the validation tests, showing a satisfactory agreement between test and simulation. In Section 4, the simulation environment has been used to perform an extensive efficiency analysis of the algorithm, which shows that the implementation of an advanced control strategy allows to achieve remarkable energy savings, without any need of modifying the mechanical system structure. Finally the developed algorithm has been implemented on board of a commercial chiller unit, and its performance has been evaluated on the experimental testing facility that has been used to validate the model, confirming the simulation results. Concluding remarks are given in Section 5.

2. Development of the mathematical model

2.1. Mathematical model

In Fig. 1 the block structure of the system taken as a reference in the paper is reported. Three basic blocks can be pointed out:

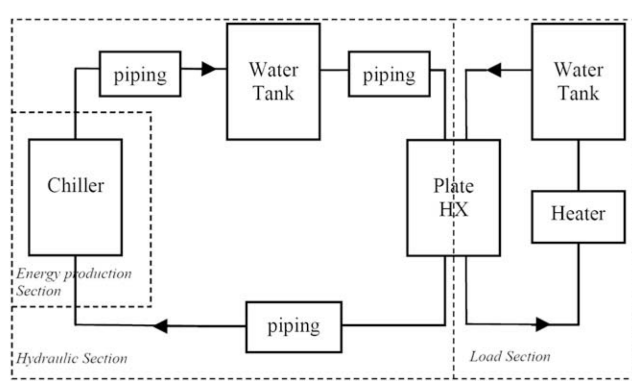

Fig. 1 – System block structure.