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Mode switching control of dual-evaporator air-conditioning systems

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ABSTRACT

Modern air-conditioners incorporate variable-speed compressors and variable-opening expansion valves as the actuators for improving cooling performance and energy efficiency. These actuators have to be properly feedback-controlled; otherwise the systems may exhibit even poorer performance than the conventional machines which use fixed-speed compressors and mechanical expansion valves. Particularly for an air-conditioner with multiple evaporators, there are occasions that the machine is operated in a mode that only selected evaporator(s) is(are) turned on, and switching(s) between modes occurs(occur) during the control process. In this case, one needs to have more carefully designed control and switching strategies to ensure the system performance. In this paper, a framework for mode switching control of the dual-evaporator air-conditioning (DEAC) system is proposed. The framework is basically an integration of a controller and a dynamic compensator. The controller, which possesses the flow-distribution capability and assumes both evaporators are on throughout the control process, is intended to provide nominal performance. While mode switching is achieved by varying the reference settings in the controller, the dynamic compensator is used to improve the transient responses immediately after the switching. Experiments indicate that the proposed framework can achieve satisfactory indoor temperature regulation and provide bumpless switching between different modes of operation.

1. Introduction

Due to the growing demand of multi-room air-conditioning service for common households, small and medium sized office buildings, multi-evaporator air-conditioners (MEAC's) are now attracting significant market attention. As one MEAC can replace several single-evaporator machines, using the MEAC not only saves more space, but also provides cost advantage and installation flexibility. The operation of the MEAC is based on vapor compression cycle. According to the schematic in Fig. 1, the machine consists of one compressor, one condenser, several evaporators and the same number of expansion valves. Because the compressor has to drive several evaporators simultaneously, the dynamics of the MEAC are more complicated than its single-evaporator counterpart. For example, if the cooling capacity and the environmental condition vary among the evaporators, then the operation in one room may influence those in the others. Consequently, the conventional on/off control may not be suitable for the MEAC.

Recently, the successful adoption of variable-speed compressors and electronically controllable expansion valves in single-evaporator air-conditioners has opened up the opportunity to devise advanced control strategies for the MEAC. However, probably due to the complex nature of the problem, only few studies on the control of MEAC systems have been reported. Among the limited literature, Choi and Kim [1] investigated the capacity modulating characteristics of the inverter-driven multi-air conditioner by experimentally varying indoor load, electrical expansion valve openings, and the compressor speed. The experimental results presented therein can serve as rules for open-loop control. Rajat et. al. [2] used the mean void fraction [3] and moving boundary approach [4] to develop an MEAC system model and designed the corresponding feedback controller to regulate evaporator pressures and superheat temperatures. In [5], He et. al. presented a new feedback linearization approach to the advanced control of MEAC systems. The simulation results show good control performance in the superheat and evaporator temperatures. It should be noted that the studies mentioned above are focused on vapor compression cycles alone. The indoor temperatures are regarded as constant parameters rather than dynamic variables. For the regulation of indoor temperatures, Chen et al. [6] proposed a fuzzy control algorithm to control the indoor temperatures at different conditions, but the performance of the control system was only verified through simulations.

In [7], the authors proposed a cascade control structure to deal with the fast and the slow dynamics in the MEAC system. The control experiments indicate that the proposed controller can regulate the indoor temperatures and maintain the steady-state superheat temperatures at acceptable levels. Regardless of the promising results shown in [7], the control structure therein lacks of flow

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Nomenclature

ω_c	compressor speed
α_v	expansion valve opening
T	temperature
υ	indoor thermal disturbance
δ	perturbation operator
$C_i(s)$	controllers of each mode
d	disturbance
$\delta\alpha_{v'_{10}}$	constant negative opening 1
$\delta\alpha_{v''_{10}}$	constant positive opening 1
γ	positive constant
$\delta\alpha_{v_{20}}$	constant positive opening 2
ξ	state of the dynamic compensator
A, B, C	system matrices
K	output matrix of the dynamic compensator
u'	input of the dynamic compensator
v, w	outputs of the dynamic compensator
$K_i(s)$	inner outer loop controllers
Subscripts	
set	reference setting
o	outdoor environment
i	indoor environment
sh	superheat
e	evaporator
nominal	nominal value

distribution capability that when the thermal demands for the indoor rooms differ, the control system may not generate desirable responses unless the reference settings in the controller are chosen properly. In [8], the authors modified the cascade structure of [7] and proposed a control strategy which can properly distribute the refrigerant to accommodate different thermal demands in different rooms. Experiments indicated that the proposed strategy can successfully regulate the indoor temperatures regardless that the temperature settings for respective rooms are different and the settings are switched in the middle of the control process.

In [8], as well as in all the other references mentioned, it is assumed that the MEAC machine is operated in the mode that all the evaporators are on throughout the control process. Practically, there are occasions that the MEAC machine is operated in a mode that only the selected evaporator(s) is(are) turned on, and switching(s) between modes occurs(occur) during the control process. Although one can apply the results of [8] to design a controller for each of the modes, whenever a mode switching occurs, directly switching from one controller to another could lead to discomfort to the users in the room(s) where the temperature(s) has(have) already been settled (as will be demonstrated later in the paper). Moreover, because the number of switching modes (N) and the number of evaporators (n) are related by $N = 2^n - 1$, when the number of evaporators becomes large, the embedded control system needs to have a large size of memory to store corresponding sets of controllers. This certainly increases system cost and hardware complexity.

In this paper, a framework for mode switching control of the dual-evaporator air-conditioning (DEAC) system is proposed. The framework is basically an integration of a single controller and a dynamic compensator. The controller, which is designed based on both of the evaporators are on throughout the control process, is intended to provide nominal performance. While mode switching is achieved by varying the reference settings in the controller, the dynamic compensator is used to improve the transient responses immediately after the switching. The paper is organized as follows. Section 2 reviews the controller previously proposed by the authors to achieve flow distribution for MEAC's. Then Section 3 experimentally investigates the control performance associated with direct switching between controllers which are designed for specific modes of operation. The framework for dynamic mode switching is proposed in Section 4. Section 5 shows the experimental validations of the dynamic mode switching strategy, and finally conclusions are given in Section 6.

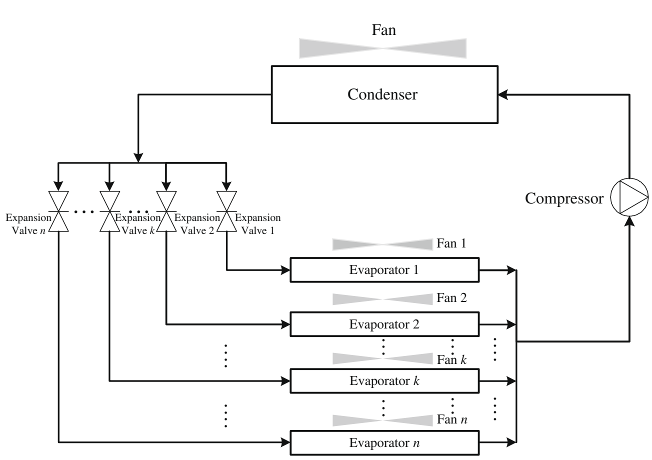

Fig. 1. The schematics of an MEAC machine.

2. Review of the controller for flow distribution

In this paper, a dual-evaporator air-conditioner (DEAC) is used as the target machine to illustrate the control concept and to verify the control performance. The controller of the framework proposed in this paper basically follows a similar cascading structure as the one proposed in [8]. A brief review of the controller is given below.

The controller is based on linearization of the system dynamics. The linearized model for the vapor compression cycle is assumed to be in the form:

$$\begin{bmatrix} \delta T_{e_1} \\ \delta T_{e_2} \\ \delta T_{sh_1} \\ \delta T_{sh_2} \end{bmatrix} = \begin{bmatrix} \frac{b_{11}}{s+a_1} & \frac{b_{12}}{s+a_1} & \frac{b_{13}}{s+a_1} \\ \frac{b_{21}}{s+a_2} & \frac{b_{22}}{s+a_2} & \frac{b_{23}}{s+a_2} \\ \frac{b_{31}}{s+a_3} & \frac{b_{32}}{s+a_3} & \frac{b_{33}}{s+a_3} \\ \frac{b_{41}}{s+a_4} & \frac{b_{42}}{s+a_4} & \frac{b_{43}}{s+a_4} \end{bmatrix} \begin{bmatrix} \delta\omega_c \\ \delta\alpha_{v_1} \\ \delta\alpha_{v_2} \end{bmatrix} \tag{1}$$

and the linearized model for the indoor dynamics is assumed to be in the form:

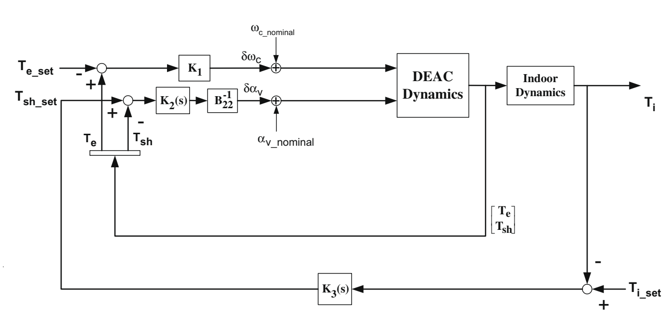

Fig. 2. The block diagram of the control system proposed in [8].