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Modelling and control of a free cooling system for Data Centers

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Abstract

Data centers are facilities hosting a large number of servers dedicated to data storage and management. In recent years, their power consumption has increased significantly due to the power density of the IT equipment. In particular, cooling represents approximately one third of the total electricity consumption, therefore efficiently cooling data centers has become a challenging problem and it represents an opportunity to reduce both IT energy costs and emissions environmental impact. The efficiency of computers room air conditioning (CRAC) systems can be increased using both advanced control techniques and new free cooling technologies, such as the indirect adiabatic cooling (IAC), that is the humidification of air under adiabatic conditions. Water sprinkled by spray nozzles humidifies and cools down the air taken from the outside, which then cools down the computers room air by means of a crossflow heat exchanger. In this way, the process air temperature is economically reduced and the cooling process is effective even when the outside temperature is warmer than that desired in the computers room. Beside the traditional approach, that improves energy efficiency of CRAC systems through advanced hardware design, nowadays advanced control systems offer the opportunity to improve both efficiency and performance by mostly acting on software components. In particular, a model-based paradigm can result very useful in the design of the controller. This approach involves three main steps: plant modelling, controller design, and simulations. In this paper, First-Principle Data-Driven (FPDD) techniques have been considered in the modelling phase, in order to obtain a model as simple as possible but accurate enough. All the main components of the plant, such as fans, spray nozzles, heat exchanger, and the computers room have been taken into account and they have been calibrated exploiting real data. The dynamics of the computers room variables (e.g. temperature) are slower than those of the components of the cooling system, due to higher thermal inertias of the computers room. Therefore, fans, heat exchanger, and spray nozzles are described by static models, whereas the computers room is described by a LTI dynamic model. Once obtained a model of the plant, a simulation environment based on Matlab/Simulink is designed accordingly. The developed control system is hierarchical: a supervisor determines the best combination of CRAC water and process air flows which minimizes the total power consumption, while satisfying the cooling demand. This system energy management problem is formulated as a non-linear optimization problem,

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subject to internal air condition requirements and system operating constraints. The optimization problem is repeatedly solved at each supervision period by using a population based stochastic optimization technique (Particle Swarm Optimization). Results of simulations show that the proposed control system is effective and minimizes the input electric power while satisfying both the data center thermal load and system operating constraints.

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Keywords: Cooling Device; Energy Efficiency; HVAC

1. Introduction

Data centers are facilities hosting a large number of servers dedicated to massive computation and storage. They can be seen as a composition of information technology (IT) systems, which provides services to the end users, and a support infrastructure, which supplies power and cooling. Power consumption in data centers has increased significantly in the past few years. In particular, costs for air conditioning systems represent more than one third of the total energy consumption, therefore efficiently cooling data centers has become a challenging problem. New free cooling technologies, coupled with advance control systems, allow the increase of the efficiency of computers room air conditioning (CRAC) systems, [1]. Among the available free cooling technologies, the indirect adiabatic cooling (IAC) grants low energy consumption while meeting air conditioning needs, [2]. Nowadays, advanced control systems give the chance to improve both system efficiency and performance by mostly acting on software components. Modelling and control of data centers is discussed in various works in the latest literature, for example in [3] a control-oriented data centers model is depicted, including the coupling in the dynamics between computational and cooling resources. In [4], a control strategy that provides the best trade-off between energy consumption and cooling needs satisfaction is presented. In [5], a MPC approach is used to obtain a cooling control system for data centers based on the use of indirect fresh air.

In this paper, a model-based approach is developed for the design of an efficient control strategy for CRAC systems. This approach involves three main steps: system modelling, analysing and developing of the controller, and simulating both the plant and the controller. In particular, a model for the IAC system has been obtained by resorting to First-Principle-Data-Driven technique, [6]. Moreover, a simulation environment based on Matlab/Simulink is designed accordingly. Then, a hierarchical control system for CRAC optimal operation has been developed. Specifically, the problem is formulated as a non-linear constrained optimization problem and it is solved by a population based stochastic optimization technique, the PSO (Particle Swarm Optimization). Simulations results show that the proposed control strategy minimizes the input total power while satisfying the operational constraints.

2. Indirect Adiabatic Cooling

In this paper, an IAC system is considered. It exploits the outside air to cool an internal environment, avoiding external and internal airstreams to directly mix. Cool air taken from the outside is forced through a heat exchanger (HX) and then immediately exhausted, whereas internal air is drawn from the room and circulated through the other side of the HX before being re-inserted into the room. In order to economically reduce even more the temperature of the air used for cooling, the outside air is humidified before it enters the heat recovery unit. This reduces the use of traditional expansion air conditioning systems, reducing the cooling costs. This also makes the cooling system effective even during periods when the outside air temperature is warmer than the desired internal room condition. In particular, a system of spray humidifiers delivers moisture to the air using water. The fact that the internal air never mixes with the outside air reduces the possibility of internal air contamination due to external pollutants. The IAC considered system is depicted in Fig. 1. Two distinct air passages can be distinguished, called respectively primary (or supply) and secondary (or process). Main components of the cooling system are fans, spray nozzles, HX, and computers room.