Journal of Energy Storage 8 (2016) 129–141

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Energy model optimization for thermal energy storage system integration in data centres

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ARTICLE INFO

Article history:
Received 2 August 2016
Received in revised form 17 October 2016
Accepted 17 October 2016
Available online 24 October 2016

Keywords:
Data centre
Thermal energy storage
Dynamic energy model
Economic evaluation

ABSTRACT

In the last years the total energy consumption of data centre industry has experienced a rapid increase due to the vast growth in internet usage. This phenomenon has aroused the interest for both, data centre industry and researchers in energy consumption and carbon footprint mitigation. Data centres operational expenses are also a key parameter for the productivity and competitiveness of the industry. In the present work, the implementation and optimization of thermal energy storage (TES) into a real data centre is presented. To the knowledge of the authors this is the first time that a methodology based on TraNsient System Simulation (TRNSYS), GenOpt and the application of Hooke and Jeeves optimization algorithm is used to study the implementation of TES, in particular water storage tanks, in data centres. A sensitivity analysis on the TES system cost is performed in function of the available literature information. The results show that the operating temperature of the chillers should be as lower as the system allows and therefore this open the possibility to study ice storage system. Regarding the economic analysis, the data centre electricity expenses can be reduced annually up to 3%. The uncertainty of the electricity price in the future is a major issue and it is also discussed.

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1. Introduction

Data centres are facilities used to house computer systems and associated components with the particularity to aim 24/7 for performance, reliability and security; transforming them into a highly energy demand infrastructures. The energy consumption of the data centre industry represents almost 2% of the total energy consumption worldwide [1,2] and the overall information and communication technologies (ICT) sector reaches 15% [3]. During the last years, the interest in data centre energy consumption and carbon footprint mitigation has become of great interest not only for industry but also for researchers. The information technology (IT) sector has been studying different strategies to reduce the overall data centre consumption and total cost of ownership by the implementation of energy efficiency strategies and the integration of on-site renewable energy sources. Recently, Oró et al. [1] and Shuja et al. [2] published different overviews of the actual data centre infrastructure and summarized a number of currently available energy efficiency measures and renewable energy integration. There are different approaches to reduce the energy demand and operational expenses in these infrastructures:

- The implementation of energy management solutions. Many researchers and European funded projects have been developing energy management platforms to improve energy efficiency under fluctuating load [4–6]. Currently, the technique of power-aware task scheduling, based on dynamic voltage scaling has been most widely used in the energy-saving research field of processors. This technique may reduce the power consumed by processors through reasonable task scheduling [7]. This strategy also can be applied to match on-site renewable energy production and IT workload, increasing the greener energy consumed by the data centre [8,9]. IT workload can also be scheduled between data centres; in this sense, Yao et al. [10] proposed a novel framework named Cost Optimization for Internet Content Multihoming (COMIC). COMIC dynamically balances IT loads among data centres to minimize the content service cost reaching energy reductions up to 20%. Recently, the integration of data centre into Smart Grid scenario by proposing techniques for scheduling and optimizing their operation allowing them to participate in smart demand response programs is deeply addressed [11].
- The use of thermal energy efficiency strategies. The most common strategy is to implement cold and hot aisle containment to avoid air mixing and enhance air management through the IT room. This strategy is experimentally [12] and numerically

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http://dx.doi.org/10.1016/j.est.2016.10.006
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[13] proved and well-spread. Currently, the use of direct and indirect air free cooling is also being implemented in most of the new data centres [14,15]. Other thermal strategies are the implementation of variable air flow, increase of the inlet air temperature, etc.

- The use of electrical energy efficiency strategies. There are mainly two measures: the use of modular and bypassed uninterruptible power supply (UPS) unit. On one hand, by using a modular UPS, it matches the UPS size with the IT load reducing the electrical losses. On the other hand, implementing a bypassed UPS, the IT servers are connected directly with the main grid avoiding the electrical losses in this equipment.
- The use of renewables in data centres [16,17]. Renewable are already playing an important role in data centre industry, but only big players such as Google and Facebook, have started to adopt this strategy. In particular, Google goals to have zero carbon emission, by compensating the energy consumed for its data centres producing green energy and selling it to the grid [18].
- The use of thermal and electrical energy storage systems. The approach of energy storage is used to store cheap electricity energy when the electricity price from the grid is low or when renewable energy is available. Recent works shows that energy storage usage can significantly reduce the operation cost for data centres [19–21]. In particular, many researchers investigated cost reduction opportunities that arise by the use of UPS units as electric energy storage (EES) [22,23] and by the use of water/ice storage tanks as thermal energy storage (TES) systems [24–26]. The implementation of EES and TES not only take profit of cheap electricity energy but also can help to reduce power system operation costs by reducing peak usage and flattening out the load profile

This work is focused on the implementation of TES systems, in particular water storage tanks, in data centres and studies how they can play an important role to reduce operational costs. The main drawback of using TES systems in real application is first, the investment cost which needs to be carefully analysed, and second, each TES implementation needs a careful energy analysis for each application. Moreover, it is reasonable to expect that an optimal configuration, including energy storage and energy management, exists for a current situation and in particular for a specific data centre characteristics. For this reason, it is really important to develop energy and economic dynamic models to find the most appropriate system configuration and control management [27,28]. On one hand, computational fluid dynamics (CFD) studies have been used for many researchers to study the behaviour of air management within data centres [29,30]. However, due to the complexity of CFD models and the difficulties in obtaining accurate input variables, CFD analysis can often include inaccuracies, besides being highly time consuming. On the other hand, dynamic energy modelling using TraNsient System Simulation program (TRNSYS) [31] is also being used to predict the behaviour and the performance of TES implementation in any application [32] and transient thermal systems of data centres within a common sense time consuming [33,34].

This paper presents an optimization study of a multi-dimensional model in TRNSYS for TES system implementation in a real data centre of 100 kW IT consumption located in Barcelona to reduce the overall operational expenses. The dynamic energy model used is already described and validated in previous author's work [35] and here the optimization process is under study.

2. Methodology

2.1. Data centre description

An operative data centre with a total IT capacity of 140 kW is used to study the implementation of TES systems. This data centre is being used to provide computing and information services for the Polytechnic University of Catalonia, in Barcelona (Spain). Nowadays, the IT consumption of the infrastructure is 100 kW IT and it is not planned to be reduced nor enhanced. The data centre has an IT room area of 285 m^2 which is located on a second basement surrounded by other refrigerated areas. Fig. 1 shows the scheme of the data centre and the equipment distribution. The facility is composed by 70 racks of data and 12 racks of communication equipment. Some racks are distributed in cold aisle containment and some other racks are placed with no containment in the whitespace.

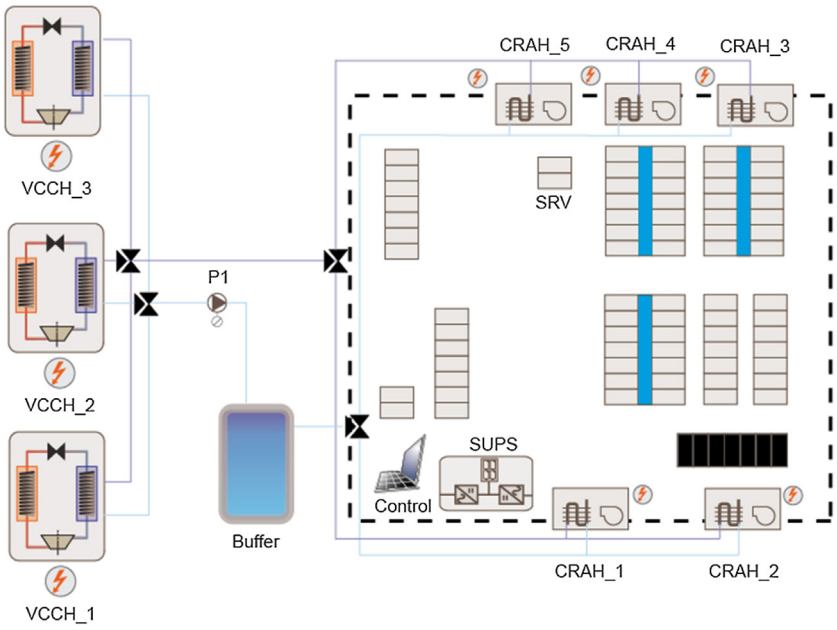

Fig. 1. Data centre cooling system configuration and whitespace distribution.

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