Energy Conversion and Management 85 (2014) 328–332

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Thermoeconomic evaluation of air conditioning system with chilled water storage

Hu Lin [a,b,*], Xin-hong Li [a], Peng-sheng Cheng [a], Bu-gong Xu [b]

[a] Shenzhen DAS Intelligent Technology Ltd. Co., Shenzhen 518057, China
[b] South China University of Technology, Guangzhou 510641, China

ARTICLE INFO

Article history:
Received 14 February 2014
Accepted 22 May 2014
Available online 19 June 2014

Keywords:
Thermodynamic performance
Thermoeconomic analysis
Chilled energy storage
Air conditioning system

ABSTRACT

As a good load shifting technology for power grid, chilled energy storage has been paid more and more attention, but it always consumes more energy than traditional air conditioning system, and the performance analysis is mostly from the viewpoint of peak-valley power price to get cost saving. The paper presents a thermoeconomic evaluation methodology for the system with chilled energy storage, by which thermodynamic performance influence on cost saving has been revealed. And a system with chilled storage has been analyzed, which can save more than 15% of power cost with no energy consumption increment, and just certain difference between peak and valley power prices can make the technology for good economic application. The results show that difference between peak and valley power prices is not the only factor on economic performance, thermodynamic performance of the storage system is the more important factor, and too big price difference is a barrier for its application, instead of for more cost saving. All of these give a new direction for thermal storage technology application.

1. Introduction

The extensive use of air conditioning for indoor cooling of large commercial or public buildings represents a major part of the power and electricity consumption in many countries. In the whole social energy consumption, building energy consumption is about 40%, including 50–60% of air conditioning energy consumption [1]. In China, the energy peak load of building matches with peak load of electricity grid, which is about more than twice of valley load, resulting in more peak load power plants being needed. Many hydropower stations for energy storage in off-peak period are built or to be built to shift peak load, which needs large of capital cost and leads to environmental problems. Therefore, air conditioning load shifting is critical for the whole grid. Then the chilled energy storage technology for air conditioning system has been paid more and more attention, due to its less capital cost and fewer environmental effects. But in traditional, air conditioning system with chilled energy storage, shown in Fig. 1, always consumes more 5–10% power than traditional air conditioning system. The cost saving just results from power prices difference between peak and valley periods. In some situation, much bigger difference is even pursued to get more power cost saving [1–4]. By this way, application of thermal storage technology increases social total energy consumption, which does not meet the need of sustainable development.

In recent researches, economic and thermodynamic performances have been evaluated. Some researches mentioned on energy and exergy analysis of thermal energy storage. These work focus on comparing different storage technologies performances or how to improve energy storage performance. But the relationship between thermodynamic and economic performances is not very clearly. Furthermore, it is doubtful whether much bigger power prices difference among different load periods of power grid is better for storage technology application [5–10].

The purpose of this paper is to reveal how thermodynamic performance and power prices difference influence on power cost saving, and a new evaluation method will be built, which can supply a new direction for thermal storage technology application.

2. Thermoeconomic evaluation methodology

2.1. Traditional methodology

In traditional, economic performance analysis of air conditioning system with chilled energy storage is mainly based on cost saving of power input and the payback time of capital cost for the

* Corresponding author at: Shenzhen DAS Intelligent Technology Ltd. Co., Shenzhen 518057, China. Tel.: +86 18665896701; fax: +86 0755 26639599.
E-mail address: linhu1978@gmail.com (H. Lin).

http://dx.doi.org/10.1016/j.enconman.2014.05.079
0196-8904/

Nomenclature

A	energy level
a	ratio of peak to valley power prices
C	cost ($)
COP	coefficient of performance
C_T	specific heat capacity of water (kJ/kg K)
E	exergy (MW)
E_C	stored chilled energy (MW)
H	enthalpy (MW)
K	chilled energy lost rate of tank
PCS	primary cost saving ratio (%)
Q	flow (m^3/h)
S	entropy (kJ/kg K)
T	temperature (K)
W	work or power consumption (MW)
x	COP ratio of reference system to chilled storage system
η	volume efficiency of storage tank

Acronyms and subscripts

0	traditional air conditioning system
E	air conditioning equipment
N	normal period of power load
O&M	operation and management
P	peak period of power load
R	air conditioning system with chilled storage
S	chilled storage equipment
V	valley period of power load
W	work or power

chilled storage equipment. Then, primary cost saving ratio (PCS) is the key evaluating indicator, defined as follow:

$$PCS = (C_0 - C_R)/C_0 \tag{1}$$

Here C symbols cost, subscript 0 means the normal air conditioning system, and R means the air conditioning system with chilled storage.

From the viewpoint of technical economics, C_0 and C_R can be expressed as [11–13]:

$$C_0 = (C_W + C_E + C_{O\&M})_0 \tag{2}$$

$$C_R = (C_W + C_E + C_S + C_{O\&M})_R \tag{3}$$

In which, subscript W identifies work or power, E and S symbols air conditioning equipment and chilled storage equipment respectively, then C_E and C_S mean related capital cost to equipment, and O&M symbols operating and management excluding power cost.

Then Eq. (1) can be shown as:

$$\begin{aligned} PCS &= C_0 - C_R/C_0 \\ &= \frac{(C_W + C_E + C_{O\&M})_0 - (C_W + C_E + C_S + C_{O\&M})_R}{(C_W + C_E + C_{O\&M})_0} \\ &= \frac{(C_{W,0} - C_{W,R}) + (C_{E,0} - C_{E,R}) + (C_{O\&M,0} - C_{O\&M,R}) - C_S}{(C_W + C_E + C_{O\&M})_0} \end{aligned} \tag{4}$$

In more situation, chilled storage technology is adopted to reform the old air conditioning system. Mainly with chilled water storage, it is unnecessary to increase chillers or to reform chillers, and the cost of O&M excluded power goes up smaller. Then capital cost of air conditioning system and O&M cost almost have no increment with energy storage, which means that both $C_{E,0} - C_{E,R}$ and $C_{O/M,0} - C_{O/M,R}$ can be neglected. So PCS can be changed as:

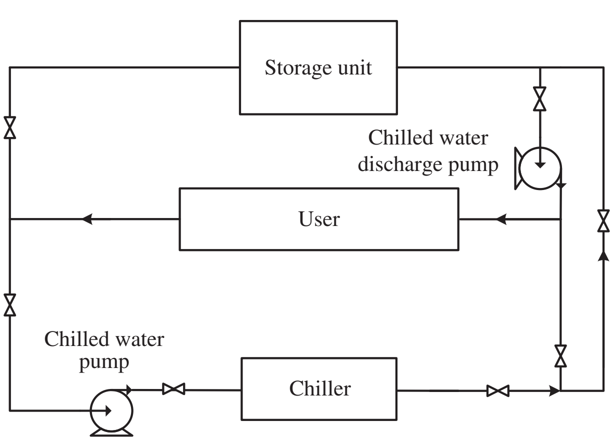

Fig. 1. Chilled water storage system.

$$PCS = \frac{(C_{W,0} - C_{W,R}) - C_S}{(C_W + C_E + C_{O\&M})_0} \tag{5}$$

For application of chilled storage for power cost saving, power consumption almost increases, and it mainly based on the difference between electricity costs of peak and valley periods of power grid, for example in China, power cost in peak period is more than 3 times of that in valley period of power grid in some places.

Because power supply can usually be divided into three periods as valley, normal and peak, then Eq. (5) can be changed as:

$$PCS = \frac{(C_{P,0} - C_{P,R}) + (C_{N,0} - C_{N,R}) + (C_{V,0} - C_{V,R}) - C_S}{(C_W + C_E + C_{O\&M})_0} \tag{6}$$

where subscripts P, N and V symbol peak, normal and valley periods respectively. Here we assume that chilled storage system do not supply energy for users in normal period, and there is no load for system without chilled storage in valley period. Then,

$$PCS = \frac{(C_{P,0} - C_{P,R}) - C_{V,R} - C_S}{(C_W + C_E + C_{O\&M})_0} \tag{7}$$

which shows economic performance of the system with chilled storage from the viewpoint of conventional economic evaluation, getting cost saving just from power prices difference.

2.2. New thermoeconomic evaluation methodology

It is well known that in normal, chiller mostly runs for 7 °C chilled water outputs, but in chilled water storage condition, chilled water is always 4 °C. For the chiller, with 1 °C decrease, chilled energy outputs can be reduced about 3% points, which means that thermodynamic performance of air condition system is decreased, but which cannot be shown in Eq. (7). How the change of thermodynamic performance effects on economic performance is not obvious. But this change can be reflected by increment of power consumption, which shown as power cost going up. So Eq. (7) can be shown as:

$$\begin{aligned} PCS &= \frac{(C_{P,0} - c_{V,R}) - C_{P,R} - C_S}{(C_W + C_E + C_{O\&M})_0} \\ &= \frac{c_V(aW_{P,0} - W_{V,R}) - c_V aW_{P,R} - C_S}{(C_W + C_E + C_{O\&M})_0} \\ &= \frac{c_V(aE_C/COP_0 - E_C/COP_R) - c_V aW_{P,R} - C_S}{(C_W + C_E + C_{O\&M})_0} \\ &= \frac{(a-1)c_V E_C/COP_0 - (x-1)c_V E_C/COP_0 - ac_V W_{P,R} - C_S}{(C_W + C_E + C_{O\&M})_0} \end{aligned} \tag{8}$$