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Toward an architecture for integrated gas district cooling with data center control to reduce CO_2 emission

Jun Okitsu[a,*], Mohd Fatimie Irzaq Khamis[b], Nordin Zakaria[c], Ken Naono[a], Ahmad Abba Haruna[c]

[a] R&D Department, Hitachi Asia Malaysia Sdn. Bhd., Kuala Lumpur, Malaysia
[b] Property Management & Maintenance, Universiti Teknologi PETRONAS, Perak, Malaysia
[c] Computer & Information Sciences, Universiti Teknologi PETRONAS, Perak, Malaysia

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ABSTRACT

Gas District Cooling (GDC) provides electricity and chilled water to facilities with relatively low running cost and has the potential to reduce CO_2 emission as it can make effective use of wasted energy. However, the present CO_2 emission tends to be higher than expected due to the chilled water supply–demand gap. To efficiently manage the gap, this paper introduces a novel chilled water supply–demand gap model and proposes an integrated GDC and Data Center (DC) control based on the model. The gap model, defined by GDC plant and DC controllable parameters, estimates the required additional chilled water supply. Then, DC and chillers in the plant are controlled based on the model to minimize the required additional supply. The analysis using GDC operational data in Universiti Teknologi PETRONAS shows that the accuracy of the models depends on temperature differences between rooms and outdoor, and Steam Absorption Chillers (SAC) operations. Thus, the analysis suggests that the incorporation of room and outdoor temperature sensors in the DC, and the proper scheduling of SAC operation can improve the accuracy of the models. The improved accuracy will in turn allows the GDC operation to be better optimized, resulting in a reduced CO_2 emission.

1. Introduction

Natural gas is now drawing more attentions as in International Energy Agency (IEA) report mentioning "Golden Age of Gas" [1], or in current news on so-called "Shale Gas Revolution." The topic is mainly discussed in terms of upstream technologies, that is, how to exploit the natural resource. But, in views of sustainability issues on global energy consumptions, it should be also argued in terms of downstream technologies, that is, how to use the natural resource efficiently. Thus, this paper focuses on exploring more efficient use of natural gas based on co-generation system of electricity and chilled water, called Gas District Cooling (GDC), which is one of the Combined Heat and Power technologies.

The issue being addressed in this paper is that the present CO_2 emission of the GDC tends to be higher than expected because of the chilled water supply–demand gap. When the chilled water generated by the waste heat from gas turbine in GDC is insufficient, additional electricity will be generated so that more chilled water will be produced by the electric chillers. This additional electricity generation results in the increase of CO_2 emission.

To address the issue, we consider the fact that increasingly Data Center (DC) is becoming a major consumer of energy. According to the report of US Environmental Protection Agency (EPA) [2], for example, the estimated energy consumption in USA data centers in 2011 reaches 100 billion kWh or more, about three times higher than that in 2000. While the report is concerned with DCs in the USA, we note that the trend is becoming increasingly similar in the fast growing ASEAN region. Among the huge energy consumption, the cooling energy dominates about one third of total DC energy. While free cooling strategy is often used [3] elsewhere, it is not generally applicable in hot countries such as that in South-East Asia, where generally constant artificial cooling is needed to sustain DC operation.

To solve the aforementioned problems, this paper proposes the concept of GDC-DC, namely, integrated Gas District Cooling with Data Center control. So far, there have been a few trials to build power plant next to a DC. For example, QUALCOMM has built a GDC plant next to a DC to provide electricity and chilled water to the DC [4]. But, as far as the authors know, this is the first trial to consider

* Corresponding author. Tel.: +60 123203807.
E-mail addresses: jokitsu@has.hitachi.com.my (J. Okitsu), fatimieirzaq@petronas.com.my (M.F.I. Khamis), nordinzakaria@petronas.com.my (N. Zakaria), knaono@has.hitachi.com.my (K. Naono), ahmadydee@gmail.comNordin (A.A. Haruna).

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GDC-DC type energy estimate in hot countries. Our novelty is two-folds. First, in order to minimize the gap, this paper proposes a model of chilled water supply–demand gap and a method of GDC-and-DC integrated control based on the model. Secondly, this paper derives requisites toward architecture for GDC-DC through analysis using the proposed model with GDC real operation data in Universiti Teknologi PETRONAS (UTP).

The rest of the paper is organized as follows. Section 2 provides related work to improve GDC energy efficiency. Section 3 presents GDC and GDC chilled water supply–demand gap problem. The GDC-DC architecture and chilled water supply–demand gap model to solve the problem are presented in Sections 4 and 5, respectively. The experiment to validate the model and discussion of the architecture to improve the model accuracy are presented in Section 6. Finally, Section 7 presents conclusion and future work.

2. Literature review

Improvements on GDC energy efficiency have been researched on the chilled water demand, the chilled water supply, and both so far.

In the chilled water demand research, optimization methods to reduce the demand have been studied extensively. Some of them are such as temperature condition relaxation with DC servers of high guaranteed operating temperature [5] and with thermal variance minimization using DC job scheduling [6,7].

In the chilled water supply research, optimization methods to increase the supply have been also studied. Some of them are optimization of steam absorption chiller (SAC) [8,9], and that of thermal storage tank (TES) [10]. However, in the GDC, these optimization methods should take into account both demand and supply side, instead of ether one side. Actually, the efficiency of the operations substantially depends on the chilled water supply-and-demand gap. For example, under condition that the supply exceeds the demand, the operations to decrease the demand are inefficient to reduce CO_2 emission. Similarly, under condition that the demand exceeds the supply, the operations to increase the supply are also inefficient. Therefore, our gap model determines the condition and makes the optimization methods to be efficient in GDC.

In the chilled water both demand and supply research, optimization methods have been also studied. Some of them are thermal storage tank optimization based on chilled water demand prediction [11,12], chilled water distribution network optimization based on building cooling load patterns [13], and electricity demand forecasting for GDC optimization [14]. However, these methods are intended for supply optimization based on demand information, and efficiency of the methods is lower than that of both optimizations. It is because, without demand optimization, supply optimization should prepare larger margin for unexpected demand rise. With demand optimization, the unexpected demand rise can be mitigated. Thus, combining with demand optimization based on supply information can improve the efficiency.

Therefore, our architecture and model are intended for both supply and demand optimizations based on both side information. SAC in GDC plant and job schedulers in DC are controlled to minimize the gap of SAC chilled water supply and chilled water demand.

3. Gas District Cooling

3.1. Gas District Cooling

GDC consists of GDC plant and facilities. The GDC diagram is shown in Fig. 1. The GDC plant generates and supplies electricity (ELE) and chilled water (CHW) to the facilities. The GDC plant consists of gas turbine generators (GTGs) to generate electricity and waste heat, heat recovery steam generators (HRSGs) to generate steam, steam absorption chillers (SACs) to generate chilled water with the steam, electric chillers (ECs) to generate chilled water with electricity.

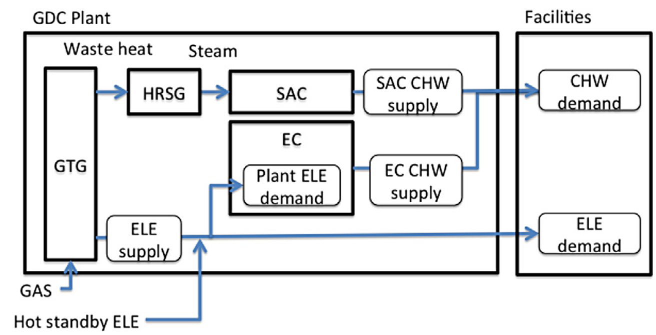

Fig. 1. Gas District Cooling.

The GTGs generate electricity (ELE supply) to satisfy the electricity demand (ELE demand). If the electricity demand exceeds the supply, a public utility company supplies hot standby electricity (Hot standby ELE). Thus, no electricity supply–demand gap occurs.

The SAC generates chilled water (SAC CHW) using waste heat from GTGs. Because the SAC makes use of the waste heat, the SAC has potential to reduce CO_2 emission for the same energy consumption in comparison with the EC.

The EC generates chilled water (EC CHW) using electricity. The EC chilled water supplements the SAC chilled water when the latter does not meet the chilled water demand.

Since the GDC plant makes use of the waste heat to produce chilled water, the plant supplies electricity and chilled water with lower CO_2 emission than electricity-only chilled water supply system.

Table 1 shows daily electricity consumption to supply chilled water, daily CO_2 emission to supply chilled water and daily chilled water supply in the UTP GDC plant. These values are calculated for each SAC, EC and total of them. The CO_2 emission is estimated under assumption that CO_2 emission is proportional to the electricity consumption. The electricity consumption is estimated using the GDC plant electricity model discussed in Section 5.3.

Table 1 also shows chilled water supply per electricity consumption and chilled water supply per CO_2 emission of the SAC, the EC and the total in the UTP GDC plant. The chilled water supply per electricity consumption is generally used to describe EC efficiency and is known as coefficient of performance (COP).

Chilled water supply per CO_2 emission is used to evaluate efficiencies of EC, SAC and plant in this paper. Since the definition of COP is different between EC and SAC, it is difficult to evaluate the efficiencies using the COP. For the rest of this paper, the term "plant efficiency" refers to the chilled water supply per CO_2 emission of the plant.

Note that in order to evaluate SAC chilled water supply per CO_2 emission strictly, not only SAC related CO_2 emission but also steam related CO_2 emission of GTGs and HRSGs should be estimated. However, the steam related CO_2 emission is not estimated in this paper, and only SAC related CO_2 emission is estimated to evaluate it.

Table 1
Profiling of daily supply in the UTP GDC plant.

	SAC	EC	Total
Electricity consumption [MWh]	6.2	11.4	17.6
CO_2 emission [CO_2-ton]	4.2	7.8	12.0
Chilled water supply [MWh]	79.0	61.7	140.7
Chilled water supply per Electricity	12.7	5.4	8.0
Chilled water supply per CO_2 [MWh/CO_2-ton]	18.8	7.9	11.7