Concept of Energy Efficient Datacenter in ASEAN Region

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Datacenters are a fundamental part of the social infrastructure in today's world. While outdoor free air is used to cool datacenter computers, the technique is difficult to apply in hot countries. This article outlines the concept behind an energy-efficient datacenter called the GDC-DC that is the product of joint research by Hitachi and Universiti Teknologi PETRONAS. To achieve energy efficiency in the ASEAN region, optimization is extended beyond datacenter energy demand to include the energy supplied by GDC. GDC uses SACs because of their superior energy efficiency compared to ECs. Operational data from the GDC plant at Universiti Teknologi PETRONAS was used to estimate the PUE using Hitachi's SAC at 1.21 (1.0 is energy use for computer execution and 0.21 is for computer cooling). This compares to typical PUE values in Malaysia of 1.6, with world-leading datacenters achieving about 1.1. The research found that use of SAC played a key role in achieving lower PUEs, even in hot areas where free cool air cannot be used.

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1. INTRODUCTION

DATACENTERS are a fundamental part of the social infrastructure in today's world. However, the cooling required to remove heat from computer hardware means their energy consumption is growing rapidly. Even the state-of-the-art datacenters are using free cooling, which means that datacenters tend to be located in cool region where they can make use of the free cool air outside. The best achieve power usage effectiveness (PUE) values as low as 1.1 or 1.07 (the closer the PUE is to 1.0 the better).

However, it is difficult to make use of free cool air in hot countries such as Malaysia. One Malaysian datacenter, for example, has only been able to achieve a PUE of about 1.6 despite considerable efforts to optimize the cooling facilities.

To overcome this problem, joint research by Hitachi and Universiti Teknologi PETRONAS (UTP) has devised a concept called "Gas District Cooling based Datacenter" (GDC-DC). The concept extends energy optimization beyond datacenter energy demand to include the energy supplied by GDC. GDC uses steam absorption chillers (SACs), which are more energy-efficient than electric chillers (ECs). Malaysia has already been using GDC with SACs for more than 10 years. Another feature of the Association of Southeast Asian Nations (ASEAN) area is the availability of natural gas resources and pipelines.

Research into the concept has focused on four areas: GDC-DC energy gap modeling, GDC-DC campus grid job scheduling, the GDC-DC energy sensing system, and GDC plant maintenance efficiency. This article describes the concept behind GDC-DC and reviews the main research work undertaken for proof-of-concept.

2. BASIC CONCEPT OF GDC-DC

The GDC plant supplies the UTP campus with electricity and chilled water produced using natural gas. Since 2003, the plant has been supplying electricity and chilled water to campus buildings that house the "Campus Grid," a network of thousands of personal computers (PCs). The UTP GDC plant is fitted with SACs (which Hitachi has introduced in 2013) that efficiently produce chilled water from the waste heat of a gas turbine (see **Fig. 1**).

Research at UTP has focused on four areas: GDC-DC energy gap modeling, GDC-DC campus grid job

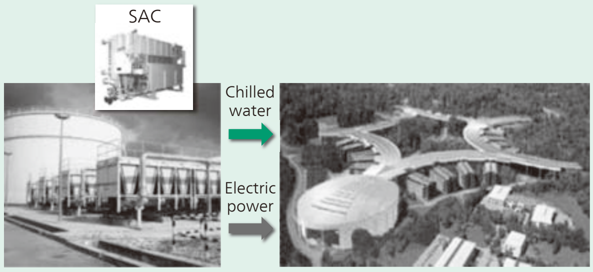


Fig. 1 | Gas District Cooling based Datacenter (GDC-DC).

The concept behind datacenter energy management at the Universiti Teknologi PETRONAS (UTP) campus involves using SACs for their higher efficiency. It also features a GDC plant that supplies both chilled water and electric power to the campus, which includes a datacenter.

scheduling, the GDC-DC energy sensing system, and GDC plant maintenance efficiency.

The research into GDC-DC energy gap modeling involved determining the gap between demand for chilled water and the supply of energy, and then conducting optimization modeling in the form of a minimization problem (minimizing this supply-demand gap)[(1)]. The GDC plant is controlled to ensure that the electricity supply matches demand, with the supply of chilled water being proportional to the amount of electricity supplied. In other words, the supply of chilled water is determined not by demand for chilled water but by demand for electricity, resulting in a supply-demand mismatch.

Research into GDC-DC campus grid job scheduling, meanwhile, involved designing new job scheduling algorithms to minimize this energy gap[(2) (3)]. When there is an excess supply of chilled water, such as at night, the job scheduling algorithm changes the execution timing of some batch jobs to shift the data center's demand for chilled water from day to night. Because the data center workload includes batch jobs with one- or two-day completion requirements, it has the flexibility to make these schedule changes.

Research into the GDC-DC energy sensing system looked at the system design of data aggregation from the GDC plant as well as from the datacenter into an energy management computer. The energy gap calculation uses GDC plant operational data (such as chilled water flow rate and temperature) to estimate energy supply, and uses datacenter energy consumption and environmental data (such as electricity consumption and temperatures inside and outside the datacenter) to estimate energy demand. Data from the GDC plant and datacenter are gathered from supervisory control and data acquisition (SCADA) systems, and also from wireless sensors. The diversity of communication protocols used in the SCADA systems makes data connectivity an important issue. The Plant Information (PI) System* developed and supplied by OSIsoft, LCC[(4)] is used for this purpose.

Table 1 | COP Comparison of SAC and EC.

Note that the supply of chilled water is presented in units of MWh rather than tons.

Performance indicator	SAC	EC
Power consumption (MWh)	6.2	11.4
Chilled water supply (MWh)	79.0	61.7
Chilled water per unit of electric power (COP)	12.7	5.4

EC: electric chiller, COP: coefficient of performance

GDC plant maintenance research used root cause analysis (RCA) correlation calculations to determine which system components adversely affect GDC performance[(5) (6)]. Good maintenance of the GDC plant is important because the operational efficiency of this plant has a major impact on GDC-DC. The reason ECs are used instead of SACS, despite the superior energy efficiency of the latter, is because ECs are easier to maintain. For example, measured by the standard coefficient of performance (COP) the energy efficiency metric, the SACs at UTP are twice as effective as the ECs (see **Table 1**).

3. ENERGY GAP MODELING AND ENERGY SENSING SYSTEM FOR GDC-DC

The architecture for GDC-DC includes the GDC plant, UTP campus, and an integrated control system (see **Fig. 2**).

The GDC plant includes a gas turbine generator (GTG), heat recovery steam generator (HRSG), SAC, EC, and thermal energy storage (TES), with electricity sensors and temperature sensors. The GTG simultaneously generates electricity and waste heat from natural gas. The electricity is supplied to the UTP campus. The HRSG generates steam from the waste heat, and the SAC generates chilled water from the steam. This chilled water is also supplied to the UTP campus. The EC, meanwhile, generates chilled water from electricity. Chilled water from the EC is stored in the TES during the night and supplied to the UTP

* PI System is a trademark of OSIsoft, LLC.

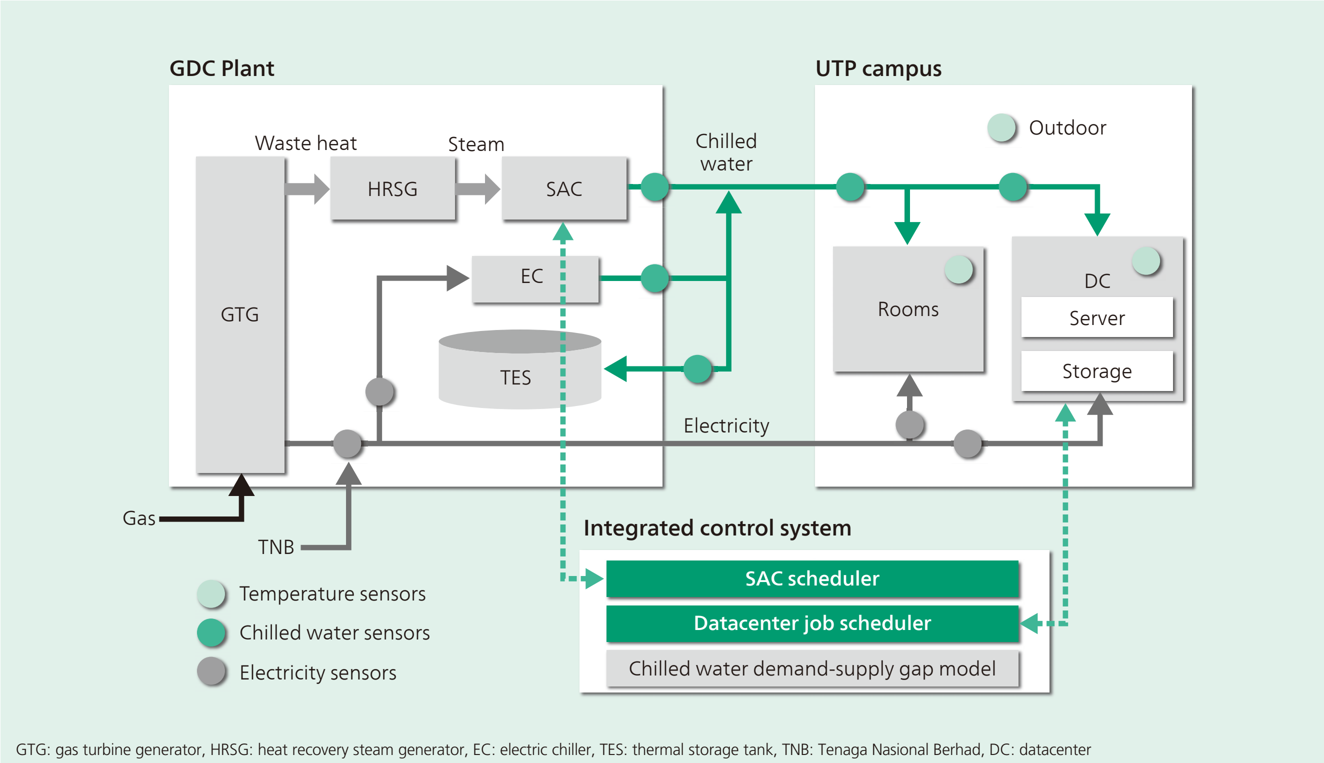


Fig. 2 | GDC-DC Architecture (Sensing System and Energy Control).
The SAC scheduler and datacenter job scheduler control the SACs and datacenter jobs, respectively, using sensor data and based on the gap between supply and demand for chilled water.

campus during the day. When the electric power generated by the GTG is insufficient, supplemental power is provided to the GDC plant from Tenaga Nasional Berhad (TNB), the Malaysian national electricity supply company. In addition to its labs, classrooms, and other teaching facilities, the UTP campus also has a datacenter that houses servers and storage. Chilled water is the primary means of cooling the datacenter and teaching facilities, and it is supplemented with electric air conditioning.

Under the GDC-DC concept, the integrated control system calculates the gap between supply and demand for chilled water based on sensing data from electricity sensors, temperature sensors, and chilled water sensors (flow rate, pressure, and temperature) in the GDC plant and UTP campus. The integrated control system controls SAC scheduling and datacenter job scheduling to minimize the supply-demand gap and improve the datacenter energy efficiency.

The derivation of the chilled water demand-supply energy gap model is described in detail elsewhere [1]. The core of the model is as follows.

$$H\_GAP(t) = |H\_SAC(t) - H\_demand(t)|$$

where:
H_GAP(t): Energy gap at time t
H_SAC(t): Chilled water energy from SAC at time t
H_demand(t): Energy demand at time t

The model is based on the assumptions that, (1) Chilled water is mainly supplied from the SAC, with supplementary supply from the EC, and (2) Supply and demand of electric power must be kept in balance.

H_demand(t) is calculated from the heat generated in the campus buildings (teaching facilities and datacenter), and the heat entering from outside the buildings. These are calculated using the sensors depicted in **Fig. 2**.

There are two ways to minimize the energy gap *H_GAP(t)*. One is to control supply when *H_SAC(t)* > *H_demand(t)*. The other is to control demand when *H_SAC(t)* < *H_demand(t)*. Supply-side control includes SAC scheduling and use of the TES[5]. Demand-side control includes datacenter job scheduling[2] [3].

Connectivity between the two SCADA systems is an important element of the data processing system architecture (see **Fig. 3**). These are the SCADA system for the GDC plant and the SCADA system for the UTP buildings. Because they use different data formats, the PI

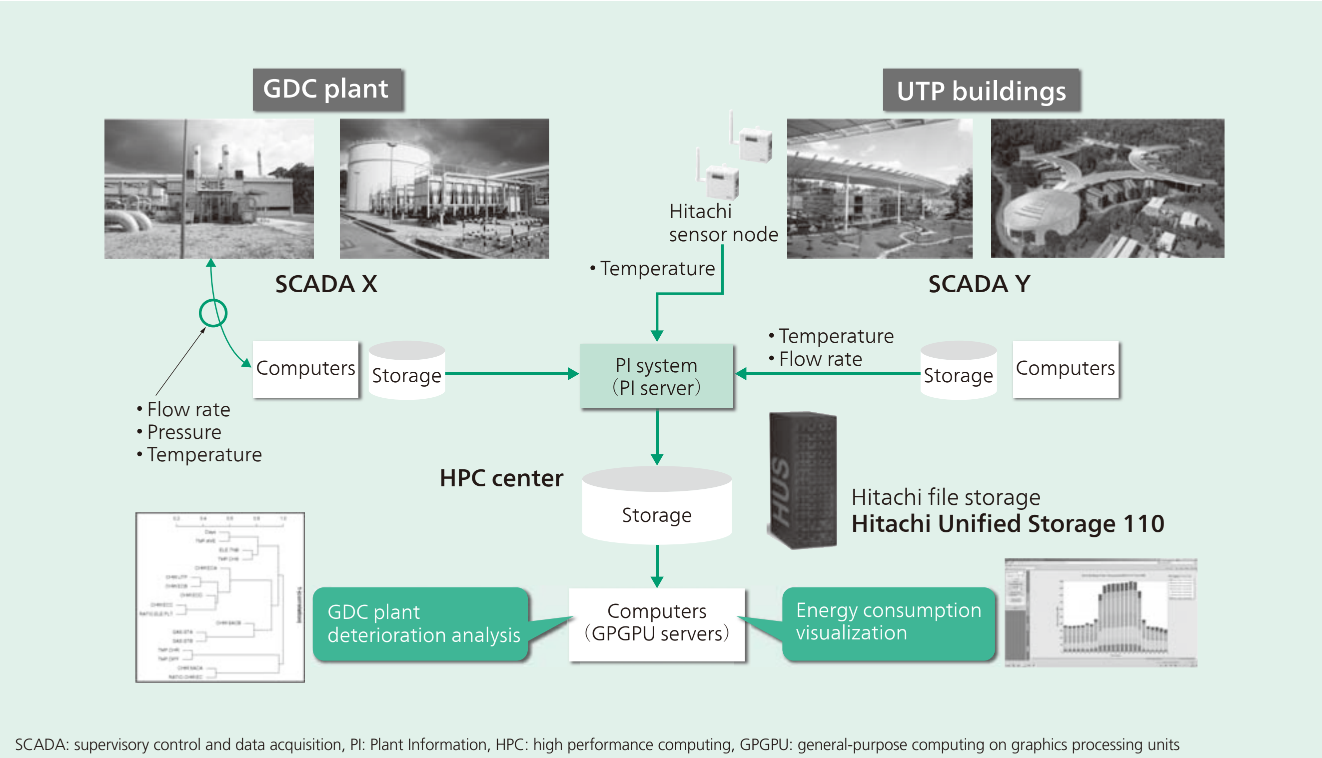


Fig. 3 | **Energy Monitoring Network at UTP GDC-DC.**
The PI System is used for interconnectivity between the two SCADA systems, which use different data formats. Data is stored in the HPC center, and can be viewed or analyzed by applications such as GDC plant deterioration analysis and energy consumption visualization.

System, an interconnectivity system developed and supplied by OSIsoft[4], plays the critical role. The PI System supports interconnectivity between more than 400 different SCADA and distributed control systems (DCSs).

4. PUE ESTIMATES FOR GDC-DC

Although GDC-DC has not yet completed overall system development, the estimated energy efficiency can be calculated from GDC plant operation data and from the temperatures inside and outside the campus buildings. As UTP has installed additional SACs between 2012 to 2014 to cope with campus expansion, estimates are calculated for three different SAC operation patterns (see **Table 2**).

The estimates show that GDC-DC performs competitively even in comparison with the world's best data centers in cool climates (see **Fig. 4**). Changing from ECs to SACs played a major role in this improvement, primarily as a result of the better COP of SACs, as shown in **Table 1**.

Table 2 | **Chiller Operation Patterns.**
Day is from 7 am to 7 pm, and night is from 7 pm to 7 am.

Pattern (Year)	Day	Night
P1 (2013)	SACs from other suppliers and EC	EC
P2 (2014)	SACs supplied by Hitachi	EC
P3 (2015 planned)	SACs supplied by Hitachi	SACs supplied by Hitachi

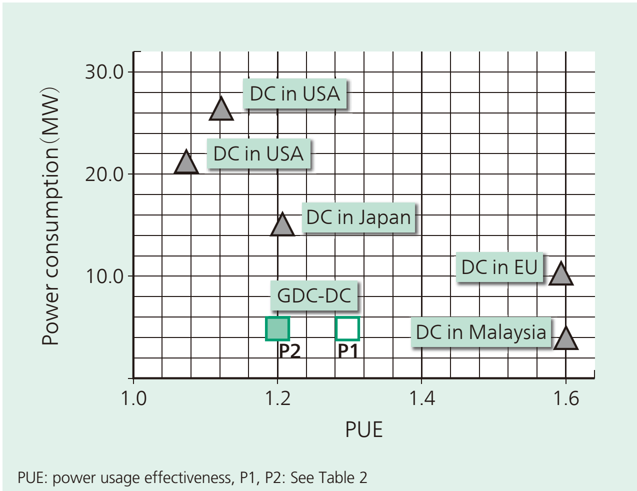


Fig. 4 | **Comparison of Estimated PUE of GDC-DC (Two Operation Patterns) with other Datacenters.**
Despite being situated in a hot climate, the estimated PUEs for GDC-DC are better (lower) than those of other Malaysian data centers, and are competitive with those in Japan.

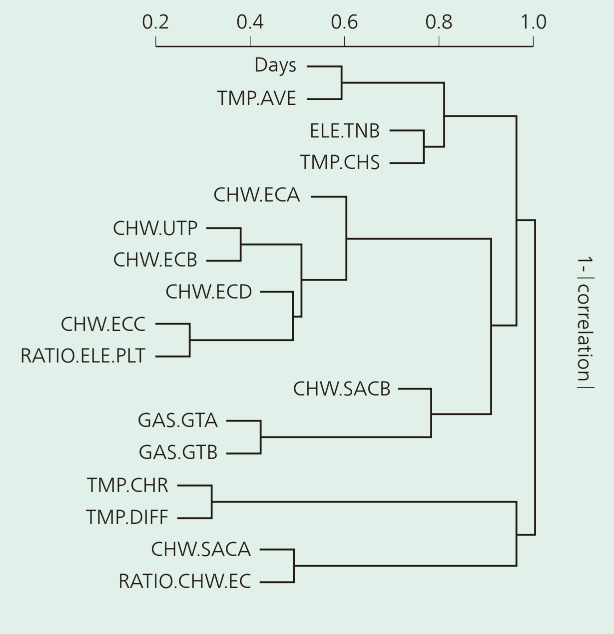
5. DETECTING CAUSES OF GDC PLANT PERFORMANCE DETERIORATION

Despite their energy efficiency benefits, use of SACs in GDC plants is not currently widespread in Malaysia due to their more difficult operation and maintenance (O&M). Accordingly, to achieve the energy efficiency benefits of GDC-DC in practice, it is crucial to consider O&M and to tackle the factors that cause performance deterioration in GDC plants.

Energy consumption has been rising at the UTP GDC plant over the last two years. However, the reasons for this had remained unclear despite the plant having invested in the maintenance and cleaning. In response, the authors undertook an RCA[6] by calculating correlations between historical data stored in the GDC plant SCADA system (See **Fig. 5**).

Before performing the analysis, it was expected that RATIO.ELE.PLT would be tightly correlated with RATIO.CHW.EC because all the four ECs at the UTP GDC plant were of the same age and had the same specifications. In fact, the analysis revealed that RATIO.ELE.PLT is more tightly correlated with CHW.ECC than with the other ECs. This suggested that EC-C required additional maintenance. The plant manager also reported that the pumps used with EC-C had suffered from problems in the past. This indicated that maintenance of EC-C and its pumps had been insufficient, and that maintenance of the other chillers has been appropriate.

The results of this analysis also indicate that the ongoing collection and analysis of data from the SCADA and sensing systems are very important for maintaining the energy efficiency of GDC-DC.



Days: elapsed days from 2010 April 4, TMP.AVE: temperature of outdoor average within one day, ELE.TNB: electricity from Tenaga Nasional Berhad (external supply), TMP.CHS: temperature of supplied chilled water to campus buildings, CHW.ECA: chilled water supply from EC-A, CHW.UTP: chilled water demand from entire UTP, CHW.ECB: chilled water supply from EC-B, CHW.ECD: chilled water supply from EC-D, CHW.ECC: chilled water supply from EC-C, RATIO.ELE.PLT: ratio of electricity consumption of GDC plant to that of entire UTP, CHW.SACB: chilled water supply from SAC-B, GAS.GTA: gas consumption in gas turbine A, GAS.GTB: gas consumption in gas turbine B, TMP.CHR: temperature of returned chilled water from campus buildings, TMP.DIFF: temperature of chilled water difference between supplied to and returned from campus buildings, CHW.SACA: chilled water supply from SAC-A, RATIO.CHW.EC: ratio of chilled water energy of EC to that of whole plant chillers

Fig. 5 | Root Cause Analysis Based on Correlations between Daily GDC Plant Data at UTP from 2010 to 2012.

The left-to-right position of the variable pairs represents their degree of correlation (where left means more tightly correlated). For example, RATIO.ELE.PLT is tightly correlated with CHW.ECC.

6. RELATED WORK

Research into chilled water demand has included extensive study of optimization methods for reducing demand. These include relaxing the temperature requirements for datacenter servers that have a high guaranteed operating temperature[7], and the use of datacenter job scheduling to minimize thermal variance[8] [9]. Research into chilled water supply has also studied optimization methods for increasing supply, including SAC optimization[10] and TES optimization[11]. In the case of GDC, however, it is necessary to consider both supply and demand, with operational efficiency being highly dependent on the gap between supply and demand for chilled water. When supply exceeds demand, for example, decreasing demand is not an efficient way to reduce CO_2 emissions. Similarly, when demand exceeds supply, increasing supply is also inefficient. Therefore, the gap model selects the best form of optimization for GDC efficiency based on actual conditions.

The research into supply and demand for chilled water also included study of optimization methods. These included thermal storage tank optimization based on chilled water demand prediction[12], chilled water distribution network optimization based on building cooling load patterns[13], and electricity demand forecasting for GDC optimization[14]. However, because these methods are intended for supply optimization based on demand information, their efficiency is lower than optimizations that consider both supply and demand. This is because optimizing supply but not demand requires a larger margin to deal with unexpected increases in demand. When demand optimization is also performed, these unexpected increases can be mitigated. In other words, efficiency can be improved by taking account of the supply situation when optimizing demand.

7. CONCLUSIONS

This article has described collaborative research between

Hitachi and UTP for energy efficient datacenters in order to contribute to the development of Malaysia. The authors have created the GDC-DC concept for realizing energy efficient data centers in the ASEAN region, where free cool air is not available. The research found that using SACs in the GDC plant is key to achieving lower PUE. The research also clarified the importance of the sensor data collection network, including the SCADA and wireless sensors, to system design for maintenance of the GDC plant.

Future work will include a detailed study of GDC-DC grid job scheduling, and the implementation and evaluation of an energy sensing system that will incorporate the PI System. By combining job scheduling and energy sensing systems with GDC-DC energy modeling and more efficient practices for GDC plant maintenance, GDC-DC can provide data centers with world-class energy efficiency, not only on campus but also in other university-related industrial uses.

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