Power Saving Technologies for Environmentally Conscious Data Centers

Tatsuya Saito
Yoko Hirashima
Hideho Yamamura, Ph. D.
Tomohiro Yoshida

OVERVIEW: Data centers house IT equipment centrally and run diverse IT services that form part of our social infrastructure, and factors such as their growing size and the increasing density of installed IT equipment have made the associated increase in power consumption a matter of concern around the world. It is believed that the solution to this problem can be found not only in reducing the power consumption of individual equipment but also through the coordinated control of all the equipment in the data center. Hitachi develops a range of different equipment and systems for data centers and in 2007 embarked on an "Environmentally Conscious Data Center Project" that draws on the overall capabilities of the Hitachi Group and an "IT Power-saving Plan" for reducing the power consumption of IT equipment. The major outcomes of this work to date have included the commercialization of a power supply unit for IT equipment and a spot cooling system that features natural circulation of the refrigerant. Future initiatives will include technology for collaborative control of IT and facilities which fits in with the overall aim of implementing center-wide control.

INTRODUCTION

ALTHOUGH the data centers that run the diverse IT (information technology) services as a part of our social infrastructure are playing a growing role as our society becomes more IT-based, the increasing power consumption of these data centers has become an issue around the world[1]. In addition to servers, storage, network equipment, and other IT hardware, data centers are also equipped with various auxiliary equipment ("facilities") such as air conditioning and power supply systems that keep this IT equipment operating smoothly. The IT equipment and facilities now have roughly similar power consumption[2] and therefore comprehensive measures that address both are needed to improve the energy efficiency of the data center.

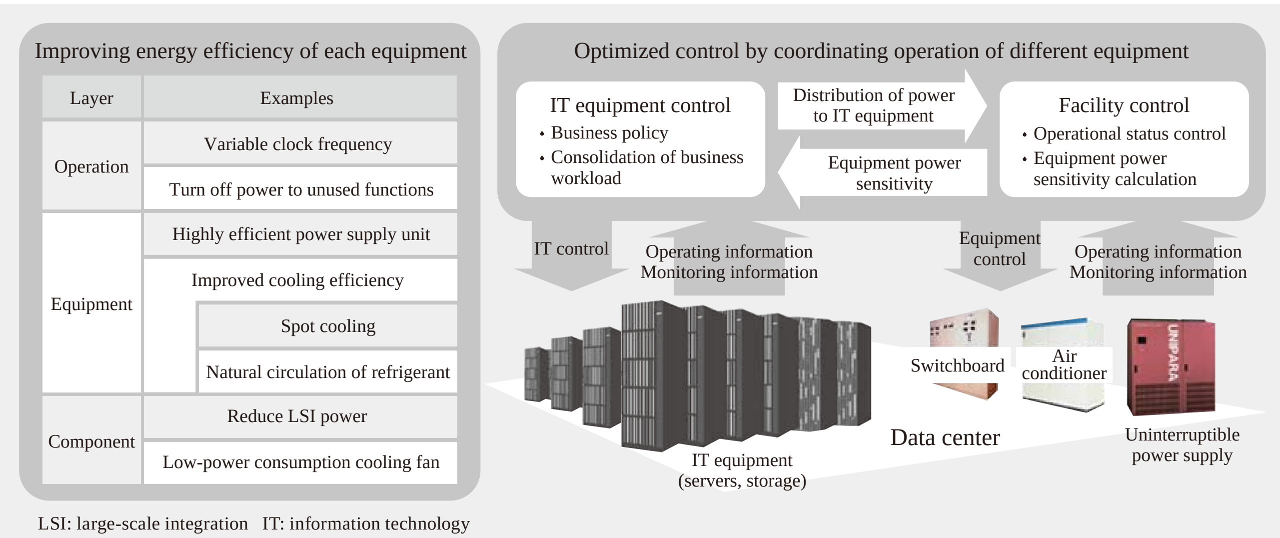

Fig. 1—Targets to improve Data Center Energy Efficiency.
The aim is to reduce power consumption across the entire data center, not only by improving the energy efficiency of specific devices in the component, equipment, and operational layers respectively, but also through optimized control of the overall data center achieved by coordinating operation of different equipment.

Because Hitachi produces a wide range of IT equipment, facilities, and other systems used at data centers, it embarked on an "Environmentally Conscious Data Center Project" in 2007 to apply the comprehensive capabilities of the Hitachi Group to the problem. In the same year, it also formulated and implemented an "IT Power-saving Plan" aimed at IT equipment in particular(3), (4).

KEY ISSUES IN REDUCING DATA CENTER POWER CONSUMPTION

The best approach to reducing the power consumption of a data center is considered to be the combination of improvements in the energy efficiency of individual systems with overall control that coordinates multiple equipment (see Fig. 1). The former reduces the amount of heat generated as well as the load on the power supply and therefore reduces the amount of power consumed by the cooling system, which must cool both the equipment itself and its power supply, and may even reduce the number of cooling units required. Accordingly, the IT Power-saving Plan set out to develop power-saving technologies and products for the component, equipment, and operational layers respectively as shown in Fig. 1(3). Improvements have included reducing the power consumption of LSIs (large-scale integrated circuits), cooling fans, and other devices in the component layer, increasing the power supply unit efficiency and cooling efficiency in the equipment layer, and the use of variable clock frequencies and management techniques such as turning off the power to unused functions in the operational layer.

This article describes two particular results of note from the equipment layer, a power supply unit and a spot cooling system featuring natural circulation of refrigerant, and also describes technology for collaborative control of IT and facilities which is being developed in line with the future aim of implementing center-wide control.

HIGHLY EFFICIENT POWER SUPPLY UNIT FOR IT EQUIPMENT

Status of Power Supply Units

Because power supply units supply power to all components including the LSIs, HDDs (hard disk drives), fans, and other internal components, the units' efficiency affects the power consumption of the overall system. In other words, improving the efficiency of the power supply units achieves a proportionate reduction in the overall power consumption of the system. Although little attention tended to be paid to the power efficiency of power supply units in the past, activity has notably quickened recently, including the publication by the Climate Savers Computing Initiative (CSCI)*1 in 2007 of a standard specifying targets for improving the efficiency of power supplies for which the 80 PLUS program*2 of the Electric Power Research Institute (EPRI) instituted a scheme for measurement and certification in 2008. In 2009, the US Environmental Protection Agency (EPA) also set standards for server power consumption under its ENERGY STAR*3 program that are substantially equivalent to those of the CSCI.

Hitachi Power Supply Unit Development

Hitachi has been involved in standard-setting and related activities as a sponsor of CSCI since it was first established. Hitachi has also developed a highly efficient power supply unit with a typical power efficiency of 92.73% which in March 2009 became the first in Japan to achieve 80 PLUS Gold certification, and has released Hitachi's high-end blade server which complies with CSCI standards. This was followed by 80 PLUS certification and CSCI registration being received by mid-range and PC (personal computer) servers (see Fig. 2). In this way, Hitachi has raised its power efficiency which averaged around 80% prior to 2008.

This success in quickly producing highly efficient power supply units is based on the technologies developed for large-scale computers such as mainframes and supercomputers. Hitachi has been developing technology for highly efficient power supply units for many years to increase power and ensure adequate cooling. Hitachi's super technical

*1 Hitachi is a sponsor of CSCI. Climate Savers is a trademark or registered trademark of the World Wide Fund for Nature (WWF).
*2 80 PLUS is a registered trademark of Ecos Consulting Inc. Hitachi is a registered member of the 80 PLUS program.
*3 ENERGY STAR is a registered trademark of the USA. Hitachi is a registered member of the ENERGY STAR program.

Fig. 2—80 PLUS Certified Power Supplies.
Hitachi was the first Japanese company to receive 80 PLUS Gold certification.

server (supercomputer) has a power supply efficiency of 89% and the computer's power consumption has been reduced by approximately 15%. Hitachi is further improving its technologies, which include a power recycling snubber circuit, and is implementing them in blade servers and other systems.

A SPOT COOLING SYSTEM WITH NATURAL CIRCULATION OF REFRIGERANT

Overview

Other requirements for data centers include improving the energy efficiency of air conditioning and adopting measures to deal with hot spots. In particular, past cooling systems that used down-flow package air conditioners consumed considerable power to transport refrigerant and chilled air and reducing this conveyance power is an effective way of improving energy efficiency. In response, Hitachi has developed the spot cooling system with natural circulation of refrigerant which uses natural circulation to transport the refrigerant without consuming any power and localized chilled air circulation to circulate air from the air conditioner around the racks.

This system consists of a chilled water-refrigerant heat exchanger which uses chilled water from a high-efficiency heat source to cool the refrigerant and spot cooling units that perform localized cooling of the indoor server outlet air (see Fig. 3). During winter and intermediate seasons, the high-efficiency heat source operates as a free cooling system that utilizes cold air from outside. The chilled water produced by the high-efficiency heat source is used to exchange heat with the refrigerant gas in the chilled water-refrigerant heat exchanger which causes the gas to condense into liquid. This refrigerant liquid is then supplied via gravity-feed to the spot cooling units loc ated below the chilled water-refrigerant heat exchanger where it is used for evaporation cooling of the server outlet air before being returned to the water/refrigerant heat exchanger.

Because refrigerant circulation is unforced, it does not need refrigerant conveyance power. Also, because the chilled air is circulated locally around the racks, the power consumed in transporting the air is less than for the previous method which used a raised floor space for cold air. As a result, a significant reduction of about 60% was achieved in air conditioning power consumption (compared to previous Hitachi system).

The cooling units used in the system include door units fitted to the rear of server racks, rack units located between racks, and cloud units attached to the ceiling. Combining these different types of unit delivers significant power savings because it allows the data center to configure a spot cooling system that uses natural circulation of refrigerant for all air conditioning units. Also, because PACs (package air conditioners) that blow up through the floor are no longer required, the floor height can be lowered reducing the cost of data center construction (15% savings for 5-kW/m^2 data center compared to previous Hitachi product).

Example Spot Cooling Unit

Fig. 4 (a) shows a door cooling unit which is one of the spot cooling units used by the system. The unit consists of a cooling coil, cooling fan, and hinge mounting mechanism. The unit can output 2000 m^3/h of air and has a cooling capacity of 10 kW. Also, optimization of the design of the cooling coil inside the unit has shrunk it to a thickness of less than 150 mm.

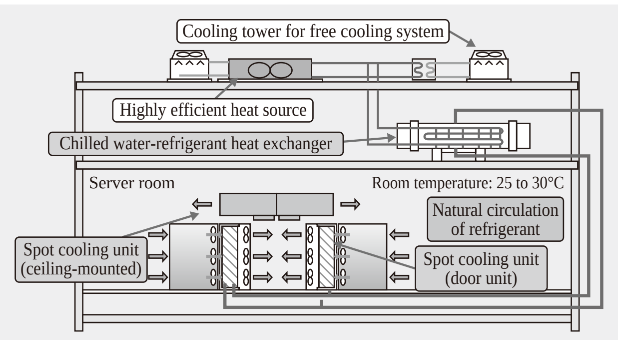

Fig. 3—Overview of Spot Cooling System with Natural Circulation of Refrigerant.
The system consists of a chilled water-refrigerant heat exchanger which uses chilled water from a high-efficiency heat source to cool the refrigerant and spot cooling units that perform localized cooling of the indoor server outlet air.

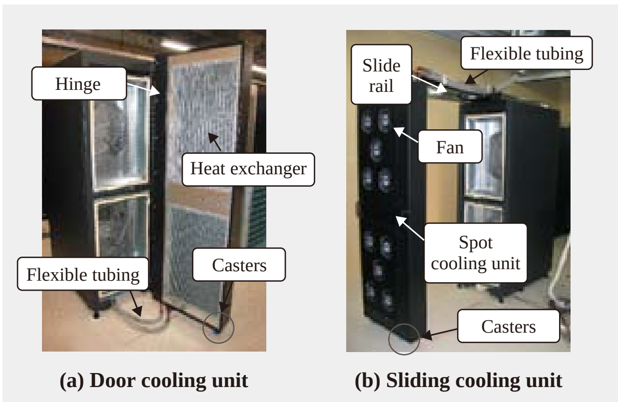

Fig. 4—Spot Cooling Units.
Door and sliding spot cooling units can satisfy a wide range of customer needs for both new construction and upgrades to existing data centers.

The unit is mounted on the hinges on the rear door of a server rack.

Similarly, Fig. 4 (b) shows a sliding cooling unit which is designed for upgrades to existing data centers and can be attached using only click-fit mounting, a feature that meets the requirements of customers with restrictions such as prohibiting the drilling of screw holes into existing server racks.

TECHNOLOGY FOR COLLABORATIVE CONTROL OF IT AND FACILITIES

Overview

An effective way to improve the overall energy efficiency of a data center is to control all of the equipment in a coordinated way. One example is to consider how the air conditioning power consumption and power supply losses vary in response to factors such as where the application processing load is being executed and how the consumption of power is distributed across the center. If execution of the applications running on the IT equipment is consolidated and control of the facilities equipment implemented, the overall power consumption of the data center, including both the IT equipment and facilities, can be reduced by turning off the power to devices that are temporarily not in use (see Fig. 5).

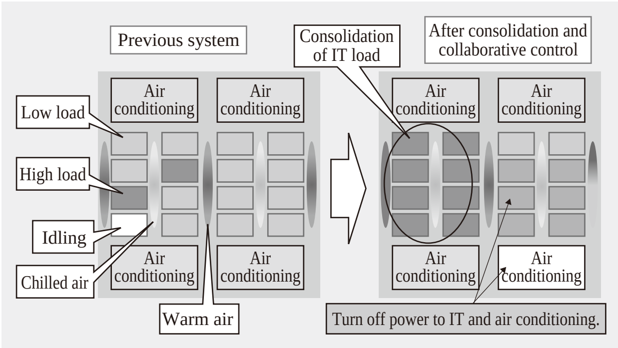

Fig. 5—Operation of Technology for Collaborative Control of IT and Facilities.
The number of hardware units in use can be reduced by consolidating the application workload being processed by the IT equipment. The control of the air conditioning is then adjusted to match this shift in power distribution.

Consolidation of IT Load

As IT equipment typically continues to consume some power even with a 0% processing load, consolidating the processing onto a subset of the IT equipment and turning off the power to those devices that are temporarily unused is an effective way of reducing the power consumption. Accordingly, Hitachi is developing a system for the consolidation of business workload which reduces power consumption while maintaining application performance.

Two ways of consolidating processing are reactive consolidation in which processing is shifted immediately in response to changes in load and adaptive consolidation which uses statistical predictions based on past load behavior to consolidate processing adaptively. As the way in which application loads vary is typically uncertain, consolidating processing carries the risk that the IT equipment will have insufficient capacity if the load subsequently increases. Accordingly, reactive consolidation needs to allow a safety margin of capacity to ensure that application performance is maintained. Because adaptive consolidation predicts characteristics such as the amplitude and frequency of load variations and takes account of these in its operation, it requires less of a safety margin and can be expected to achieve greater savings in IT equipment power consumption.

To compare the two methods, Hitachi conducted testing based on four days of CPU (central processing unit) utilization records from eight servers at an operating data center. The CPU utilization for reactive consolidation was limited to no more than 60%. Adaptive consolidation forecasted the CPU utilization for the fourth day in one hour increments based on the records for the previous three days. Fig. 6 shows the actual power consumption and results for each method on the fourth day in the form of the total power consumption and variation in power consumption through the day of the eight servers.

Compared to the case when consolidation is not used, reactive consolidation achieved a reduction in total power consumption of 29% and adaptive consolidation achieved 45%. Also, the close agreement

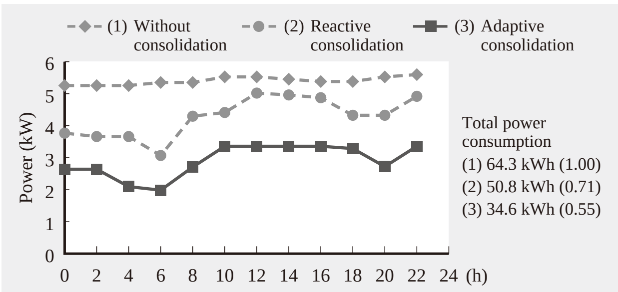

Fig. 6—Server Power Savings Achieved through Application Load Consolidation.
Compared to the case when consolidation is not used, reactive consolidation achieved a reduction in total power consumption of 29% and adaptive consolidation achieved 45%.

between the load without consolidation and the load predicted by adaptive consolidation indicates that there would have been no adverse effects on processing performance.

Control of Air Conditioning Based on IT Power

Consolidating processing creates an uneven distribution of power consumption across the IT equipment (which corresponds to the distribution of heat generation) and it is possible to reduce the power used for air conditioning by controlling the air conditioning equipment based on this distribution. Although air conditioners have conventionally been controlled by keeping constant the temperature of the air they supply, performing control based on the temperature sensitivity calculated by three-dimensional thermohydrodynamic simulation is also a possibility.

First, a temperature sensitivity analysis was used to produce Jacobian matrices representing the relationships between the return air temperature for each air conditioner and inlet air temperature for each item of IT equipment, and between the air supply temperature for each air conditioner and the rise in the temperature of each item of IT equipment. Next, an air conditioner operation simulator was used to determine the power consumption of each air conditioner using as inputs the external air temperature and the return air temperature and air supply temperature for each air conditioner from the temperature sensitivity analysis. This enabled the combined power consumption of all of the air conditioners to be formulated as a function of the return air temperature and air supply temperature. Using this formula as the target function and treating the return air and air supply temperatures for each air conditioner as the manipulated variables, nonlinear programming was used to obtain the optimum solution within the constraints from which could be obtained the return air and air supply temperatures to set to each air conditioner.

The steepest descent method was used to obtain the solution and this was evaluated against a model of a typical data center. Fig. 7 shows the power consumption for the previous constant air supply temperature control and constant return air temperature control methods and the new control method. Compared to constant air supply temperature control, constant return air temperature control reduces air conditioner power consumption by 10% and the new control method reduces power consumption by 12%. Although the difference between constant return air temperature control and the new control method is small due to the test using a model with a relatively uniform distribution of IT power consumption, it is likely that greater power savings could be achieved if application processing is consolidated as described above because this increases the non-uniformity in the distribution of power consumption.

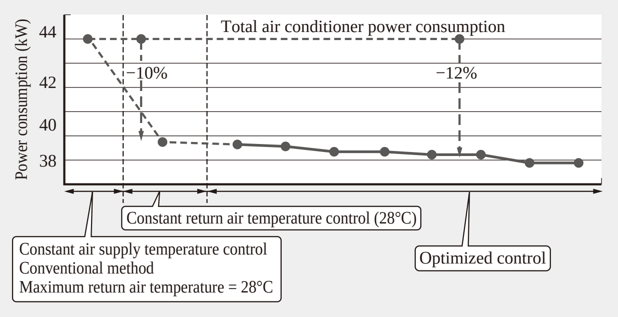

Fig. 7—Air Conditioning Power Savings Achieved by Controlling Air Conditioning based on IT Power Consumption.
Compared to constant air supply temperature control used previously, constant return air temperature control reduces air conditioner power consumption by 10% and optimized control reduces power consumption by 12%.

CONCLUSIONS

This article has described improvements in the efficiency of a power supply unit for IT equipment and a spot cooling system featuring natural circulation of refrigerant, as well as giving a detailed explanation of technology for collaborative control of IT and facilities which is being developed in line with the future aim of implementing center-wide control. These systems are the results of work by Hitachi to develop technologies for reducing data center power consumption. Hitachi intends to continue to improve these technologies to achieve even greater power savings and increase the value added by data centers in their role as part of our social infrastructure.

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ABOUT THE AUTHORS

Tatsuya Saito

Joined Hitachi, Ltd. in 1986, and now works at the Green Computing Research Department, Environment Conscious Datacenter Project, Central Research Laboratory. He is currently engaged in research of energy conservation technology for environmentally conscious data centers. Mr. Saito is a member of The Institute of Electrical and Electronics Engineers, Inc. (IEEE) and The Institute of Electronics, Information and Communication Engineers (IEICE).

Yoko Hirashima

Joined Hitachi, Ltd. in 1994, and now works at the 3rd Department, Systems Development Laboratory. She is currently engaged in research and development of power saving operation and maintenance control over IT platforms. Ms. Hirashima is a member of the Information Processing Society of Japan (IPSJ).

Hideho Yamamura, Ph. D.

Joined Hitachi, Ltd. in 1981, and now works at the Advanced Product and Technology Development Operation, Enterprise Server Division, Information & Telecommunication Systems Company. He is currently engaged in the development of technologies for hardware of computers and servers. Dr. Yamamura is a member of IEEE, IEICE, and The Institute of Electrical Engineers of Japan (IEEJ).

Tomohiro Yoshida

Joined Hitachi Plant Engineering & Construction Co., Ltd. in 1989, and now works at the Technical Engineering Department, Planning & Development Division, Air Conditioning System Group, Hitachi Plant Technologies, Ltd. He is currently engaged in planning and development of air conditioning systems.