A New Advanced Controller for Building HVAC Central Plants that Provides High Added Value

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For control of central plant equipment, which is an important part of a building's HVAC facilities, we have sold PARAMATRIX for more than 30 years, during which time we have accumulated know-how on various kinds of controls. In the aftermath of the Great East Japan Earthquake, the configuration and method of operating central plant equipment is changing, and furthermore, in view of the declining population, the need to improve work-life balance, etc., minimization of the labor required in installation and engineering is desirable. In addition, since the effective utilization of energy is an important issue worldwide, the importance of controllers of central plant equipment for buildings is increasing. To meet these new needs, we have developed the Advanced Controller for building plant systems for global and domestic markets as part of the savic-net G5 new building automation system.

1. Introduction

For many years, Azbil Corporation has sold PARAMATRIX, a controller designed for control of the number of operating units and for pressure control for the central plant equipment of buildings. It has successfully contributed to automatic operation and energy conservation. However, in the current building automation market, an open system independent of specific suppliers is strongly desired. In the aftermath of the Great East Japan Earthquake, many air conditioning systems now use not only electricity, but also gas as a primary energy source, and different kinds of central plant equipment and heat storage tanks are intermingled. Increasingly, the operation sequence of central plant equipment changes depending on the season or time of day, and ever stricter energy conservation is required. Furthermore, from the perspective of the construction industry, there is concern about a shortage of labor due to demand from the 2020 Tokyo Olympic and Paralympic Games, so improved productivity through better working methods is desired.

Against this background, and building upon the proven functions of PARAMATRIX, Azbil Corporation has developed a new controller for the central plants of buildings. It is a key controller in the savic-net G5 building automation system, whose features include open-network support, support of different kinds of HVAC central plant equipment, energy conservation control, visualization, and minimization of installation and engineering labor. Since this controller will be available in both the domestic and global markets, it is designed to be compatible with the instrumentation requirements of central plant facilities in foreign countries.

This paper describes the new functions provided by the Advanced Controller for HVAC central plant facilities and the technologies employed to realize the new functions.

2. System Overview

2.1 System Configuration

The system configuration of savic-net G5 using the Advanced Controller for HVAC central plants is shown in figure 1.

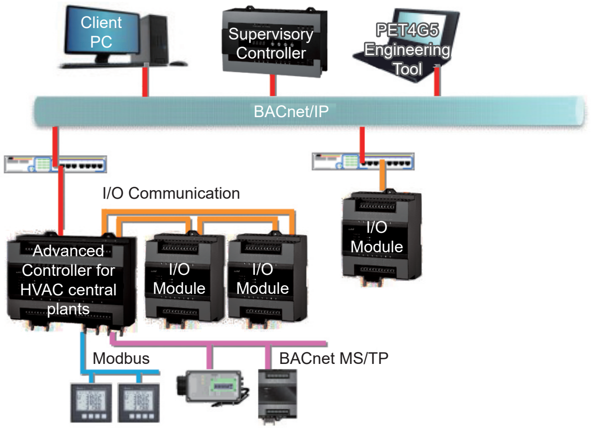


Figure 1. System configuration

From the viewpoint of system configuration, the Advanced Controller has the following characteristics.

- It can be connected to various central monitoring systems, including Azbil Corporation's Supervisory Controller, using open-network BACnet communication.
- In addition to the I/O modules on the controller main unit, I/O modules can be installed in a remote panel via a communication channel. This allows wiring work to be reduced, because individual signal lines between the controller and each device are unnecessary.
- Fault tolerance for problems such as wire disconnection is enhanced by implementing a ring-type Ethernet connection for I/O communication.
- By connecting calorimeters, watt-hour meters, etc., to the controller via Modbus™ or BACnet MS/TP, it is possible to monitor all measurement data, including accumulated values, as points. By collecting the internal data from chillers that are compatible with Modbus via the Modbus communication line, it is also possible to use the data to improve operation and maintenance.

2.2 Software Configuration

From the viewpoint of software configuration, the Advanced Controller for HVAC central plants has the following characteristics.

- Applications for controlling central plant equipment, such as supply-water pressure control, load control when starting equipment, and control of the number of operating units can be configured using the direct digital controller (DDC) programs in combination with DDC program blocks, which execute control calculations (see fig. 2).

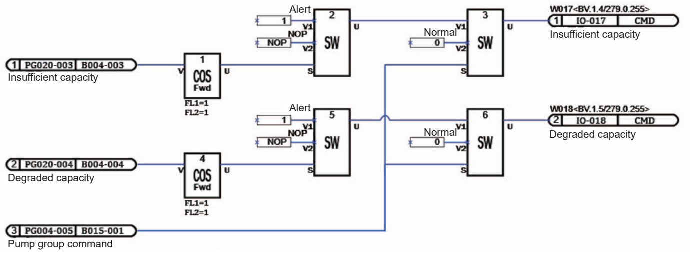


Figure 2. DDC program example

- It is possible to generate an instrumentation code (see table 1), which provides a standardized model number for the desired I/O configuration, point configuration, and DDC program configuration. When the instrumentation code is used to order the product, the hardware and software configurations required for instrumentation can be obtained, without the need to configure the points and applications for each worksite. (At the worksite, it is necessary only to add or modify to obtain unique requirements that differ from the standard model number.)

Table 1. Instrumentation code

WJ-1102Q(1)(2)(3)(4)(5)(6)

(1) Instrumentation type		(2) Number of units		(3) Control method for number of operating units		(4) Pressure control / primary pump variable flow control		(5) Other		(6) Supply powerspecifications	
1	Single-pump system	2	2 units	3	Flow 1 system (with calorie calculation)	0	—	0	Fixed	W	100–240 V AC
		4	4 units	4	Flow 4 system (with calorie calculation, calorie 4 system with addition)	1	Proportional bypass (current/voltage)				
		8	8 units			3	Primary pump variable flow control (inverters for all units + proportional bypass (current/voltage))				
2	Dual-pump system	2	2 units	2	Flow 1 system (with calorie calculation)	0	—	0	Fixed	W	100–240 V AC
		4	4 units	6	Flow 4 system (with calorie calculation, calorie 4 system with addition)	1	Primary pump variable flow control (divided load)				
		8	8 units								

WJ-1102P(1)(2)(3)(4)(5)(6)

(1) Instrumentation type		(2) Number of units		(3) Control method for number of operating units		(4) Pressure control		(5) Other		(6) Supply power specifications	
1	Fixed	2	2 units	3	Flow 1 system (with calorie calculation)	0	—	0	Fixed	W	100–240 V AC
		4	4 units	4	Flow 4 system (with calorie calculation, calorie 4 system with addition)	1	Proportional bypass (current/voltage)				
		8	8 units			3	Inverter (n units) + proportional bypass (current/voltage)				
						5	Inverter (all units) + ON/OFF bypass				

- Since all instrumentation code's controller data is included in the engineering tool for the savic-net G5 system, unlike conventional products, it is possible to change or add points or change the DDC programs before the controller is delivered to the worksite, allowing the engineering work at the worksite to be shortened.
- Using the DDC program editing function in the engineering tool, DDC programs can be easily configured at the worksite. In addition, the output of each program block can be checked graphically, which makes checking of control operation much easier than with the conventional product.

3. Supporting Instrumentation for Various HVAC Central Plants

In order to meet the often-seen needs related to a variety of HVAC central plant instrumentation and the worksite operations, we have expanded and added functions from conventional products.

3.1 Enhanced Functions

3.1.1 For a greater variety and amount of plant equipment

In the aftermath of the Great East Japan Earthquake, for the purpose of risk distribution for HVAC central plant equipment and reduction of peak power consumption, there is increasing use of applications for switching between multiple kinds of the central plant equipment according to the time of day or season. This equipment includes (electrical) turbo chillers, gas absorption chillers, heat exchangers (heat storage tanks), etc. Also, the amount of central plant equipment is increasing. Since these trends are noticeable at large-scale sites, with the Advanced Controller it is possible to increase the number of controllable central plant equipment units (chillers and pumps) by expanding the capacity of the controller. Owing to the enhancement, this product can handle even the largest sites encountered in the past.

3.1.2 Increased number of points

Conventional products handle a maximum of 99 points, which is not a problem when implementing applications with typical models. However, when adding a complex customized control application or a customization function to a model with many points, there have been cases where the number of points was not sufficient, the application could not be created, or the application was created by somehow cutting existing points. Also, many points are needed for overseas HVAC central plant instrumentation, as explained below. The Advanced Controller can handle as many as 300 controller points while maintaining better measurement and control performance than conventional products. This makes it possible to cope easily with complicated control applications.

3.2 Support for Changing the Equipment Operation Sequence

In conventional products, the need to change the order in which equipment is operated was assumed only for the switch between daytime and nighttime. With this approach, the operation of high-performance central plant equipment is prioritized during the daytime to improve the ability to meet large daytime air conditioning loads, and low-performance equipment is operated mainly at night, when the air conditioning load is low, in order to save energy.

Now, however, depending on the time of day, complicated operating schemes are being requested, such as prioritizing heat exchangers (priority on heat storage), gas absorption chillers (priority on gas), or turbo chillers (priority on electricity). It is hard for conventional products to cope with these requests by switching between day and nighttime operation sequences only.

For that reason we enhanced the operation sequence change function. Since there are many cases in which a change between daytime and nighttime sequences is sufficient, the conventional approach is retained with the same engineering method as the existing products. With this basic function, we made it possible to select up to 8 patterns in order to change the daytime table to meet the desired operation sequence control (see table 2). In addition, by making it possible to specify the operation sequence pattern by means of a point, the operation sequence can be changed by manual operation of the central monitoring unit, time schedule, or DDC program. In particular, by using a DDC program, it is possible to have a high degree of flexibility for applying different conditions and for meeting various user needs. Regarding condition for changing and the number of operation sequence patterns, we verified their appropriateness by examining actual jobs.

Table 2. Example of an operation sequence changes

(1) Operation sequence pattern settings

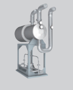
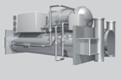
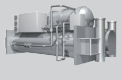
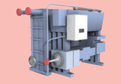
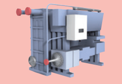
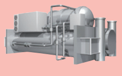
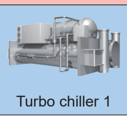
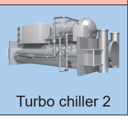
Pattern No.	Turbo chiller 1	Turbo chiller 2	Gas absorption chiller 1	Gas absorption chiller 2	Heat exchanger
(1)	2	3	0	0	1
(2)	3	0	1	2	0
(3)	1	2	0	0	0
⋮					
(8)					

(2) Operation sequence pattern change (for the time schedule)

8:00 13:00 16:00 22:00

Operation pattern 1 | Operation pattern 2 | Operation pattern 3

(3) Actual operation sequence

Time slot	Operation pattern	Operation sequence No. 1	 No. 2	 No. 3
8:00 – 13:00	(1) Heat exchanger prioritized	 Heat exchanger	 Turbo chiller 1	 Turbo chiller 2
13:00 – 16:00	(2) Gas prioritized	 Gas absorption 1	 Gas absorption 2	 Turbo chiller 1
16:00 – 22:00	(3) Electricity prioritized	 Turbo chiller 1	 Turbo chiller 2	

3.3 Support for Overseas Central Plant Instrumentation

For HVAC central plant instrumentation in Japan, there is a one-to-one correspondence between the chiller and the primary pump or cooling water pump as shown in figure 3, and when the chiller is turned on or off, the corresponding pump is turned on or off by a sequence circuit. The starting or stopping of chillers (control of the number of operating units) is done by the controller made by the automatic control supplier (e.g., Azbil), and the linked starting/stopping of the pump is done by the chiller manufacturer.

In overseas HVAC instrumentation (except for Japanese companies), however, there is not a one-to-one correspondence between the chiller and the primary pump or cooling water pump (see fig. 4), and the respective operating units can be freely combined. Therefore, the automatic control supplier's controller must handle the control of the number of operating units not only for the chillers but also for the primary and cooling water pumps.

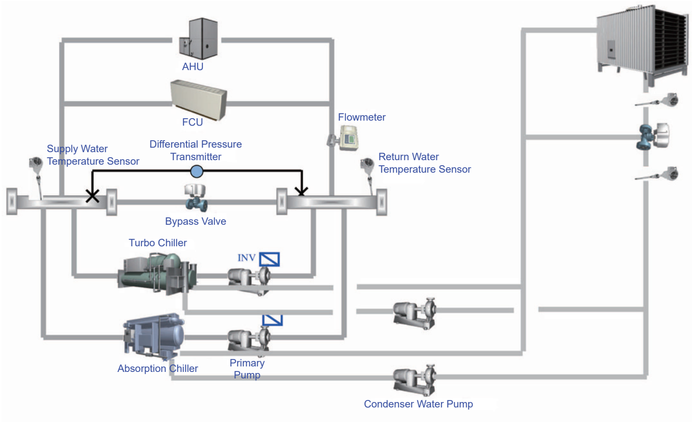


Figure 3. Instrumentation for Japan (single-pump system)

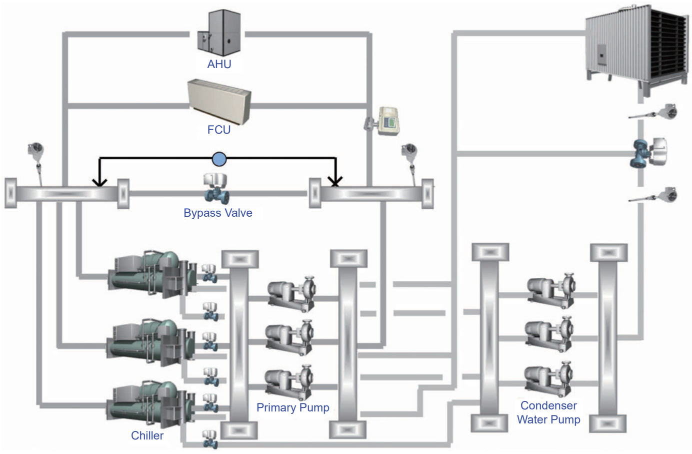


Figure 4. Instrumentation for overseas (single-pump system)

When implementing the overseas HVAC central plant instrumentation with our conventional products, as many as 4 controllers were required to control the number of operating units for the chillers, primary pumps, cooling water pumps, and cooling towers. In addition, in order to share data between the 4 controllers, one general-purpose controller was required, so the system became complicated.

By greatly improving the control capacity and processing capacity of the controller, we made it possible to simultaneously execute up to 4 DDC program blocks controlling the number of operating units. The conventional product could execute only one DDC program block. As a result, it is possible to control the number of operating units for 4 types of chiller plant equipment simultaneously using only one Advanced Controller.

4. Energy Management and Energy Conservation

In order to meet the demand for energy management and energy conservation in the field, new functions for visualizing and minimizing the energy consumption of the HVAC central plant for the entire building have been implemented. By implementing these functions as DDC program blocks, we made it possible to use the results of calculation from other applications, as well as to configure DDC program blocks freely for each site, for example by making the unit for calculation an individual HVAC central plant or a group of plants.

4.1 Visualization of Chiller COP

The coefficient of performance (COP) of a chiller is an indicator of its efficiency. The COP is determined by dividing the amount of calories generated by the amount of power consumed. For this product, we developed a DDC program block (called CPC) to calculate the COP. Since it is possible to calculate and output the COP hourly and daily, by checking the COP values, chiller operation can be improved by means such as adjusting the supply water temperature. When the COP worsens due to contamination of the chiller's condenser or evaporator, maintenance can be carried out easily.

By using a DDC program, it is possible to make an application (using point notification) that prompts the user to check the equipment when COP deterioration is suspected.

4.2 Visualization of Pump Power Consumption

To visualize the energy consumption of HVAC central plant pumps (primary pumps, secondary pumps, and cooling water pumps), it was previously necessary to measure the cumulative volume. For this product, as shown in figure 5, we developed a calculation algorithm, implemented as DDC program blocks PC1 and PC2, that is based on pump characteristics, allowing power consumption to be calculated from the operating state of the pumps without volume measurement. This permits visualization of pump power consumption at a low cost.

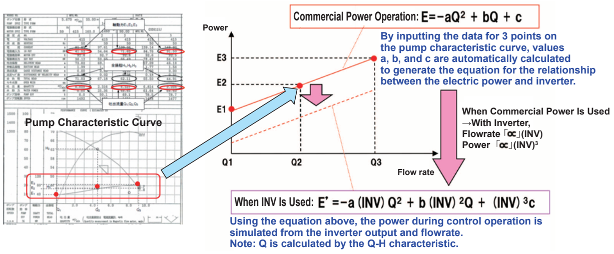


Figure 5. Energy calculation method of PC2

PC1 calculates the power consumption of the primary pump, and it also can calculate the total power consumption of any number of pumps, so that it can be used for an individual HVAC central plant, a group of HVAC plants, etc., according to the needs of the site. In addition, it has the ability to calculate power consumption assuming that all pumps are operated at their rated specifications (using commercial power). This enables it to visualize not only the amount of power consumption at the present time, but also the effect on energy efficiency if an inverter is introduced.

PC2 calculates power consumption mainly for secondary pumps that execute variable flow control (for energy conservation). Like PC1, it can calculate the total power consumption of any number of pumps, so it can be used for an individual HVAC central plant, a group of HVAC plants, etc., according to the needs of the site. In addition, it has the ability to calculate the amount of power consumption assuming that the discharge pressure is constant and that all pumps are operated at their rated specifications (using commercial power). This enables it to visualize not only the amount of power consumption at the present time but also the effect on energy efficiency if variable flow control and an inverter are introduced (see fig. 6).

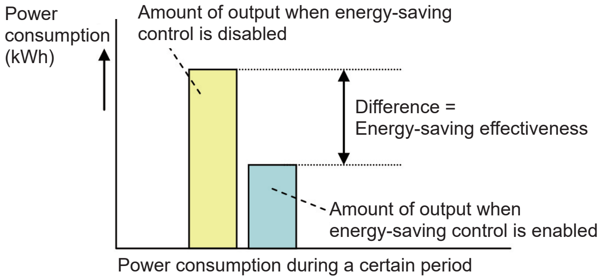
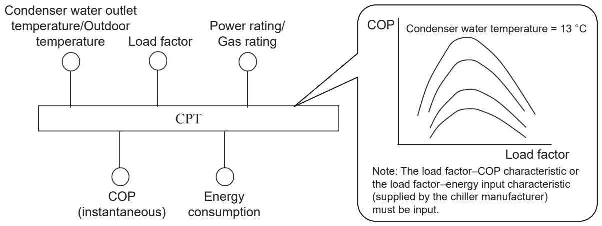


Figure 6. Verification of energy-conservation effectiveness

4.3 Visualization of Chiller Power Consumption

As with the pumps, in order to visualize chiller energy consumption, it was previously necessary to measure the cumulative volume. The COP of chillers greatly changes depending on the water temperature in the condenser. If the relationship between the load factor of the chiller and the COP for various temperature conditions, which is supplied by the chiller manufacturer, is assigned to a parameter, or if the characteristic data for the relationship between the load factor and input energy is assigned to a parameter, an algorithm we developed can calculate the power consumption from the state of the cooling water and the load factor. The algorithm, which is implemented as a DDC program block ("CPT"), calculates chiller power consumption without the need to measure volume (see fig. 7). This allows chiller power consumption to be visualized at a low cost.



Note: The load factor–COP characteristic or the load factor–energy input characteristic (supplied by the chiller manufacturer) must be input.

Figure 7. Overview of CPT

4.4 Control of the Optimum Number of Operating Units

In normal control of the number of operating units, a second chiller is not added unless the load is greater than the first chiller's capacity. However, an HVAC central plant facility with multiple high partial-load-efficiency chillers (inverter-turbo chillers or inverter-screw chillers), which also minimizes pump energy consumption by variable flow control, may have lower costs by operating two chillers rather than by operating one chiller based on the status of its load.

The Advanced Controller for HVAC central plants, using the DDC program blocks PC2 and CPT described above, compares the energy consumption of the plant in its present operating state and its consumption if the number of chillers is increased. If the latter is more efficient, it is possible to make an application which optimizes the number of operating units by increasing the number of chillers. By optimally controlling the number of operating units, it is possible to increase the number of chillers at the optimal timing to maintain comfort, as with normal control of the number of operating units, and also to pursue energy conservation.

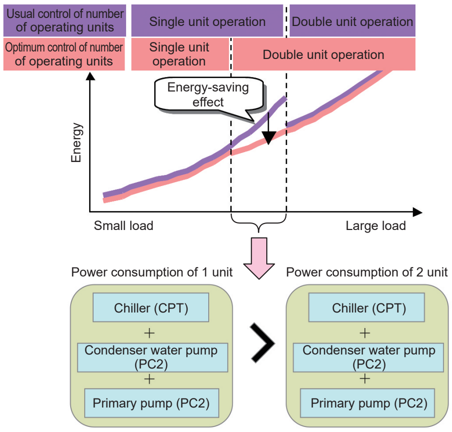


Figure 8. Energy-conservation effectiveness of control of the number of operating units

5. Reduction of Installation and Engineering Loads

In order to meet the demand for reduced installation and engineering workloads, we adopted a mechanism to reduce wiring work and developed an online engineering function.

5.1 Reduction of Installation Workload

Since our conventional product is configured to directly connect I/O modules to the controller, it is necessary to lay many wires from the equipment panel (in the case of equipment that communicates with the controller) to the controller panel, if the equipment is installed apart from the controller. If additional wires are required later, wiring work is again necessary.

The Advanced Controller is connected to I/O modules via Ethernet, which enables high-speed communication and makes it possible to install the I/O modules apart from the controller while ensuring measurement and control performance that is the same or better than the conventional product. Therefore, even if the equipment that communicates with the controller is installed apart from it, wiring work is greatly facilitated compared to the conventional product by installing the I/O module only in the panel that contains the equipment (see fig. 9).

Also, if additional I/O modules are needed due to facility expansion or the like, by using daisy chain wiring for Ethernet, the I/O modules can be added easily by wires between the modules without adding a new hub. For the daisy chain wiring, the ring connection technology is adopted so as to enhance fault tolerance.

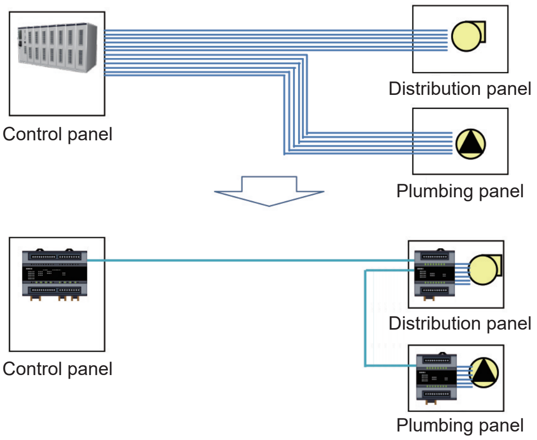


Figure 9. Reduction of installation workload

5.2 Reduction of Engineering Load

When modifying files on our conventional controller (by downloading files or changing parameters), the controller must be stopped and be in offline mode. As a result, if modifications were necessary after the controller began operating in a building, the work had to be done at night or during a long holiday.

Data in the Advanced Controller is stored in dual memory areas, master and work, as shown in figure 10. After modifying the settings data in the work area, only the relevant applications are stopped, and then the master data is updated without stopping the controller. In this way, the conventional product's downtime in excess of one minute can be avoided, and maintenance work can easily be accomplished during building operating hours. Also, after modifying the settings data in the work area, it is possible to verify the integrity of all the settings to detect inconsistencies across multiple applications, thus preventing malfunction due to incorrect modifications.

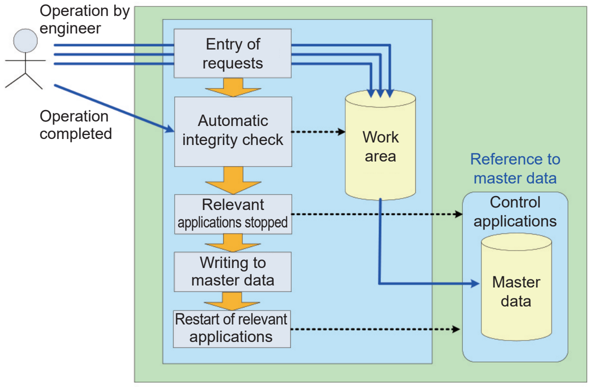


Figure 10. Mechanism of online engineering

6. Future Enhancement

A redundant controller system is required in the data center and district heating and cooling (DHC) markets. If a controller should fail, control must be switched to the alternative controller immediately.

Our redundant controller system is configured as shown in figure 11. The active and standby controllers monitor each other's operating status and the communication status of higher and lower level networks. If the active controller fails or experiences a communication error, the standby controller is switched to active status and continues control operation.

This redundant controller system will be introduced in the future.

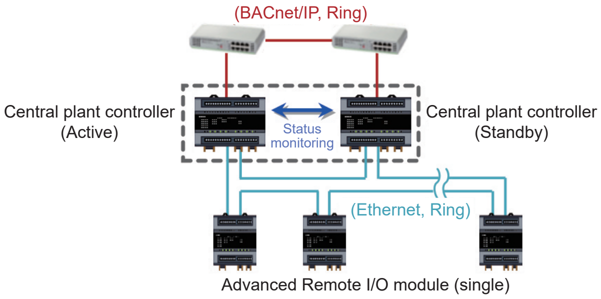


Figure 11. Controller redundancy

7. Conclusions

We have given an overview of the Advanced Controller for building HVAC central plants and the new functions that were not available in the conventional product. In the future, in addition to controller redundancy as described above, we plan to add heat storage control as a basic function. Also, by strengthening cooperation with the Supervisory Controller, we would like to provide a predictive function for control target values based on big data, as well as parameter-based operation improvements and more efficient energy conservation functions.

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