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Research and Development of Air-Conditioning Chiller IoT Controller and Experiment of Automatic Demand Response Unloading Strategy

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Abstract

The purpose of this paper is to design and develop an air conditioning chiller IoT controller with automatic demand response load control strategy by using the Internet of Things sensing layer technology. The proposed IoT controller adopts MODBUS-based air conditioner control systems to read and write operational data, and has the function of uploading information to the cloud server via wired Ethernet or wireless 4G transmission network. The proposed controller proceeds the automatic demand response of load management strategy for the power company or the energy service center, as well as carries out the demand side management, and implements the load control strategies of the user-side air-conditioning chiller to effectively reduce the peak load. The developed IoT controller initially used the Liling chiller as the test host, which provides three modes of line current control, unloading control, and chiller outlet/inlet temperature control for users to choose. Once the automatic demand response load shedding signal is activated, the IoT controller provides communication protocols of custom automatic demand response and an open ADR 2.0b to transfer the information with the service center of the aggregator. In instruction to verify the practicability and effectiveness of the IoT controller developed, this study selected the chiller with variable frequency and fixed frequency dual compressors in the southern public office for actual testing and verification. The test results can be used as guidance for chiller to participate in the automatic demand response.

Keywords: Air conditioning chiller, Internet of Things Controller, Automatic demand response, Load shedding strategies, energy service center, load management strategy.

Introduction

In instruction to solve the dilemma of insufficient peak load power in summer, and to continue to cooperate with the energy conservation policy of promoting the goal of non-nuclear homes in response to the world energy crisis, demand-side management measures are the established effective goals and development directions of the government [1].

Automatic demand response is a very important method in the demand side management. Its purpose is to inform the end consumers of electricity with the difference in electricity prices, financial incentives, environmental conditions or reliability signals, so as to reduce the consumption of a specific period of time. Electric load, or shift the demand for electricity to other periods, to reduce the bottleneck of the power supply and reduce the high cost of the equipment running, or Achieved No need Take turns power supply of Section, gradually extending investment benefits of new power plant set up [2].

Taipower has promoted demand response measures for more than 30 years. It has plans for continuous management of balanced system loads and has continued to improve [5]. Table 1 shows the effectiveness of Taiwan current demand response [1,3,4]. In 2015, Taipower Import demand bidding scheme, which combined with other load management schemes, has a huge benefit for summer peak loads.

From Table 1 can found that users cooperate with preferential measures to reduce electricity consumption as the main source of demand response. Taipower conducted a research on the demand response plan for congested areas in 2014. According to the research results, high- and low-voltage users who are mainly air- conditioning systems, coordinate effective air-conditioning load control strategies, can produce a large number of peak load suppression effects [1, 6].

Recently, many studies focus on reduce electricity consumption by the HVAC system of abuilding without affecting the privacy and comfort level of the occupants of the building [6,13]. Therefore the applied technical approaches such as Kalman filtering, gray-box models, cloud computing, big data analytics, business intelligence models etc. have developed. In [7], the authors propose a Kalman filtering based gray box model to predict and determine statistical process control limits for controlling the power consumption of buildings. An intelligent controller with neural network model is designed in [8] by integrating IoT with cloud computing and Web services. Besides, a smart home energy management system using IoT and big data analytics is proposed in [9], which predominantly focuses on the electricity consumption of the HVAC system. In particular, the proposed mechanism makes use of business intelligence and big data analytics software packages to better manage energy consumption and to meet consumer demand [10]. In particular, authors in [11, 12] propose occupancy behaviour based model with predictive control scheme for building indoor climate survey. In [14], HEMS with demand response function has applied optimal and machine learning rule.

Table 1. Promotion Of Taiwan Demand Response Plan

Load management measures	Implementation object	Performance in 2015
Time price	•Low voltage users can choose •Mandatory for users above high voltage	119,677 users choose
•Preferential measures for off-peak power consumption of cold storage air-conditioning system	Users of cold storage air-conditioning system choose	•310 users choose •Participation capacity is 455,456HP
Concessionary measures for periodically suspending air-conditioning and air-conditioning	User selection of large air-conditioning system	•125 customers choose • Participation capacity of 27,887 frozen tons
Users cooperate with preferential measures to reduce electricity consumption	Limited selection of contract capacity for a certain scale	• 1,122 customers choose • Participation demand is 1,560MW • Summer peak has 65MW load suppression effect
Demand bidding	Limited selection of contract capacity users of a certain size	•161 customers choose • Participation demand is 103MW • Summer peak has 17MW load suppression effect

Source: Provided by Taipower (2014)

In smart grid applications, intelligent electricity with ADR and control methods for air conditioning system are very attracted to survey [15]. In [16] a supply-based feedback control strategy of air-conditioning systems for direct load control to meet the request of power company has developed. Thermal comfort evaluation in [17] is applied in campus classrooms during room temperature adjustment for demand response. Similarly, supply-demand coordination for urgent responses to smart grid has proposed for fast building load control [18, 19, 20]. In [21], a model-based control strategy to recover cooling energy from thermal mass in commercial buildings has been developed. A useful method-direct chiller power limiting for peak load shedding control in building has developed and validated on site. Besides, in [23] an algorithm involving building thermal mass, indoor and outdoor mean running temperatures has proposed to enhance the control of night ventilation.

The author's research team is currently implementing the air-conditioning demand response plan of the Ministry of Science and Technology [5]. The purpose is to develop an automatic demand response system for “Shulun Smart Green Energy Science City” to implement large-scale demand response control strategy planning and full-scale experiments for air conditioning systems. The research plan focuses OpenADR instruction command to a client site (Site) from a public utility (Unity) or Independent System Operator (ISO). In addition, an OpenADR device can respond to the upper-level VTN server as a VEN at the upper level of the layered architecture, and also can commands to the lower-level VENs at the same time as the lower-level VTN. Exchange events in either direction can be independent of each other and the OpenADR Alliance does not define information on how to react at the nodes. On nodes that support both the VTN and VEN interfaces (such as the energy integrator Aggregator), there are no specifications and restrictions on how the messages received inside the VEN interface are coupled or translated into VTN messages and sent on the development of an ADR (Automated Demand Response) system to realize the demonstration field and benefit evaluation of user group representatives, and the integration of the client VEN and the BEMS (Building Energy Management System) or HEMS (Home Energy Management System) central air-conditioning host controller, participating in the power company's demand response plan to control the load that needs to be unloaded and invested in each period to verify various types of air-conditioning systems. It reduces the peak efficiency, and can obtain real-time energy management information to achieve the overall energy saving effect.

Introduction To The Architecture Of Automatic Demand Response System

Corresponding VEN relationships based on the OpenADR 2.0 protocol based on the automatic demand response system architecture. The simplest case is to give an from its interface, opposite the same. They are considered as two completely independent interfaces and tested independently to ensure that they conform to specifications and Interoperate principles. The actual System deployment scheme depends on the agreement between the utility and participating customers.

These VTNs and VENs nodes can communicate using Simple HyperText Transfer Protocol (Simple HTTP) or XMPP (XML Messaging and Presence Protocol) communication protocols. Simple HTTP only uses the POST method in the HTTP standard, and can be divided into the PUSH mode in which VTN initiates communication and the PULL mode in which VEN requests VTN messages to open a series of messages. The PULL mode is adopted by most devices at present, and its biggest advantage is that it is convenient for users to set and install. XMPP was originally used in network communication software for

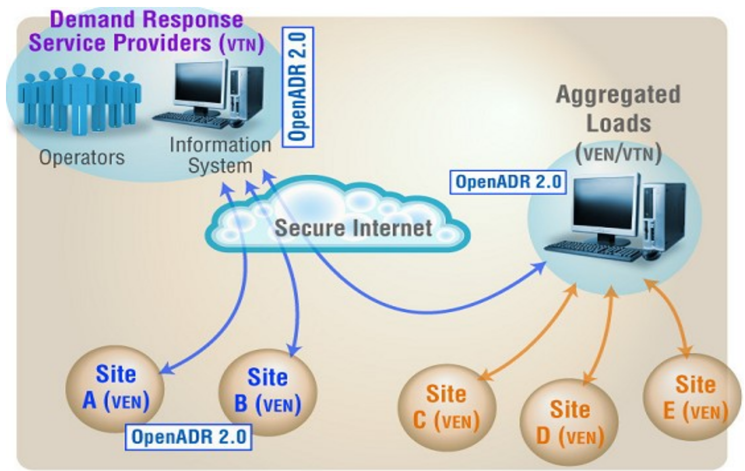


Figure 1. Relationship between OpenADR2.0 VTN and VEN

Peer-to-Peer (P2P) message exchange. It is highly flexible. All communications are carried out between one VTN and one or more VENs. That is, VTNs cannot communicate directly with other VTNs, nor can VENs communicate directly with other VENs. The OpenADR Alliance mandates that certified VTN devices must support Simple HTTP and XMPP protocols; VEN must support at least one of them.

Design and Development of Demand IoT Controller

Hardware / Firmware Integration Planning

The idea of this article is to develop a simple-volume IoT controller, which is the communication medium between the energy aggregator and the Chiller controller under the central air conditioning system. Or Programmable Logic Controller (PLC).The main task of the demand IoT controller is to integrate the client VEN with the central air-conditioning host controller of the building energy management system (BEMS) or home energy management system, and cooperate with the energy aggregators to participate in the "user demand bidding" plan, implemented by the power company. Participate in demand bidding daily. When the bid is obtained, the Demand Response Aggregation Service Center will on Specified time operate the air-conditioning system to partially unload by the demand IoT controller to achieve the ADR event, reduce the power demand for the electric grid system, and accomplish peak transfer effect of the power system , while reducing the cost of electricity bills for the client.

The demand IoT controller act procedure:

(1) The power information and operating status of the central air-conditioning system are usually uploaded to the demand response aggregation service center database by the demand IoT controller to provide user-side power management. And load forecasting applications.

(2) When Aggregator receives the ADR event required by the power company, Aggregator will also give DR command to the central air-conditioning system for the demand IoT controller, and the demand IoT controller will receive the unloaded demand air-conditioning packet from Aggregator. According to this packet format, the packet is decapsulated 解封的, According to the communication protocol of the air conditioner host controller, an instruction to unload part of the demand control is issued to meet the demand of the DR. Until the end of the ADR event time, the demand IoT controller will switch the ADR schedule of the central air conditioning host back to the original schedule to continue execution, and wait for the next ADR event to trigger.

Demand IoT controllers have dual identities, and can be divided into front and back ends based on communication technology planning, as shown in Figure 2. In the front-end communication between the demand IoT controller and the air conditioner host controller, the air conditioner host controller is the server side, and the demand IoT controller is the client. When the demand IoT controller sends a request to access the air conditioning system information, the air conditioner The host controller will receive and respond to the demand of the IoT controller's request service and return the information of the air-conditioning system.

This communication uses the RS-485 or RS-232 communication interface, and uses the industrial standard Modbus communication protocol as Communication technology and transmission packet format; in the back-end communication between the demand IoT controller and Aggregator, Aggregator is the client, the demand IoT controller is the server, and the demand IoT controller responds to the request from Aggregator to access the air-conditioning information. At the same time, the corresponding data is returned. This communication uses Ethernet or Wi-Fi as the communication technology, and uses the OpenADR standard protocol or a customize communication protocol as the back-end communication specification. The integration of front-end and back-end communication technology is centered through an embedded system development board. With a variety of communication functions, it can respond to air-conditioning equipment of any field and any brand, and can control the current-limiting operation of various types of air-conditioning mainframes..

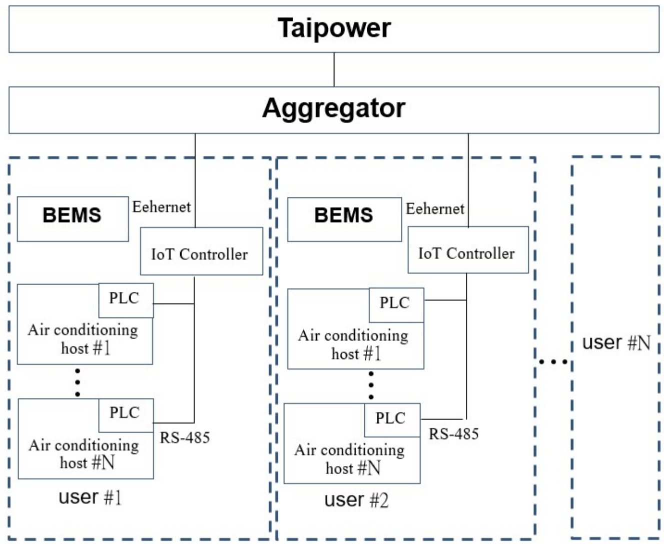


Figure 2. Communication technology planning for demand IoT controllers

The Chiller temperature control unload operation and load% operation strategy mode operation to achieve the ADR event, the following sections will be detailed description of the hardware circuit design and firmware procedure.

Hardware Circuit Design

The demand IoT controller is developed by combining the embedded system development board and various communication modules. Its hardware planning is based on the communication technology shown in Figure 2, and its hardware architecture is shown in Figure3.The communication between the modules is a CUP module using the OpenWrt Linux operating system. The purpose of this module is to serve as a prototype platform for IoT devices. It can also interface with Wi-Fi network cameras and sensors used in homes and offices. As a cloud real-time monitoring system, It has communication ports such as GPIO, I2C, I2S, SPI, UART, PWM, and Ethernet. The software development can support OpenWRT, Python, Node.js, Arduino, and native C language. Development environment. This module has built-in 32MB flash memory and 128MB DDR2 memory. Based on rich memory and storage space, it can realize rich application development. Wi-Fi connection can support 802.11 b / g / n, and its size is 24mm x 32mm, and its antenna and SD can be adjusted to be external, providing greater flexibility in product application planning. The equipment specifications for the IoT controllers are shown in Figure 4.

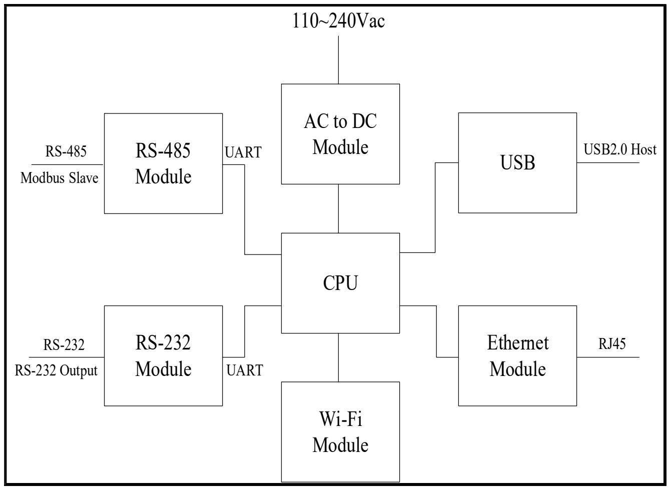
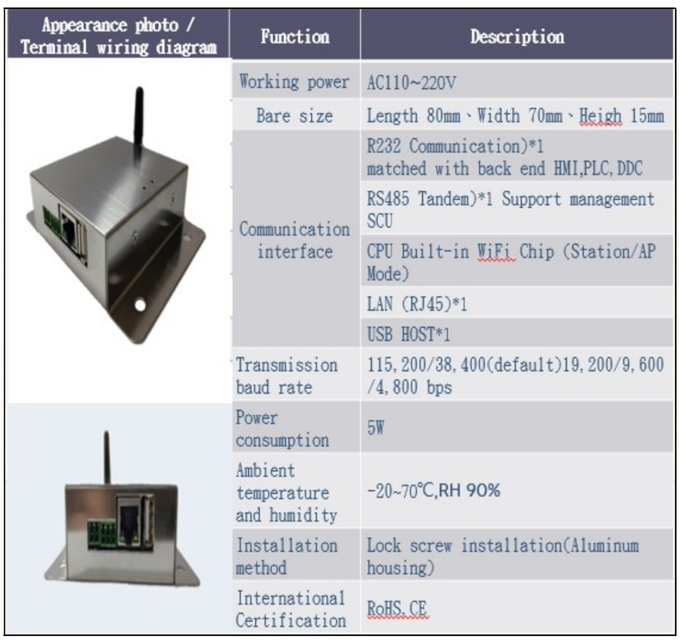


Figure 3. Hardware Architecture Diagram of Demand IoT Controller



Appearance photo / Terminal wiring diagram	Function	Description
	Working power	AC110~220V
	Bare size	Length 80mm、Width 70mm、Heigh 15mm
	Communication interface	R232 Communication)*1 matched with back end HMI,PLC,DDC
		RS485 Tandem)*1 Support management SCU
		CPU Built-in WiFi Chip (Station/AP Mode)
		LAN (RJ45)*1
		USB HOST*1
	Transmission baud rate	115,200/38,400(default)19,200/9,600 /4,800 bps
	Power consumption	5W
	Ambient temperature and humidity	-20~70℃,RH 90%
	Installation method	Lock screw installation(Aluminum housing)
	International Certification	RoHS,CE

Figure 4 Equipment specifications for demand IoT Controllers

Firmware programming design

The firmware design of the IoT controller required in this article is like the development of communication technology can be divided into front and back ends. The communication between the front end and the demand IoT controller is mainly to read the operation information of the air conditioning system, and to Give a DR instruction for the partial unloading of theChiller of the air conditioning system when the ADR event is performed. The communication technology uses RS-485 or RS-232, and the packet format of the communication uses the Modbus standard protocol; the back-end communication with Aggregator is to upload the information of the air-conditioning system to the Aggregator database. Its technology is Ethernet or Wi-Fi. The communication packet format uses the OpenADR standard communication protocol or a custom communication protocol The operation procedure of the demand IoT controller is shown in Figure 5.

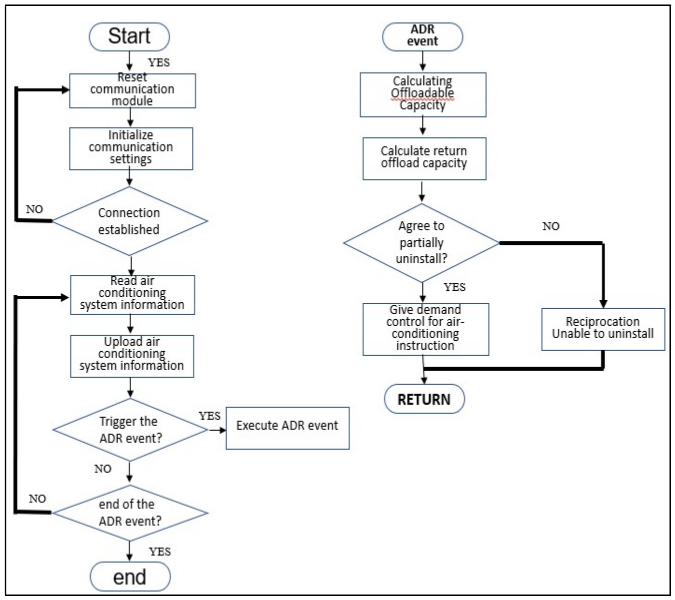


Figure 5. Operation flow of demand IoT controller

Practical Testing And Functional Verification

Practical Testing

In instruction to understand the characteristics of the demand IoT controller and the feasibility of the overall operation, a centrifugal inverter host is selected for communication testing and experiments in government agencies to ensure that it can operate and communicate normally. The demand IoT controller is deployed in the field. The architecture and test construction are shown in Figure 6 and 7. The uplink of the demand IoT controller uses Ethernet communication technology to the 4G module, and then communicates with Aggregator through 4G communication. It mainly uploads the operation information and power information of theChiller to Aggregator, and can also receive Aggregator's The DR command for partial uninstallationinstruction, so the 4G module must be placed near the external air outlet (so as not to be rained and does not affect the operation of the organization).

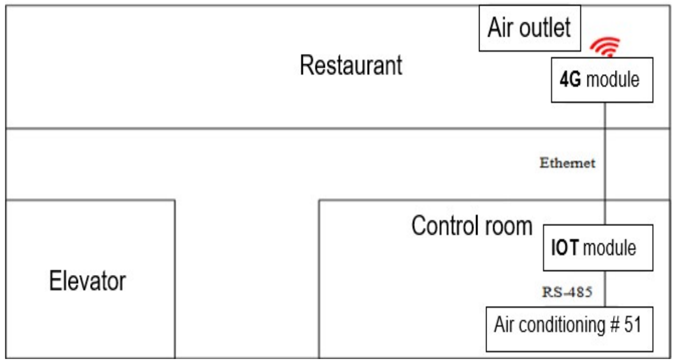


Figure 6. Demand IoT controller test architecture

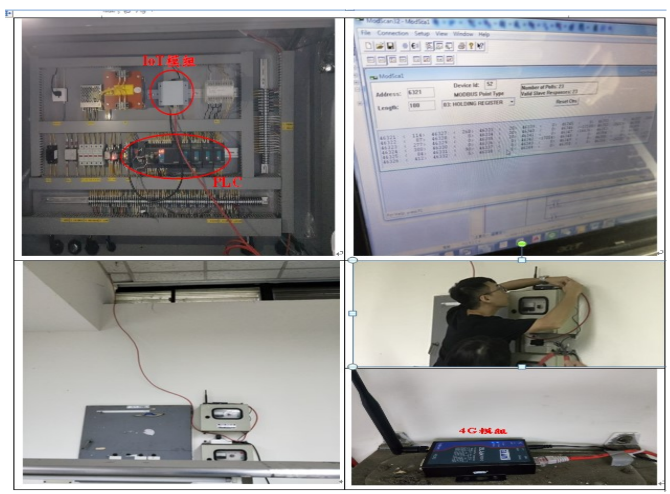


Figure 7. Demand IoT controller construction and test chart

Functional Verification

The Ethernet cable used for the CAT-6 network cable can not only improve the local network The speed and stability can also strengthen the signal's protection ability against crosstalk and system noise. The downlink of the demand IoT controller is to use RS-485 communication interface to read data from the programmable controller of theChiller, and also perform unloading control on theChiller.

In order to effectively verify the function of the automatic demand response IoT controller developed in this paper, a set of centrifugal air-conditioning ice water mainframes with a ratio of 60%: 40% are selected in this paper, of which 60% of the capacity is a frequency conversion main-frame and 40% of the capacity It is a fixed-frequency main mechanism. When the IoT controller receives the instruction from the aggregator to issue the ADR event, it acquires the master control and adjusts the operation mode of the BEMS energy management system to the operation mode of the IoT controller. it acquires the master control , and adjusts the operation mode from the BEMS energy management system change to the IoT controller mode. First, we use the setting of the temperature of the water outlet and return water of theChiller for control. Figure 8-10 shows the output results of this type of control. Figure 8 shows the control output curve on June 24 this year, which includes the “green” —power curve . “orange”— Host load factor curve, “yellow”— ice water temperature setting curve, “blue”—ice water return water temperature display value curve and “pink ”—ice water outlet temperature display value curve. Observe the power curve. There are two periods of IoT controller intervention control time, one of which is from 10:30 to 11:30 in the morning and 2 to 3 in the afternoon. It is learned that the power curve after receiving control in the morning is reduced from 220.5KW. To 108.8 KW, the control results in these two periods are not ideal, mainly due to the climatic conditions where the humidity is relatively high on a rainy day. At the same time, the decrease in the load rate is also very limited. According to the set value of the temperature, it is known that the temperature of the effluent and return water in the morning before the control is 9 and 12.4 ℃, and the temperature changes after the control is 10.4 and 13.4 ℃ , Which is mainly affected by the control instructions of the IoT controller.

Similarly, Figure 9 shows the control output curve on June 25. The control period is the same as that on June 24. It is clear that the control situation from 10:30 to 11:30 in the morning. The power output is determined by 230.2KW to 143.5KW, with good control effect. In the same afternoon, the controlled power is from 192.5 KW to 142.8 KW, which is mainly due to the climatic conditions on the day due to sunny and low humidity. Figure 10 is the result of the control output curve on June 26. The situation on this day is the same as that on June 24. Since the external weather conditions are not suitable for theChiller to remove the internal heat, the control effect is not ideal of.

Figures 11-13 The control output curve for these three days is the combination of current limiting control (for frequency conversion host) and unloading control (for fixed frequency host). Figure 11 shows the control situation on July 1st, of which 10 in the morning From 10:00 to 10:30 and 22:00 to 2:30 in the afternoon is the control time of BEMS. The control of the IoT controller is controlled at 10.30 to 11.30 in the morning and 2.30 to 3.30 in the afternoon. In this way, the control effect of IoT can be compared with the control result of BEMS. In the morning episode, we can clearly see whether the control result of the IoT controller and the control result of the bems can effectively reduce the load power to 8.5 KW and 13 4.1 KW respectively. Then the afternoon is 7.7 KW and 147kw. It control situation should be quite satisfactory.

Figure 12 shows the same control results on July 11. The control period of bems from 10 am to 10:30 in the morning and the control period of 3.4 bems in the afternoon are the control period of the IoT controller at 11 am. From 12:00 to 13:00

and from 3 to 4 pm, there are control curve results. We can clearly see that the control results of the IoT controller are consistent with the preset mode, that is, the IoT is preset to unload at fixed frequency. A50% frequency conversion line current load reduction 50% in the morning and afternoon is mostly the same result. The control result of Ziyu Bems is 100% fixed frequency conversion. Now this is a more extreme example. This is because the control law of the identification itself The control strategy equivalent to theChiller PLC will have such a situation. Figure 12 is the result of the control output curve on July 12. The same bems control time is from 10 am to 10:30 in the morning and from 2 pm to 10 in the afternoon. 2:30 As for the control time of the IoT controller, they are 11 to 12 in the morning and 3 to 4 in the afternoon for 1 hour. The NG placement time is rainy and the humidity is heavy, so their empty effect is the same. Do not Of resolution of July 11.

As for the result of the IoT control, it is also consistent with the preset control conditions, that is, the fixed frequency unloads 50% of the frequency converter and the current is reduced by 50%. Questioning the bems has also become a fixed frequency and does not unload the frequency conversion host to do 100%. Now this is also more extreme From the above 6-day control method, we can see that the line current control method plus the unloading control method will have a faster response speed and the effect of load reduction and unloading can be as expected. Water temperature setting control mode This type of control method has a slow response speed and the download effect is less than expected. This is the situation where we use the IoT controller and the bems energy management system to control.

Conclusions

This article requires the IoT controller to use the CPU module of the OpenWrt Linux operating system to integrate four communication technologies: Ethernet, Wi-Fi, RS-485, and RS-232. The feasibility of carrying out data forwarding (undertaking) and implementing ADR (under going) on the communication network was verified through actual machine tests. The conclusions reached are described as follows:

1. The front-end communication technology of the demand IoT controller adopts RS-485 and RS-232 technologies, and uses the Modbus standard protocol. Both are common communication technologies forChiller controllers of air-conditioning systems. With the advantages of transmission capability and good noise immunity, the front-end communication must be kept unblocked to ensure the implementation of ADR events.

2. back-end of the demand IoT controller uses Ethernet and Wi-Fi communication technologies, and selects the OpenADR standard communication protocol or a custom communication protocol, both of which are common communication technologies for the demand IoT, through stable Internet technology Upload the air-conditioning system information to the energy aggregator's cloud platform for the integration and management of huge amounts of data, and at the same time communicate the give an ADR event instruction. And effectively reduce the peak

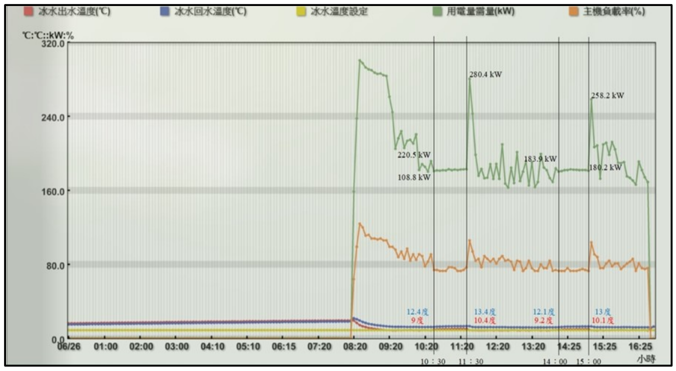


Figure 8. The trial operation of the air-conditioning water return temperature mode of the air-conditioning system involves the demand IoT controller to perform ADR

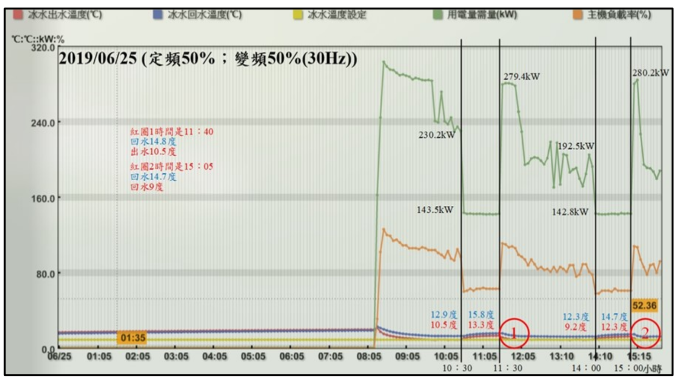


Figure 9. Air conditioner system is tested by the temperature of the ice water outlet and return water, and the demand IoT controller is involved to execute ADR-6/25

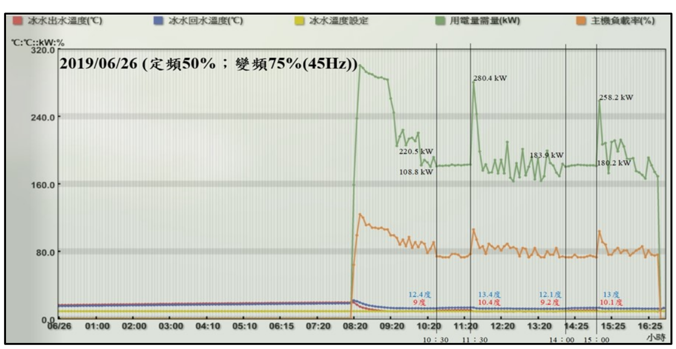


Figure10. Air conditioner system is tested by the temperature of the ice water outlet and return water, and the demand IoT controller is involved to execute ADR-6/26

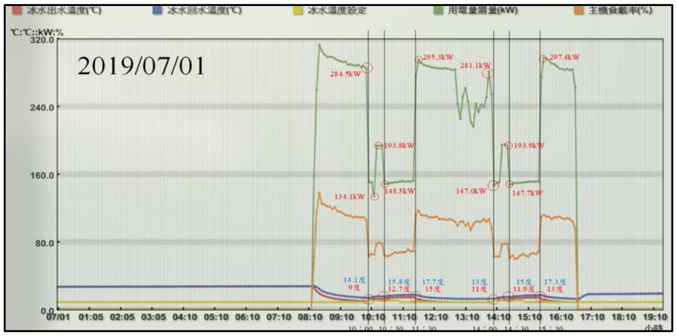


Figure 11. Air-conditioning system under the supervision of BEMS, the demand IoT controller intervenes to execute ADR-7/01

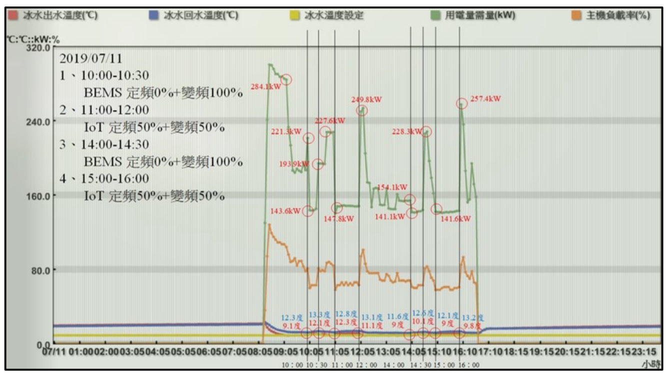


Figure 12. Air-conditioning system under the supervision of BEMS, the demand IoT controller intervenes to execute ADR-7/11

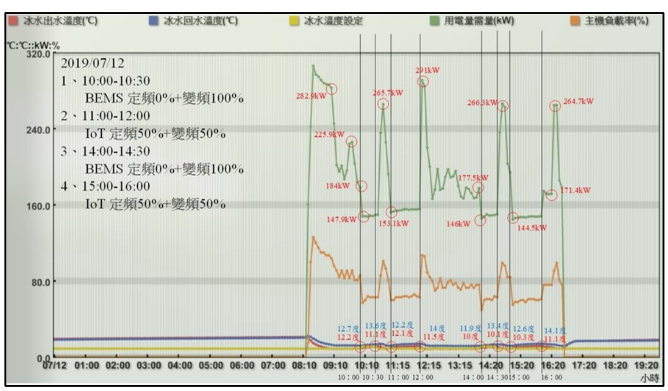


Figure 13. The air-conditioning system is monitored by BEMS, and the demand IoT controller is involved in the implementation of ADR-7/12

power consumption and achieve Energy saving and carbon saving benefit.

3. For the functional test of the demand IoT controller, this paper chooses a centrifugal inverter esthost for actual ting. In the non-triggered ADR event situation, the demand IoT controller only reads the information of the air-conditioning system and uploads it to the cloud aggregator's cloud platform management and analysis; In the triggered ADR event situation, The demand IoT controller will analyze the packets sent by the energy aggregator, and

then give a partial unloading instruction to the host of the air-conditioning system to achieve the purpose of Taipower's automatic demand response plan.

4. Cooperate with the government and Taipower's policy of promoting "demand Bidding experiment" And verify the feasibility of the demand IoT controller with the air conditioning system host.

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