Development of a web-based infrared remote control system for energy management

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Abstract. Thanks to the rapid progress in the embedded system/micro-controller and supervisory control & data acquisition (SCADA) technologies, several micro- controller-based modules were developed and presented in this paper for the purpose to monitor and control the electricity demand of the aggregated window/split air conditioners (ACs). With the abilities of collecting power consumption data on-line, controlling the developed modules through the internet, and applying available demand control rules, the proposed demand control system can effectively regulate the aggregated window/split ACs to lower the peak demand, therefore to decrease the penalty fee of violating demand contract, as well as to save the electrical energy.

Key words

Demand Control, Embedded System, Infrared Control, Remote Supervisory Control, Energy Saving, Electric Energy Management

1. Introduction

In recent years, steady depletion of fossil fuel reserves and rising crude oil price have caused the electricity price to increase. Saving the electrical energy and the bill for it becomes an essential issue to every sector of load consumers. Nowadays, in Taiwan most commercial buildings, schools, government offices, and residential houses have installed window/split air conditioners (ACs) with infrared (IR) remote controls. There are approximately 19 million ACs in Taiwan. Based on the study conducted by Taipower Company, the energy consumed by these ACs during the summer time is about 30% of total summer electric energy. And, if the temperature settings of these ACs can be set up higher by 1 ℃ during the summer time, approximately 300,000 MWh can be saved. The total amount of energy consumed by these ACs is substantial. Consequently, if these ACs can be well-controlled by a load management system, the energy savings would be also significant. However, to achieve this goal, the load management system must not be expensive so that customers are willing to invest their money to install such a system.

Thanks to the rapid progress in the embedded system, micro-controller, and supervisory control & data acquisition (SCADA) technologies [1]-[2], a web-based IR remote control system is developed and presented in this paper for energy management to control the aggregated ACs. This system consists of several micro-controller-based IR-modules for monitoring and controlling the electricity demand of the aggregated ACs. Since all window/split ACs come with IR remote controls, the developed system is designed to be capable of learning the IR remote control signals of the ACs. Also, it is capable of receiving the commands from the energy management system and then emitting the designated IR control signals to these ACs. With the aid of the developed IR-modules that can collect on-line power consumption data, control the developed modules through the internet, and apply available demand control rules, the proposed demand control system can effectively regulate the aggregated ACs to lower the peak demand, therefore to decrease the penalty fee of exceeding the demand contract, as well as to save the electrical energy. The proposed system is noninvasive, and the window air conditioners are intact. Moreover, the developed modules can also be used in the home automation to control other home appliances.

The developed modules and load management programs meet the following requirements: miniature, cost-effectiveness, distributed-control, and easy-installation. A single chip is used as the core in each developed IR-module, because the single chip is cost effective, powerful for signal processing and widely used in consumer appliances and industrial applications. The marketing potential of these modules, therefore, will be promising.

The proposed system has been put to the tests and been verified both in a laboratory and in a teaching building. According to the test results, the system can control the demand effectively and has the effect of saving electrical energy. For 28 classrooms with 56 split ACs (2.5 KW each AC), the system can decrease the over-demand penalty about NT$228,072 a year, the energy bill about NT$45,000 during the summer time, and the emission of carbon dioxide about 2,166 Kg CO_2 per month.

2. System Architecture and Modules

Hardware

Fig. 1 is the system architecture with all developed modules applied to a classroom with window/split air conditioners. In this system, the AC power to the air conditioners is controlled by an IR-controlled switch that receives the IR commands from the TCP-IR-51 module to turn the AC power on or off. The TCP-IR-51 is a web-based IR remote control with one temperature sensor, one

RJ45 port and one RS232 port. It can collect the room temperature from the temperature sensor, window status from the window status detector, and current data from current meter. Also, it can transmit these data to the remote PC via the Internet (TCP/IP), receive the signals from the remote PC server, and emit IR commands to the air conditioner and the IR-controlled switch. The IR codes to the air conditioner can change its temperature settings, its operation modes (air-conditioning mode or fanning mode), and ON/OFF modes. The current meter measures the electric current of the air conditioner. The values of current are then used by the energy management program on the remote PC to identify the operating mode of the air conditioner (air-conditioning mode or fanning mode). With all data collected on site, the energy management program then determines the proper action to take and sends signals to the TCP-IR-51. For instance, if the window is open, the AC power should not be turned on. AC power is on only when all windows are properly closed, i.e., TCP-IR-51 sends out the turn-on command to IR-controlled switch only if window status detector detects all windows are closed. Another action as an example that energy management program can take is to change the operation mode of the air conditioner via the IR remote control command. When the peak demand of the system is violating the demand contract and the air conditioner is operating in air-conditioning mode with larger current value measured by current meter, then TCP-IR-51 is instructed to send out an IR code to change the operation mode of the air conditioner. If the air conditioner successfully receives the IR command from TCP-IR-51, the value of current meter will be much less than the original (0.5~1.1A for fanning mode and 10~12 A for air-conditioning model in our system), resulting in lower demand to relieve the violating demand contract.

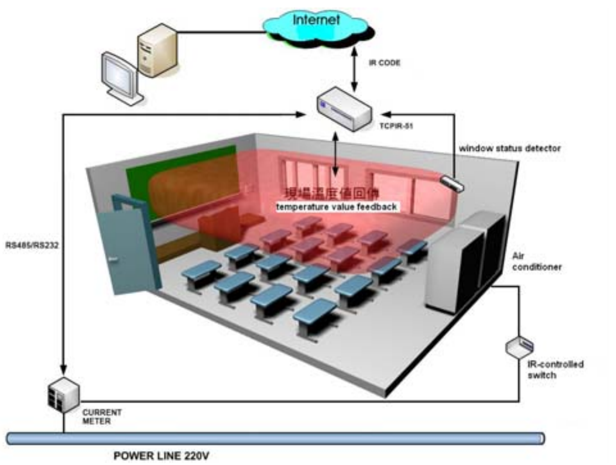

Fig. 1 Architecture for the proposed energy managemetn system

Figures 2-5 are the photos of all developed modules for the energy management system: TCP-IR-51 (Fig. 2), current meter (Fig. 3), IR-learning module (Fig. 4), IR-controlled switches (110V and 220V, Figs. 5 and 6, respectively). The systematic structure of TCP-IR-51 is depicted in Fig. 7, where the CPU is WINBOUND W78E516B and the ethernet chip is RTL8019AS. An IR-learning sub-module is built in TCP-IR-51. Fig. 8 shows the architecture of the current meter module, where CPU is PHILIPS P89C61X2BA and the Hall sensor is HY-25P. Fig. 9 illustrates the architecture of the IR-controlled switch, where CPU is ATMAL 89C2051.

Fig. 2 TCP-IR-51

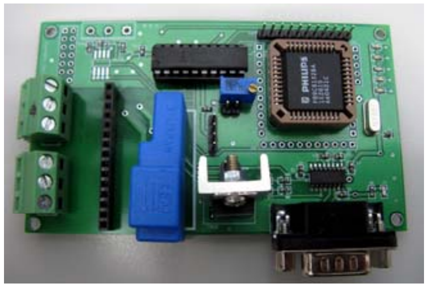

Fig. 3 Current Meter

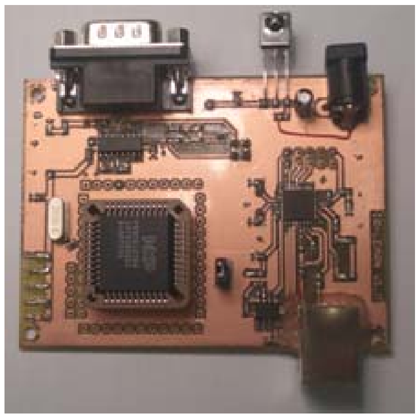

Fig. 4 IR learning module

Fig. 5 IR-controlled switch (110V)

Fig. 6 IR-controlled switch (220V)

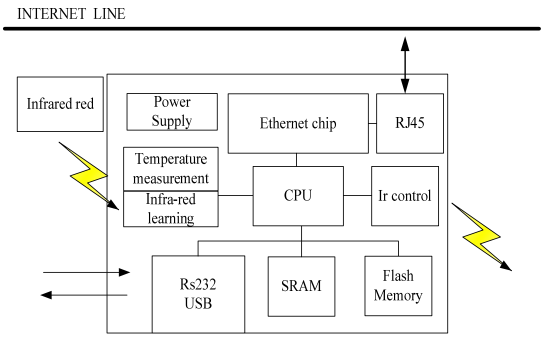

Fig. 7 Architecture of TCP-IR-51

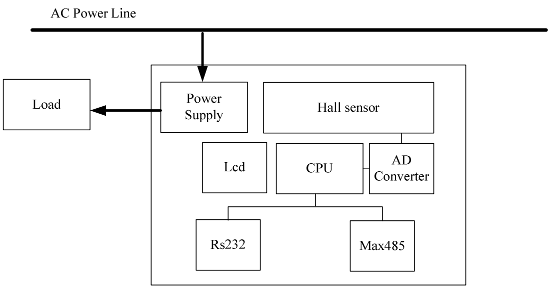

Fig. 8 Architecture of current meter

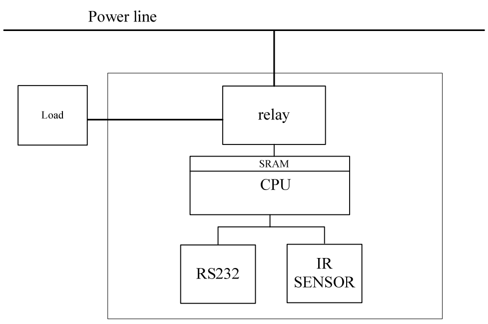

Fig. 9 Architecture of IR-controlled switch

Software

Several GUIs are developed for the presented system. Fig. 10 shows the IR learning inferface that provides the user to save/load IR code file. The user can also emit the learned IR code (shown in the ceter portion of Fig. 10) through the emitting com port specified in the left upper portion.

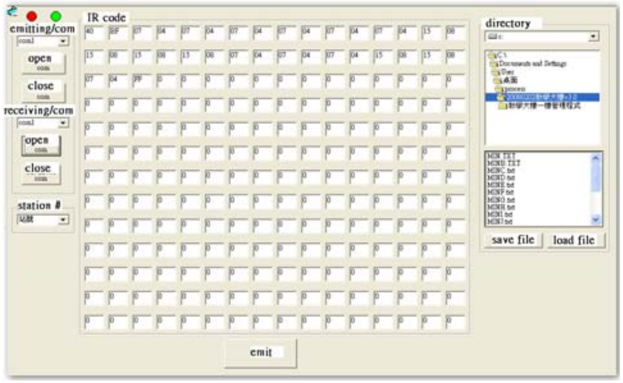

Fig. 10 GUI for IR learning

Figs. 11 and 12 are the energy management GUIs, where classroom temperature curve, load curve, and some other measurements are shown. The control actions can be performed through the buttons in these two GUIs.

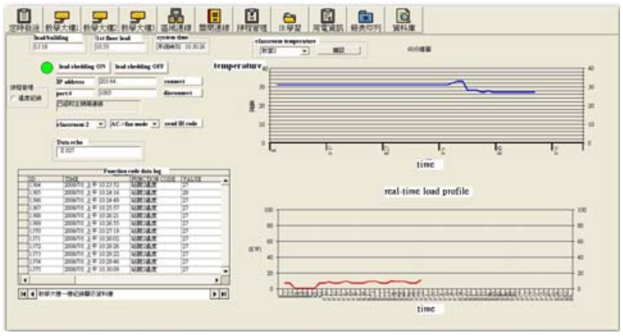

Fig. 11 energy management GUI

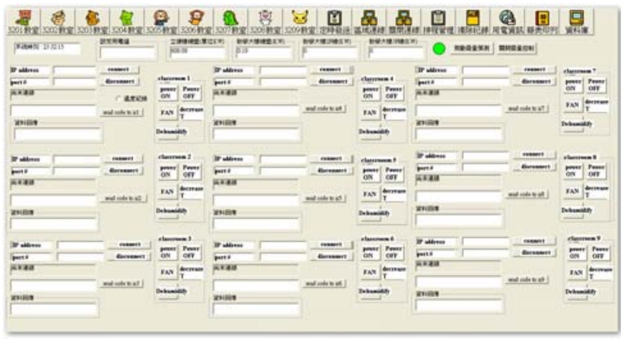

Fig. 12 energy management GUI for 9 classrooms

3. Results

The proposed system has been put to the tests and been verified both in a laboratory and in a teaching building that has 28 classrooms. Each classroom has two split ACs and each capacity is about 2.5 kW. However, only one TCP-IP-51 module is needed for each classroom, because the IR code emitted from TCP-IP-51 can simultaneously control both ACs in the same classroom. The specification of the air conditioner is listed in Table 1. For the case that both ACs are running in air-conditioning mode, the load demand is about 5 kW. For the case that both ACs are running in fanning mode, the load demand decreases to 0.22 kW approximately. Therefore, changing the operating mode from air-conditioning to fanning would decrease load demand by 4.77 kW per classroom. Ideally, 28 classrooms would have the load shedding capability of 133 kW. However, not all 28 classrooms are used at the same time during the day time. Diversity exists and therefore the actual load shedding capability would be less than 133 kW. In our test, 28 classrooms are divided into three groups (10 classrooms on the 1st floor, 9 on the 2nd floor, and 9 on the 3rd floor). Although there have been several demand control strategy available [3]-[5], the demand control strategy used in our test is quite simple and illustrated in Fig. 13. During cycle 1, we let the ACs in those classrooms on the 1st floor where students are taking classes be running for 5 minutes. Then the classroom with ACs turned on will be instructed to change their ACs' operating mode (from air-conditionig to fanning) via TCP-IR-51, if the room temperature is under 26 ℃. Load shedding for 2nd floor is excuted 5 minutes after the load shedding for the 1st floor has been done. Then load shedding for the 3rd floor is excuted 5 mimutes after the one for 2nd floor has been finished. This temperature condition set for load shedding is to keep the students in the classroom from being affected by load shedding too much. Since if the temperature is above 26 ℃ and ACs are turned off or changing to fanning mode, the room temperature will rise and students will feel hot, causing uncomfort.

Table 1 Specification of the tested AC

Capacity	2600 W
Operating current	10~12 A for air-conditioning mode 7 A for dehumidifying mode 0.5~1.1 A for fanning mode
Starting current	72 A

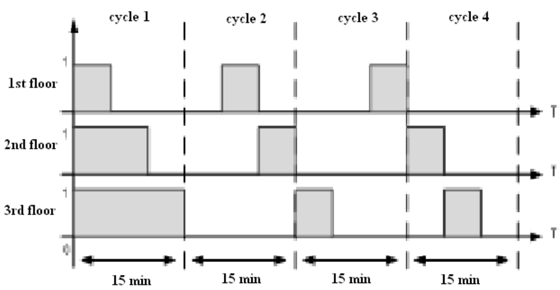

Fig. 13 Demand control strategy

Fig. 14 shows the total load variations of these 28 classrooms for two different senarios: one with demand control and the other without demand control. Both were tested on the same weekday (Thursday). The occupancy of classrooms on Thursday is dipicted in Fig. 15. In our school system, each class session lasts for 50 minutes, followed by a 10-minute break. Comparing the curves in Fig. 14 with the one in Fig. 15, we find the load variation is closely related to the occupancy of classrooms. For the load curve without demand control in Fig. 14, the peak value is 92.86 kW. On the other hand, the value at that time period for the case with demand control is 34 kW. Approximately 60 kW is decrease by using the developed modules with the presented demand strategy in Fig. 13.

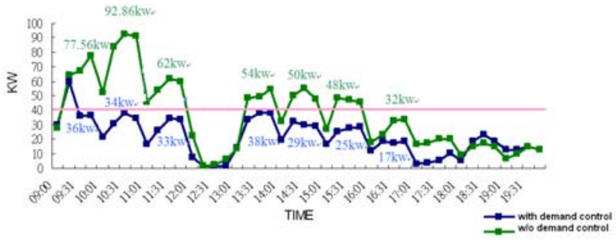

Fig. 14 Total load variations for two scenarios

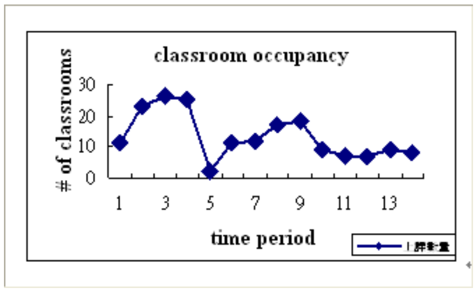

Fig. 15 Classroom occupancy on Thursday

Fig. 16 is the temperature variation of a classroom for the scenario with demand control. The temperature is well controlled around 26 ℃ by the presented demand control strategy. For this classroom, no classes are arranged during the noon time and the period from 16:00 to 18:00. Based on the test results and the Taiwan regulations for electricity price and over-demand penalty, the proposed system with demand control can decrease the over-demand penalty about NT$228,072 a year, the energy bill about NT$45,000 during the summer time, and the emission of carbon dioxide about 2,166 (Kg CO_2) per month [6]. Therefore, each TCP-IP-51 module can save approximately NT$10,000 on electricity bill per year. This is a promsing number for commercializing the presented system.

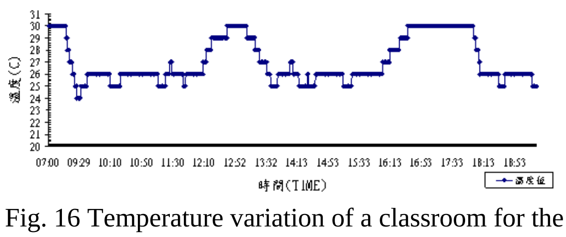

Fig. 16 Temperature variation of a classroom for the scenario with demand control

4. Conclusions

A web-based IR remote control system was presented in this paper for energy management to control the aggregated ACs. Several modules for this system were developed and installed in a teaching building with 56 split ACs. Based on the test reults, each TCP-IP-51 module can save approximately NT$10,000 on electricity bill a year, making the system practical for commercial use.

Acknowledgement

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