Energy and Buildings 72 (2014) 24–30

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A low-cost web-based infrared remote control system for energy management of aggregated air conditioners

Yu-Chi Wu [a,*], Meng-Jen Chen [b], Bo-Sen Chang [a], Ming-Tsung Tsai [c]

[a] Department of Electrical Engineering, National United University, 360, Taiwan
[b] Department of Electrical Engineering, National Kaohsiung University of Applied Sciences, 807, Taiwan
[c] Department of Electrical Engineering, Southern Taiwan University of Science and Technology, Tainan,710, Taiwan

ARTICLE INFO

Article history:
Received 6 March 2013
Received in revised form 18 October 2013
Accepted 23 December 2013

Keywords:
Demand control
Embedded system
Infrared control
Remote supervisory control
Energy saving
Electric energy management

ABSTRACT

Thanks to the rapid progress in the embedded system/micro-controller and supervisory control and data acquisition (SCADA) technologies, several micro-controller-based modules are 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, 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. Based on the testing on a university teaching building with 28 classrooms and 56 split ACs, only one developed micro-controller-based infrared remote control module (IR485/232 module with double infrared emitters) is needed for one classroom with 120 square meters to control two air conditioners in a non-invasive way, and one IR485/232 module costs less than $35. The proposed system with demand control can decrease the over-demand penalty about $7900, the energy bill about $6400, and the emission of carbon dioxide about 26,000 kg (CO_2) a year. One IR485/232 module can save approximately $350 on electricity bill a year. The proposed system is more cost-effective than a ZigBee-based system because a ZigBee system needs a pair of ZigBee modules (one in the classroom and one in the hallway) and an additional ZigBee/Infrared converter module to control two ACs in one classroom.

1. Introduction

In recent years, steady depletion of fossil fuel reserves and rising crude oil price has caused the electricity price to increase. Saving the electrical energy and the electricity bill has become 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) that have 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 °C 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.

There have been a number of studies and pilot projects investigating technologies for energy conservation. Byun et al. [1] presented a ZigBee-situation-based scheme, an event-based self-adjusting sensor network, and hardware and middleware implementation for building and home energy management services. A test bed using their system was implemented. This test bed is 198 square meters, and approximately 45 ZigBee modules were deployed to control eight air conditioners, three TVs, and one server. However, no energy saving data of these controlled appliances (air conditioners, TVs, server) after using their system were reported, and the cost of these module was not mentioned. Han et al. [2] proposed a home energy management system using a ZigBee and infrared control technology to reduce the standby power. Batista et al. [3] presented a comprehensive field tests using open source tools with ZigBee technologies for monitoring photovoltaic and wind energy systems, and also for building and home energy management. Kim et al. [4] implemented a home energy

* Corresponding author at: National United University, Department of Electrical Engineering, Miao-Li 360, Taiwan. Tel.: +886 939967722; fax: +886 37327887.
E-mail addresses: ycwu@nuu.edu.tw, ycwu0719@so-net.net.tw (Y.-C. Wu), mengjen@cc.kuas.edu.tw (M.-J. Chen), boyce50@hotmail.com (B.-S. Chang), mttsai@mail.stust.edu.tw (M.-T. Tsai).

0378-7788/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.12.035

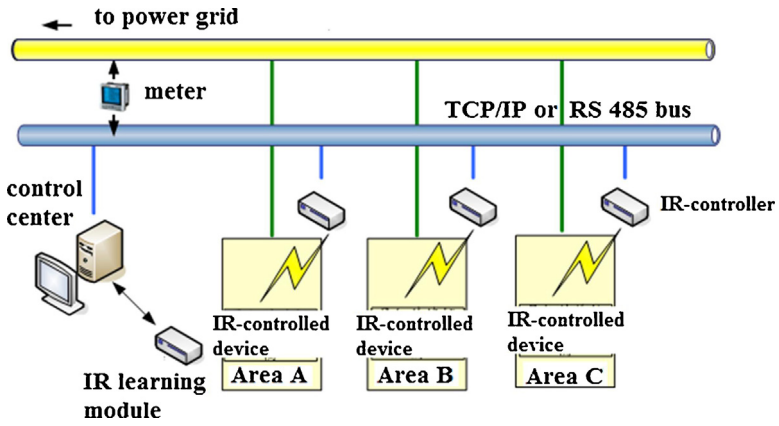

Fig. 1. Conceptual system architecture of IR-web-based demand control system.

management system with UPnP and mobile applications. However, the cost performance and the investment-on-return are not analyzed in these studies. Although several advanced devices/technologies are available nowadays, there are apparently significant barriers to adopt them widely to building/home energy reduction [5]. Economic considerations are clearly important. People cannot be expected to invest their own money in energy management system unless such investment provides reasonably short-term economic payback or some other perceived value. Individual firms are also less willing in developing products unless they see a clear market share. The ZigBee module price is approximately \$34 ~ \$138 per pair [3]. This price is still high for some applications although ZigBee modules have data gathering and processing abilities to monitor and manage situational information for various intelligent services. For example, controlling window/split ACs in a classroom has to be in a non-invasive manner through infrared remote control and therefore needs at least one pair of ZigBee modules and an additional ZigBee/Infrared converter module. When there exists concrete walls in a building, more ZigBee modules are needed, increasing the installation cost. The ZigBee system proposed in Ref. [1] consists of more than 40 ZigBee modules for a test bed with 198 square meters.

In this paper, a low-cost web-based IR remote control system is developed and presented 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 non-invasive, and therefore the window ACs 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 for testing and verified both in a laboratory and university teaching building. According to the test results, the system can control the demand effectively and has the effect of saving electrical energy bill.

2. System structure and modules

2.1. Hardware

Fig. 1 is the conceptual system architecture of the proposed IR-web-based demand control system. Each area has IR-controlled devices, such as ACs, and they can be controlled by IR-controllers. Each IR-controller is connected to TCP/IP or RS 485 bus. The control center sends/receives data to/from IR-controllers via TCP/IP or RS 485 bus. The meter measures the power usage of loads in different areas.

Fig. 2 is the detailed system architecture with all the developed modules that could be applied to a classroom with window/split ACs. In this system, the power to the ACs is controlled by an IR-controlled switch that receives the IR commands from the TCP-IR-51 module to turn on/off the power. 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 (magnetic reed switch), 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 (control center), 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 power should not be turned on. The 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 the 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