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Design and Implementation of Smart Sockets with High Frequency Acquisition of Electric Energy Parameters

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Abstract—**Behavior energy consumption is getting more attention in building energy consumption field. To distinguish the energy behavior related to sockets, a new smart socket was designed and many electrical parameters can be acquired in high frequency. This socket supports remote control, and it supports TCP protocol to send data to specific data concentrator wirelessly. The socket also based on the NTP service realizes time synchronization. Effective collection of high frequency socket electrical data with time label make identification of socket and lighting system energy behavior which is important in intelligent building and large public building possible.**

Keywords-smart sockets; high frequency collect; time synchronization; energy behavior

I. INTRODUCTION

With urbanization progress in China, energy shortage has become a prominent restriction for sustainable social progress. Researchers suggest that building energy consumption accounts for 1/3 of the total energy consumption in China while it reaches up to 40% in developed countries [1-2]. The implementation of building energy saving is the key to energy saving for whole society. More researches indicate that, sockets and lighting system energy consumption accounts for about 20% of the total building energy consumption in large public buildings [3-4]. The monitoring of sockets and lighting system is an important way to reduce building energy consumption.

Synthesize 7 main factors such as climate, building-related characteristics, user-related characteristics except for social and economic factors, building services systems and operation, building occupants' behavior and activities, social and economic factors, and indoor environmental quality required which affects the construction energy consumption[5], energy consumption is divided into 3 categories: construction equipment energy consumption, building envelope energy consumption, staff behavior energy consumption[6]. In recent years, many researchers analyzed the influence factors of building energy consumption behavior by using smart meters or special monitoring instrument to itemize meter all kinds of equipment and facility energy consumption [7-9]. Current special electric energy meters which are used for metering in socket and lighting system have many disadvantages such as using cable way in data transmission which leads to a poor mobility of the device[7-8], and record time granularity ranging from a few minutes to several hours which leads to a low sampling frequency[9-10]. With the popularity of the Internet of things, more and more smart sockets are used for terminal electric energy statistics and switch control. All of these smart sockets have general characteristics like low frequency in data collection, incomplete electrical parameters collection, and no local time information contained [7-9],[11].

This paper introduce a new smart socket which realize energy itemize metering in socket and lighting system, remote control and energy consumption for staff behavior analyses. This smart socket achieved high time resolution of electrical parameters, and wireless data transmission and remote control by using Wireless Fidelity protocol. To satisfy time synchronization in multiple smart sockets cluster using, Network Time Protocol (NTP) server in LAN is used to ensure that different smart socket own the consistent timestamp.

II. HARDWARE DESIGN

A. Hardware Designs

The hardware design includes electrical parameters acquisition module design, wireless communication module design, control module design and clock module design. Smart socket hardware framework is shown in figure 1 below.

In figure I, part 1 represents for power supply module which produces 5V and 3.3V direct voltage. Part 2 is wireless communication module and part 3 is microcontroller unit (MCU) module, and they accomplish command and data exchange in serial communication way. Part 4 is electrical parameters acquisition module, and the data exchange between part 3 and part 4 is accomplished by serial peripheral interface (SPI). Part 5 is control module. Part 6 is clock module and it is used to keep time synchronization with specific timing server.

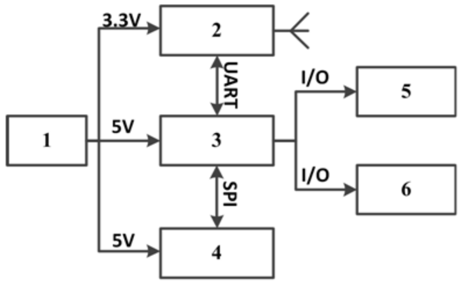

FIGURE I. SMART SOCKET HARDWARE SYSTEM FRAMEWORK

B. Electrical Parameters Acquisition Module Design

Electrical parameters acquisition module is achieved by a microcontroller chip (ATT7053BU). Two ADC channels are used to measure voltage and current. All other electrical parameters can be acquired by calculation of voltage and current. All electrical parameters are stored in the corresponding parameter register. MCU requires parameter data by sending reading command to corresponding register.

Figure II is voltage measurement circuit diagram and figure III is current measurement circuit diagram. For voltage measurement, high resistance is used in series to disperse voltage and low resistance for measuring. Taking the instantaneous voltage across the low resistance to calculate the active voltage of the working equipment, and stored it in the active voltage register. For current measurement, a current transformer (CT) is used to transform high current into low current and low resistance parallel for measuring. We taking the instantaneous voltage of the low resistance to calculate the active current of the working equipment, and then stored it in the active current register.

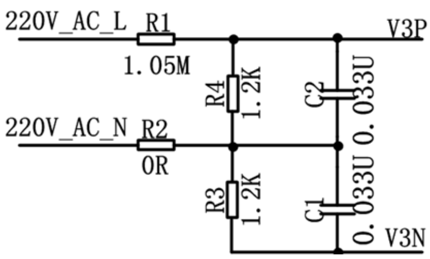

FIGURE II. VOLTAGE MEASUREMENT CIRCUIT DIAGRAM

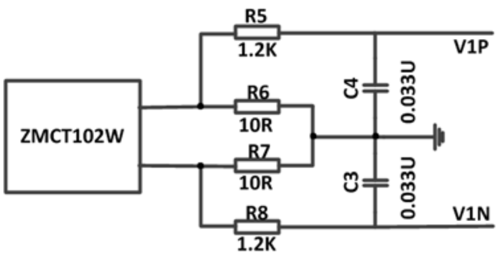

FIGURE III. CURRENT MEASUREMENT CIRCUIT DIAGRAM

C. Wireless Communication Module Design

The function of wireless communication module is based on a wireless communication chip (ESP8266). The principle diagram of the wireless communication module is shown in figure 4. MCU module and wireless communication module accomplish command and data exchange serially. MCU sends commands to set wireless communication into different modes (STA or AP) and different communication protocol (TCP or UDP).

D. Control and Clock Module Design

Wireless communication module receives the command from personal computer (PC) and sends it to MCU. MCU identifies the command and executes corresponding action. If the command is a control command, MCU would change the state of the I/O port so as to drive the relay and realize remote control. If the command is a time synchronization command, MCU would call the time synchronization program and set the clock according to the returned time data.

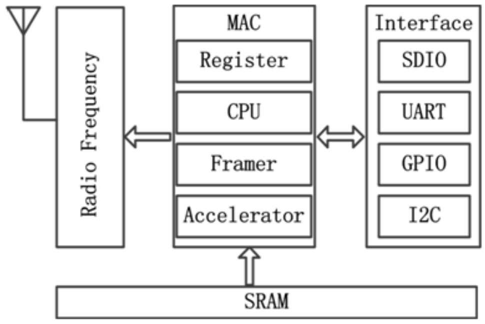

FIGURE IV. PRINCIPLE DIAGRAM OF THE WIRELESS COMMUNICATION MODULE

III. SOFTWARE DESIGN

The software of the smart socket realizes the function of electrical parameters acquisition, wireless communication, identification of time synchronization command and remote control command. The function of the software and implementation program is shown in figure V.

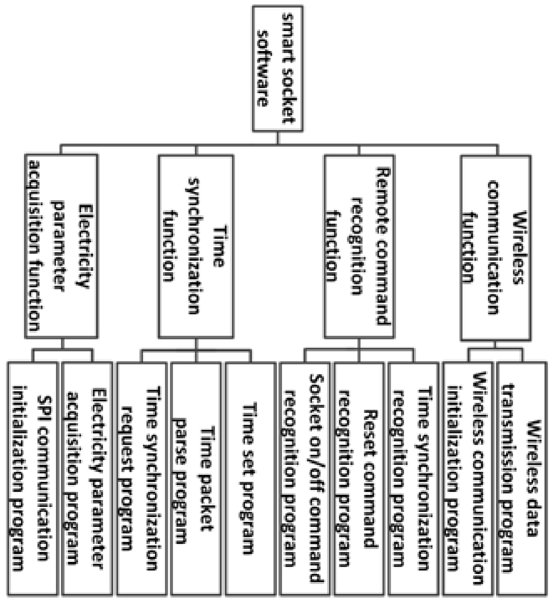

FIGURE V. SOFTWARE SYSTEM FRAMEWORK OF THE SMART SOCKET

A. Electrical Parameters Acquisition

MCU and electric energy metering chips are connected with each other serially. Electrical parameters are stored in the corresponding register. Acquiring the electrical parameters is divided into three steps. Firstly, MCU initializes its SPI communication settings. Secondly, MCU send the reading command at regular interval to electrical parameters acquisition module. And at last, MCU will receive required electrical parameters.

B. Wireless Communication and Remote Command Recognition

Wireless communication module is designed to complete data transmission. Firstly, MCU should send command to initialize settings of wireless communication module.

Remote command contains relay switch control command, frame counter reset command and time synchronization command. Remote command recognition function contains remote command recognition and corresponding action execution.

C. Time Synchronization

The time synchronization program is designed based on the NTP service which contains time synchronization request, time packet parse and time setting. Since NTP service required the use of UDP protocol while wireless communication requires the use of TCP protocol, TCP protocol is converted into UDP protocol before sending time synchronization requesting packet and change UDP protocol into TCP protocol after receiving time synchronization returned packet. Time synchronization program is shown in figure VI.

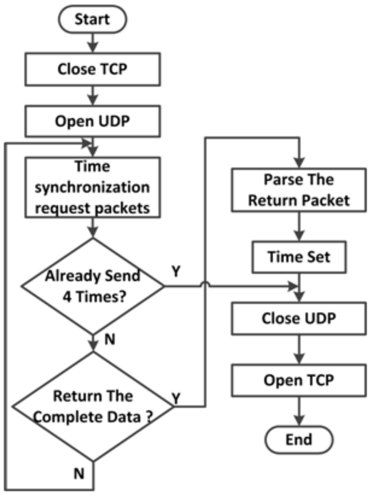

FIGURE VI. TIME SYNCHRONIZATION PROGRAM

IV. SMART SOCKET FUNCTION TEST

A. Data Acquisition Test

In the data acquisition test, we parse the data and active voltage and the result is shown in figure 7. Horizontal cordinate represents the accumulation of test time and its unit is second. In figure 7(a), vertical cordinate represents active voltage and its unit is volt (V). In figure 7(b), vertical cordinate represents active current and its unit is ampere (A). At time 1, the working appliance is a lamp. At time 2, the working appliances are a lamp and an electric soldering iron. At time 3, the working appliance is a fan. The active power of the lamp is 15 watt (W) and its normal active working current is 0.068A.

In figure VII, the active current is conformed to the actual situation. The electric soldering iron is a constant temperature electric soldering iron. It needs about 30s of heating to reach the required temperature. Then, in order to maintain the constant temperature, the electric soldering iron is circulation in an on-off status. So the active current in figure 7(b) is in an up and down status. The fan has three gears so that the active current which is shown in figure 7(b) should be divided into three stages. From figure VII, it indicates that the measurement data of the smart socket is accurate.

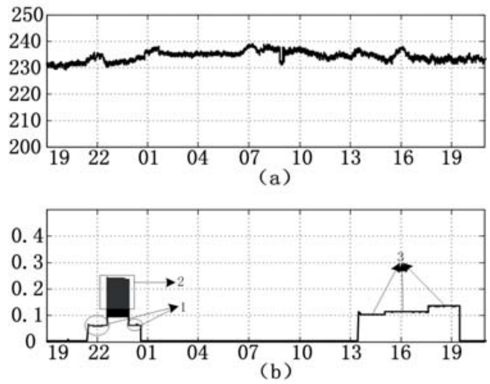

FIGURE VII. ACTIVE VOLTAGE AND ACTIVE CURRENT CHANGING CURVE

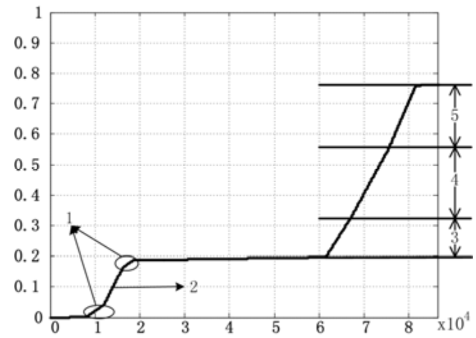

FIGURE VIII. ACCUMULATION ACTIVE POWER DUE TO WORKING APPLIANCE CHANGING STATUE

The accumulation active power due to working appliance changing status is tested and the result is shown in figure 8. In figure VIII, horizontal cordinate represents the accumulation of test time and its unit is kilowatt-hour (Kw*h).

In figure 8, part 1 is corresponding to part 1 in figure 7(b) and part 2 is corresponding to part 2 in figure 7(b). The fan has three gears so that the active power which is shown in the figure 8 should be divided into 3, 4 and 5, and they are corresponding to part 3 in figure 7(b). Comparing figure 7 and figure 8, the measurement of smart socket is conformed to the real situation and the result is accurate and effective.

B. Control Command Test

For control command test, socket on command, socket off command, frame counter reset command and time synchronization command are tested. Socket on and off command are used to turn on or off the smart socket. Frame counter reset command is used to zero clearing the frame counter. Time synchronization command is used to synchronize the time of the smart socket with the time of the specific timing server. From table I, it is concluded that all commands completed situations are coincident with the expected function.

TABLE I. CONTROL COMMAND TEST

Name	Command	Command Explain	Completion Situation
Socket On	ESPKJDQ	Power supply	Socket start power supply
Socket Off	ESPGJDQ	Power cut-off	Socket power is cut-off
Reset	RstFrame	Zero clearing the frame counter	Frame counter of next packet is zero
Time Synchronization	Synctime	Socket requests to the specified NTP server and set the local time	The socket local time is revised as the NTP server provided

V. Conclusions and Further Work

To satisfy the demands for building energy consumption behavior monitoring, we designed a new smart socket which could high frequency acquire active voltage, active current, active power, reactive power and active energy every two seconds and send the data to data concentrator wirelessly. On the basis of identification of the remote switch control command function, our smart socket realizes remote terminal switch control by change the status of the relay. At the same time, on the basis of identification of the time synchronization command function and NTP service function, our electric power data and socket behavior data have a precise time stamp. This makes the depth analysis of smart sockets cluster application data possible.

There are a large amount of electromechanical devices in intelligent building, and different devices have different characteristics. How to realize the linkage of the related device in the building from the current device electricity characteristics is one of focus on intelligent building research. By connecting the device to the designed smart socket, high frequency data sequence of working voltage, current, active power, reactive power and active energy are acquire, which can be used to analyze devices electricity characteristic. What's more, data mining technology applying in depth analysis of massive smart sockets cluster date and the results of that applied in building energy behavior analyze are worth studying.

Acknowledgment

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