Design of a UPS Outlet System Controlled by PDAs and GSM Cellular Phones

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Abstract-In this paper we describe a remotely controllable UPS outlet system for home power management that we have developed. The CUPSO (Controllable UPS Outlet) integrates multiple AC power sockets, a UPS and a low-power microcontroller into a power outlet to switch the power of the sockets On/Off, to protect a sudden loss of the AC power supply and to measure the power consumption of plugged-in electric home appliances. Using Bluetooth, our wireless system can control the home electric appliances at home without new wiring. The remote control also provides the user with the ability to control the power On/Off of home appliances through the Internet, and the GSM channel linked to the home server is able to receive the SMS (Short Message Service) for the use of the power management of the home electric appliances power On/Off anytime and anywhere.

I. INTRODUCTION

Home power consumption tends to grow in proportion to the increase of the number of large-sized home electric appliances. Therefore some form of power management in a home is a must in order to save energy and reduce carbon dioxide emissions [1, 2]. To implement home energy management, networked appliances with control/monitor capabilities and a home network without new wiring are indispensable. Together with the construction of access networks, several standards for wired home networks have previously been proposed and developed.

The Plug & Play function is indispensable for a home network in order to install and replace electric appliances without any special knowledge on the part of the user. Plug & Play is a function, which, when discovering electric appliances in a network, assigns an ID to each appliance and generates an entry for controlling and monitoring the interface from the home network [3]. However, electric appliances without expansive functions and a conventional power plug which deteriorates as a result of by the interference of other electric appliances have made it difficult to build such advanced systems [4].

Bluetooth technology provides a universal bridge to existing data networks, a peripheral interface and a mechanism to form small private ad hoc groupings of connected devices away from fixed network infrastructures. This technology, which is designed to operate in a noisy radio frequency environment such as a home, uses a fast acknowledgement and frequency-hopping scheme to make the link a robust one. Thus Bluetooth technology can replace the cumbersome cables used today to connect the PDA to any other digital device which is part of the Bluetooth network [5].

Mobile phones have become one of the most popular communication devices around the world, and the SMS is now popular among mobile phone users as a method of communicating. Since the use of SMS technology is an inexpensive, convenient and flexible way of conveying data, researchers are trying to apply this technology in many different areas that are not covered by service providers at present [6].

The UPS employs the static power converter as well as batteries to supply the critical load. Its circuit structure can be categorized into three types: off-line, on-line and line-interactive. As for the off-line UPS, when the utility source encounters any event leading to the interruption of the power supply, the off-line UPS supplies the power to the load through the inverter; however, the load needs to shoulder the power interruption for about 4–12 ms [7].

One of the key problems in an uninterruptible power supply (UPS) is estimating a battery’s lifetime. Because batteries are non-ideal power sources, different discharge patterns can result in different levels of battery efficiency [8].

A remotely controllable UPS outlet system with a wireless mechanism has been developed for home power management in this paper. By using the Bluetooth technology, UPS status and electric home appliances can be controlled and monitored without wire lines. The user can also manage both UPS status and various electric home appliances remotely by means of a GSM cellular mobile phone in order to save/monitor power. Our remotely controllable UPS outlet system consists of four major blocks: the CUPSO, the PDA control, the mobile PC control and the GSM control, as shown in Fig. 1.

![Fig. 1. Remotely controllable UPS outlet system.](image-url)
This paper is organized as follows. In Section 2 the remote CUPSO system is introduced; in Section 3 the integration design of the PDA control, mobile PC control and the GSM control is described; in Section 4 the evaluation results are summarized; and in the final Section, our conclusions are presented.

II. CUPSO DESIGN

The CUPSO is made up of multiple AC power sockets, an UPS, a MCU, a Bluetooth Module, a GSM Module and a Power Measuring Module. The complete circuit of the CUPSO is shown in Fig. 2.

![Fig. 2. The complete circuit of the CUPSO.](image)

We have used the Solid State Relays (SSR) to switch each socket into which an electric home appliance can be plugged. SSR have been utilized to replace mechanical relays because of their many advantages, like a miniaturized configuration, little or no contact bounce, low-energy consumption, decreased electrical noise, compatibility with digital circuitry and high-speed switching performance. These SSR also provide isolation between a control circuit and a switched circuit.

The MCU in the CUPSO has four functions: processing commands both from the Bluetooth Module and SMS commands from the GSM Module, controlling the SSR On/Off, measuring power consumption in real-time and detecting the status of the UPS.

The Bluetooth Module is a low-power embedded Bluetooth v2.0+EDR module with a built-in high-output antenna. The module is a fully Bluetooth-compliant device for data communication with a transmission power of up to +8dBm and a receiver sensibility of down to -83dBm combined with low power consumption. As the GSM Module is specifically designed to connect to the MCU, calls can be made using the GSM cellular mobile phone network.

A. Real-time power consumption monitoring

To show the actual status of the electric home appliances and to control the power On/Off we use the Power Measuring Module, which is a measuring circuit containing three parts: six current transformers (CT), an electrical power detector and an EEPROM. The six CT are installed in the AC power outlet. The load current of each socket is measured by the CT. By using the Hall Principal Effect the charge carriers in the CT become deflected by the magnetic field and give rise to an electric field which is perpendicular to both the current and the magnetic field, as the load current changes the output voltage signal. The voltage signal is sent to the power measuring module via the connector. The electric power detector transforms the voltage signal into digitized data for the MCU.

![Fig. 3. Block diagram of the power measurement.](image)

The root mean square (rms) value of a continuous signal $V(t)$ and $I(t)$ is defined as

$$V_{rms} = \sqrt{\frac{1}{T} \int_{0}^{T} V^2(t) dt}$$

$$I_{rms} = \sqrt{\frac{1}{T} \int_{0}^{T} I^2(t) dt}$$

For time sampling signals the rms calculation involves squaring the signal by taking the average and obtaining the square root:

$$V_{rms} = \frac{1}{N} \sum_{i=1}^{N} V^2(i) + V_{offset}$$

$$I_{rms} = \frac{1}{N} \sum_{i=1}^{N} I^2(i) + I_{offset}$$

An offset might exist in the rms calculation due to input noises that are integrated in the dc component of $V(t)$ and $I(t)$. The electrical power detector incorporates the rms offset compensation $V_{offset}$ ($I_{offset}$). We use two 12-bit, signed registers to assign the value of the $V_{offset}$ ($I_{offset}$) that can be used to remove offset in the rms calculation.

The average power consumption is defined as the rate of energy flow from the source to the load. It is also defined as the product of the voltage and current waveforms.
The electric power detector simultaneously calculates the \textit{rms} values for $V(t)$ and $I(t)$ in different registers. Thus the average power can be obtained instantly and be stored in the EEPROM.

**B. Detecting the UPS status**

Because the battery is a critical component in the UPS, its status needs to be monitored cyclically. A good battery is one that can accept and hold a charge and deliver the rated number of amps on demand. A bad battery is one that won't accept a charge or can't supply its normal dosage of amps due to damage or deterioration.

**State-of-Charge testing:** For sealed batteries, one may measure the open circuit voltage ($V_{\text{open}}$) across the battery terminals to determine the battery's State-of-Charge with the battery's electrolyte temperature at 26.7°C. A fully charged battery should read 12.65 volts. A reading of 12.4 volts equals about a 75% State-of-Charge. The state-of-charge of a battery can be obtained as shown in Table I.

**TABLE I**

<table>
<thead>
<tr>
<th>Open Circuit Voltage</th>
<th>State-of-Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.65</td>
<td>100%</td>
</tr>
<tr>
<td>12.45</td>
<td>75%</td>
</tr>
<tr>
<td>12.24</td>
<td>50%</td>
</tr>
<tr>
<td>12.06</td>
<td>25%</td>
</tr>
<tr>
<td>11.89</td>
<td>6%</td>
</tr>
<tr>
<td>11.61</td>
<td>1%</td>
</tr>
</tbody>
</table>

**Testing the efficiency of the battery:** We have designed an auto-test of the battery to determine its \textit{efficiency} ($\xi$). The efficiency of a battery is its state of health. With a battery load testing we apply a load equal to one half of the cold cranking amp rating of the fully charged battery for 15 seconds, and then measure the battery voltage ($V_{\text{load-test}}$) to calculate the $\xi$ of the battery. Fig. 5 shows the measurement results of the battery efficiency.

**Fig. 5.** The measurement results of the remaining discharge time at different loads.

We use a quadratic model to estimate the remaining discharge time of the battery.

$$T_{\text{remain}} = \frac{C \times \xi}{P} \left(\frac{V - V_{\text{cut}}}{V_{\text{Full}} - V_{\text{cut}}}\right)^2$$

**If** $V_{\text{load-test}}$ can't maintain the minimum voltage ($V_{\text{bad}}$), the battery is unsatisfactory. If a battery is dead or low, the first thing is to replace it.

**Estimating the remaining discharge time:** The reliability of backup power systems is becoming an even greater issue with the convergence of the telecommunications and data processing applications. It follows that one of the most critical pieces of information required by users of UPS batteries in many application areas is the \textit{remaining discharge time} ($T_{\text{remain}}$). The remaining discharge time is the time that the battery can supply the load with power after the AC mains have failed. The $T_{\text{remain}}$ is dependent on the discharge load and the efficiency of a battery. We propose a simple means to determine the $T_{\text{remain}}$ which does not require conducting extensive tests to characterize the battery under the current operating conditions. Fig. 5 shows the measurement results of the $T_{\text{remain}}$ at different loads.

**Fig. 6.** The measurement results of the battery efficiency.

We use a linear model to estimate the $\xi$ of the battery.
CUPSO or not. If it is, the MCU turns the power On/Off or sends power data according to the command. If the command is not for any room controlled by the CUPSO, the command is broadcast over the Bluetooth home network.

III. WIRELESS CONTROL BY PDA/MOBILE PC WITH BLUETOOTH AND REMOTE CONTROL BY GSM

A. The PDA / mobile PC control

The PDA, the PC or the Notebook with Bluetooth that is connected to the CUPSO plugged-in electric home appliances via the Bluetooth network controls and monitors the electric home appliances and the UPS indoors.

![Control Flow Chart of the MCU Program](image)

In the control field of Fig. 7 the PDA sets up the On/Off function and sends a command to the CUPSO immediately after pressing the “On/Off” button. The PDA waits for an acknowledge command from the CUPSO. The control field sends its command every three seconds if it doesn’t receive an acknowledge command, to guarantee that the power control command can be executed without being lost.

As shown in Fig. 8, the control software of the mobile PC shows the power status of each socket at the display area. The red light shows that the electric home appliance is in use and the white light shows that the appliance is off. The remote control software also shows the accumulated energy of each electric home appliance in the display area. In the control area the user can set up the sockets for the On/Off state and send the command to the CUPSO immediately after pressing the “Start” button. The remote control mechanism provides the user with a way to monitor and control the status of the UPS.

![GUI of the Remote Control](image)

B. Remote Control by GSM Cellular Mobile Phone

The CUPSO provides the user with a way to control and monitor the power of electric home appliances by using a GSM cellular mobile phone, as shown in Fig. 1. When the remote user sends the SMS with a control command by a GSM cellular mobile phone to the phone number of the CUPSO, the CUPSO receives it and checks whether the sender is allowed to control the home network. Then the CUPSO confirms the SMS command format. If the message fits in with the command format, the CUPSO changes the power state of electric home appliances or sends an SMS with the power data to the GSM cellular mobile phone. Thus the user can control and monitor the power state by use of a GSM cellular mobile phone anytime, anywhere.

With a GSM module installed in a CUPSO it is possible while using a GSM cellular mobile phone to:

1. Request the current status (On/Off) and power consumption of any socket in a CUPSO.
2. Change the current status of any socket in a CUPSO to a new status.
3. Receive a notification (alert) message that a predefined condition has been met.
Tables II and III show all possible commands that can be sent via an SMS with a brief description of the command functions. The current readings of information monitored by the CUPSO can be requested at any time by simply sending an SMS containing the desired command to the CUPSO, as shown in Table II.

### TABLE II

**COMMANDS FOR GETTING INFORMATION**

<table>
<thead>
<tr>
<th>Command</th>
<th>Execution</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSKST</td>
<td>Returns a message showing a summary of the status of all sockets</td>
</tr>
<tr>
<td>GSKPV</td>
<td>Returns a message showing the current monitored power value reading</td>
</tr>
<tr>
<td>GUPSP</td>
<td>Returns a message showing the UPS surplus power</td>
</tr>
<tr>
<td>GSPLI</td>
<td>Returns a message showing the alarm limit value of the surplus power</td>
</tr>
</tbody>
</table>

Example 1: Fig. 9 shows how to monitor the current readings of the power.

![Fig. 9. Getting the current readings of the monitored power using SMS.](image)

The following commands are used to request a power datum from the CUPSO for changing or entering information into the unit, such as alarm threshold values, alarm enables, entering passwords or switching sockets On/Off, as shown in Table III.

### TABLE III

**SETTING COMMANDS**

<table>
<thead>
<tr>
<th>Command</th>
<th>Execution</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSKST</td>
<td>Switches the sockets On/Off</td>
</tr>
<tr>
<td>SALEN</td>
<td>Selects which alarms are to be enabled</td>
</tr>
<tr>
<td>SSPLI</td>
<td>Set alarm limit value of the surplus power</td>
</tr>
<tr>
<td>SBTST</td>
<td>Battery status detecting</td>
</tr>
</tbody>
</table>

Example 2: Fig. 10 shows how to switch the sockets On/Off. The template shows the current status of the sockets and provides the correct format for changing the settings. Setting the socket value to “1” turns the corresponding socket on, setting the socket value to “0” turns it off.

![Fig. 10. Switching the sockets On/Off using SMS.](image)

**IV. IMPLEMENTATION RESULTS**

The final implementation of the CUPSO is shown in Fig. 11. The entire hardware prototype circuit of the CUPSO is now implemented on two 5 cm × 6.5 cm and a 10 cm × 13.2 cm printed circuit board (excluding battery, SSR and sockets).

![Fig. 11. The AC power plug controlled by the MCU.](image)

By using Bluetooth the CUPSO enables the home network user to connect a wide range of electric home appliances easily and simply, thus eliminating the need to purchase proprietary or additional cabling to connect individual devices. The user needs only to follow three steps to finish installing the remotely controllable UPS outlet system indoors.

1. Replace the conventional outlet with a CUPSO to provide AC power for the electric home appliances.
2. Install the PDA control software in the PDA by which the user controls the electric home appliances.
3. Connect the PDA to the CUPSO by the Bluetooth search. Now the user can display and control the electric home appliance’s power On/Off by using the PDA.
Fig. 12 shows the measurement results of the appliances plugged into a socket obtained by use of our system and by use of a power meter. We found that there existed an error of only about 5.5% between the estimated value and the measurement value.

![Fig. 12. A comparison of the measurements obtained by our system and by the power meter.](image)

The CUPSO also consumes power. The average power consumption of the CUPSO can be calculated as shown in Table IV. The total power consumption of a CUPSO is about 2.64 W and increases when the number of sockets of the CUPSO increases.

### Table IV
**The Average Power Consumption of the CUPSO Module**

<table>
<thead>
<tr>
<th>Item</th>
<th>Average Current (mA)</th>
<th>Operation Voltage (V)</th>
<th>Average Power Consumption (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM Module (1800MHz)</td>
<td>40</td>
<td>12</td>
<td>0.48</td>
</tr>
<tr>
<td>Bluetooth Module</td>
<td>25</td>
<td>12</td>
<td>0.3</td>
</tr>
<tr>
<td>Power Measuring Module</td>
<td>15</td>
<td>12</td>
<td>0.18</td>
</tr>
<tr>
<td>UPS</td>
<td>110</td>
<td>12</td>
<td>1.32</td>
</tr>
<tr>
<td>MCU and Essential Circuit</td>
<td>30</td>
<td>12</td>
<td>0.36</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>220</strong></td>
<td><strong>12</strong></td>
<td><strong>2.64</strong></td>
</tr>
</tbody>
</table>

An additional advantage of the Power Measuring Module is that it detects the status of an electric home appliance’s power use in addition to controlling the On/Off state of the sockets. In this experiment the Power Measuring Module detects an electric home appliance’s power consumption ranging from 1 W to 1200 W. We can extend the range to detect lower and higher power consumption from 0.47 W to 2500 W by changing the CT, which can increase its volume by half.

We have compared our design with other home power management designs. As a result, our design is better than others because it has more integrated functions. The details of our comparison are shown in Table V.

### V. Conclusion

In this paper a remote-controllable power outlet system and the key components for home power management have been developed. To realize remote control, the Bluetooth, the GSM and the Internet technologies for power management have been integrated. The proposed CUPSO is designed for wireless monitoring and controlling of different electric home appliances and the UPS connected over a Bluetooth network to a home environment. The CUPSO also allows a GSM cellular mobile phone using SMS to monitor and control electric home appliances and the UPS from remote locations.

The field experiments reported in this paper have demonstrated that this new system can be practically implemented and provides adequate results. While this study has its limitations, it is hoped that it will serve as a basis for further study of home power management strategies for various electric home appliances.

### Table V
**Comparison of the Home Power Management Designs**

<table>
<thead>
<tr>
<th></th>
<th>Traditional AC Power Outlet</th>
<th>Traditional UPS</th>
<th>Integrated UPS</th>
<th>HEMS</th>
<th>Our Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless Control</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>UPS</td>
<td>X</td>
<td>Yes</td>
<td>Yes</td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Remote Control</td>
<td>X</td>
<td>X</td>
<td>Internet</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Setup</td>
<td>Easy</td>
<td>Easy</td>
<td>Complex</td>
<td>Easy</td>
<td></td>
</tr>
<tr>
<td>Power Detection</td>
<td>X</td>
<td>Yes</td>
<td>X</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Device</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Base on</td>
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<tr>
<td>GSM Module</td>
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<tr>
<td>Bluetooth Module</td>
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<tr>
<td>UPS</td>
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<td></td>
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<tr>
<td>MCU and Essential Circuit</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td>Line</td>
<td>Line</td>
<td>Line</td>
<td>Line</td>
<td>10M</td>
</tr>
</tbody>
</table>

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### References


