中正嶺學報 第四十三卷 第一期 民國 103.5
JOURNAL OF C.C.I.T., VOL.43, NO.1, MAY, 2014

Development of a Demand-Side Power Monitoring System with Mobile Deployment Consideration

Min-Hsiung Hung[1*], Peng-Yu Chen[2], Allen Y. Chang[1], and Tai-Ning Yang[1]

[1] *Department of Computer Science and Information Engineering, Chinese Culture University*
[2] *Department of Vehicle Applications, AU Optronics Corp. (AUO)*

ABSTRACT

In this paper, we leverage the technologies of Web Service and embedded system to develop a demand-side power monitoring and management system (DPMS). We design a monitoring and management server (MMS) to offer various power-monitoring related Web services. Also, we adopt an embedded computer and a multi-function power transducer to design an active monitoring module (AMM) that has the plug-and-play capability and can actively acquire and deliver power information. Besides, we utilize a Web I/O unit and a Wi-Fi device to design a wireless monitoring module (WMM) so that the MMS can wirelessly monitor and control the power consumption of various apparatuses. The AMM along with the WMM can significantly facilitate the mobile deployment of the power monitoring points (PMPs) and can flexibly extend the distance between the MMS and the PMPs through network. Finally, we implement a DPMS prototype to validate the efficacy of our designs.

Keywords: Demand-Side Power Monitoring System, Mobile Deployment, Embedded Computer, Wireless Monitoring Module, Web Service

發展考量機動部署之需求端電力監控系統

洪敏雄[1*]　陳鵬宇[2]　張耀鴻[1]　楊泰寧[1]

[1]中國文化大學資訊工程學系
[2]友達光電股份有限公司車用事業群

摘　　要

本論文利用網路服務及嵌入式系統技術，發展了一個需求端電力監控系統。我們設計一個監控管理伺服器，來提供各式電力監控網路服務。我們也利用嵌入式電腦與多功能電表，發展了一種主動式監控模組，其具備隨插即用的能力，並可主動地擷取與傳遞電力資訊。同時，我們利用網路式 I/O 與 Wi-Fi 裝置發展了一種無線監控模組，可讓監控管理伺服器以無線的方式監控各種設備的電力使用狀況。我們所設計的主動式監控模組與無線監控模組可讓電力監控點的機動部署變得很容易，也可彈性地透過網路來擴展電力監控點與監控管理伺服器之間的距離。最後，我們建置了一個需求端電力監控系統的雛型，驗證了各項設計的有效性。

關鍵詞：需求端電力監控系統、機動部署、嵌入式電腦、無線監控模組、網路服務

文稿收件日期 102.1.29; 文稿修正後接受日期 102.11.4; *通訊作者
Manuscript received January 29, 2013; revised November 4, 2013; * Corresponding author

Ⅰ. INTRODUCTION

As the economic growth and quality of the life are improving constantly, the demand of the electric power increases year by year. Meanwhile, raising environmental awareness leads to the search for alternative energy solutions. However, the development of new energy source is not fast enough to fulfill the increasing power demand. Therefore, how to economize on the electricity becomes an important issue. In the past twenty years, the promotion of the apparatus energy efficiency had good achievement already. If one can strengthen the control and manage the power consuming behavior of the client side, namely, the Demand Side Management (DSM), the electricity consumption can further be reduced. Thus, to achieve the goal of economizing electricity, the power monitoring system (PMS) plays the key role in DSM.

Several prediction schemes have been proposed to effectively manage the energy. Blonbou [1] presented a predictor using artificial neural network with adaptive Bayesian learning and Gaussian process approximation for short-term wind power prediction. Gang et al. [2] introduced a dynamic energy performance scaling (DEPS) framework to explore application specific energy-saving potential in real-time embedded systems. Their framework focused on system-wide energy reduction and use power control mechanisms to trade off performance for energy savings. Bin et al. [3] proposed an energy management and optimization strategy for wireless sensor. They developed a processor module and a communication module to enhance the network energy efficiency.

With the flourishing development of the Internet technology, the concept of Web-based PMS has been proposed. The idea is to make use of the Internet to offer remote monitoring, unloading and control of electric energy facilities, and the ability of collecting and analyzing the recorded data for further study. Therefore, a typical Web-based PMS should include four main apparatuses: (1) Transducer: The Potential Transformer (PT) that converts high-voltage to low-voltage, and the Current Transformer (CT) that changes the large electric current into small electric current; (2) Remote Power Handler (RPH): Tentatively deal with the signal sent from that the on-site apparatus, and then upload to the master station through the communication system. Meanwhile, RPH also accepts commands from the master station, and convey to the on-site apparatus; (3) Communication System: the wired or wireless data transmission media between the Central Station and RPH; (4) Central Station: Made up of the multiple server level host computers. It is responsible for accepting the request for the client side and offering the desired data on demand.

Several Web-based PMSs have been developed nowadays. For example, to maximize the benefits of PMS, Nicholson et al. [4] put forward a complete functionality list of PMS that can fulfill the cost-efficiency requirement. In response to the liberalization of electricity industry, Seki et al. [5] used Common Object Request Broker Architecture (CORBA) [6] object-oriented technology to develop the information transmission system for the electrical power system. Such system could intensify client service, thereby enhancing the firm’s turnover. Modern cement factory has over 650 motors of different sizes. Their power range was reported from 0.5 horse power (HP) to 9,000 HP. In view of the importance of PMS to the cement factory, Leinmiller [7] proposed a network electrical monitoring system to shorten machinery downtime, promote the efficiency of power consuming, and reduce the operation cost. Qiu and Wimmer [8] used Distributed Component Object Model (DCOM) [9] technology to design power monitoring system. Their proposed system was capable of analyzing and evaluating the interference signals. In order to control the price, quality and reliability of the electricity, Forth and Tobin [10] introduced a Web-based PMS. Their system conveyed real-time information and control commands among the electrical power consumer, the power utilities and the energy services companies under an efficient, economical, and extendible framework. Wan et al. [11] designed a Web-based PMS which picked up the power consumption signals of 15 buildings in the vast campus and performed load balancing task. Sarkinen and Lundin [12] from Ericsson used open Internet protocol to develop a modularized PMS. It allowed remote electrical power administrator to manage the distributed electrical power apparatuses located in different places using Web browser.

Looking over the PMS implementation nowadays, there are two issues. First of all, the designs of the systems were aiming at the monitoring and management of high-power electrical facilities, which adopted fixed style monitoring architectures. As a result, the system infrastructures lacked flexibility. In other words, it was difficult to change the monitoring area and add particular monitoring point once the PMS hardware and software were deployed. Therefore, when the organization needs to purchase additional power consumption plan due to expanding new building or plant, it was inevitable to revise the software for the new remote monitoring point. The inconvenience of enterprise power management makes the fixed style monitoring architecture inadequate for controlling incidental electrical facilities.

Our previous work [13] adopted Ethernet-ready I/O module as remote power processor, and developed a portable electrical transducer with adaptor. The developed software mechanism that could deploy monitoring point on demand had already solved the system flexibility issue partially. However, the Ethernet-ready I/O module is a passive component. It needs to wait for the master station to assign the controlling command, and then passes the result back to the master station after the execution is complete. The problem arises when the master station encounters malfunction or network interruption. The electrical power administrator will lose control over the monitoring point during that period of time, and the system will have to face the open window with low system reliability. Consequently, although the Ethernet-ready I/O module offers several advantages such as small size and low cost, it cannot be operated independently.

On the other hand, embedded system has been proven to be the best combination of software and hardware for industrial automation [14]. Kumar et al. [15] indicated that the management and conservation of power was the key challenges of embedded system design. The hardware configuration of embedded systems is a design based on functional requirements. An embedded system can be small in size and applicable to various abominable environments. Its software configuration keeps only the essential parts.

Another issue of embedded systems is the insufficiency of information integration [16]-[18]. The new-generation PMS must be able to integrate distributed systems and applications over the Internet. However, the software of the systems mentioned in the literature was developed using tightly-coupled distributed object technology such as GORBA established by Object Management Group (OMG) [19], Microsoft's DCOM, and SUN's Remote Method Invocation(RMI) [20]. The links between the server program and client program of these systems are fragile. Changes on either side will cause connection interruption. There are many other common defects of those technologies. First, both sides of the communicating programs must use the same object protocol. For example, the object of DCOM cannot communicate with the object of CORBA directly. Second, those protocols cannot penetrate firewall. However, most enterprises install firewall between internal and external network for security reason. This will reduce the usefulness and effectiveness of distributed object technology. Finally, DCOM and RMI are not open distributed object technology. They belong to Microsoft and SUN, respectively. Moreover, the major shortcoming of Web applications is that information of different websites cannot be integrated automatically. The information must be integrated manually.

Instead of developing proprietary data coding methods to transfer data [21], we adopt Web services [22], which use eXtensible Markup Language (XML) [23] as the data format to transmit information. It is easy to exchange data and integrate distributed or cross-platform systems. Web services use Simple Object Access Protocol (SOAP) [24] as the communication protocol between applications. Together with Hypertext Transfer Protocol, Web services can pass through firewall easily. This solves the interaction problem of cross-platform distributed systems and applications. In addition, it is convenient to retrieve desired information from different websites using Web services. One can combine the information into proprietary form and send it to any devices. This breaks the segments among different platforms, applications, and all kinds of devices to achieve high degree of integration among heterogeneous systems. Meanwhile, the client side can retrieve information offered by the Web services any time, any place.

In view of the aforementioned advantages of embedded systems and Web services, we adopt the embedded system and new-generation distributed software technology to develop a demand-side PMS (DPMS) that takes mobile deployment into consideration. As a result, the system framework can improve the shortcomings of the aforementioned existing PMSs effectively. It can also be regarded as a reference for constructing next-generation PMSs.

The rest of the paper is organized as follows. Section II introduces the design of the DPMS framework with mobility consideration. Section III elaborates the design of the monitoring and management server (MMS). The development of system components within the MMS server is described in Section IV. The design of the power monitoring modules is explained in Section V. Section VI introduces the construction of a sample DPMS along with the system integration test. Section VII is the conclusion of this paper.

Ⅱ. THE DESIGN OF DPMS FRAMEWORK

After studying and analyzing the existing PMSs [25], we stipulate 11 functional requirements for developing the DPMS that considers mobile deployment.

(1) The communication infrastructure needs to adopt the new generation distributed object technology, i.e., Web services, to avoid the shortcomings of the traditional distributed object technology.

(2) The system should not only possess the ability of remote electricity monitoring, but also be easy to add new functionality to it.

(3) The system should possess the flexibility of plug-and-play and mobile deployment of the remote electricity processor.

(4) The system should include the security mechanism, such as device security authentication, to ensure the safety of system operations.

(5) The system should be capable of retrieving enough electricity parameters for analysis and research.

(6) The system should be capable of predicting the yearly electricity requirement so as to stipulate the best contract capacity with the power company.

(7) The system should possess the capability of electricity requirement control and automatic notification of warning messages.

(8) The system can proactively detect remote electricity processor offline to keep the system administrator up-to-date about the connection of remote electricity processors. It can reduce the probability of false judgment.

(9) The system can manage power data.

(10) The system should be easy to operate.

(11) The system should be portable to facilitate system software arrangement.

According to the functional requirements listed above, we propose the framework of DPMS with mobile deployment consideration as shown in Figure 1. The entire structure is divided into the Server Side, the Equipment Side, and the Client Side. The Server Side consists of the monitoring and management server (MMS) and database. The MMS is the core of the whole system. It is composed of various functional components. The Equipment Side is made up of Embedded Unit (EU), Multifunction Electric Power Transducer (MEPT), Wireless Monitoring Module (WMM), and the apparatus under monitor and control, including electric equipment, facilities, and Power Distribution Box (PDB). The EU has various functional components within it. Together with the MEPT, one can retrieve electricity signals from PDB. The WMM is composed of a Voltage and Current Transformation Unit (VCTU), an Ethernet-ready I/O unit, and an IEEE 802.11g Wireless LAN (WLAN) adapter. The major functionality of WMM is to monitor the equipment with electric outlet. The Client Side includes desktop PC, notebook and tablet PC.

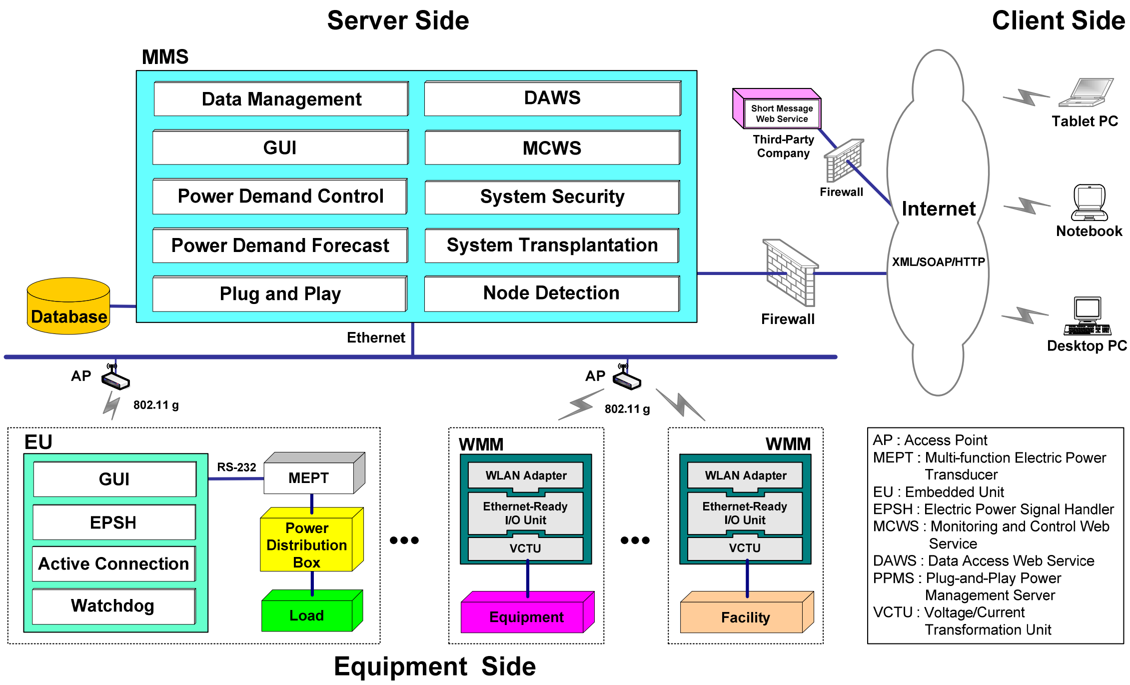


Fig. 1. Framework of DPMS with mobile deployment consideration.

We design the MMS to contain a variety of major software components to be regarded as the bridge between the Client Side and the Equipment Side. To meet the functional requirements (1) and (2), we construct various functions in the form of Web services for remote electricity monitoring and database access, namely the Monitoring and Control Web Service (MCWS) and the Data Access Web Service (DAWS). The MCWS can retrieve data or transmit control commands to the equipment and facilities under control through Ethernet-ready I/O modules. By calling the MCWS service component, the Intranet or Internet users and system components within the server can easily access the information at the monitoring point and send control signals to it. One can also access database easily by calling the DAWS. For requirement (3), we design a Plug-and-Play component as well as two Remote Power Handlers (RPHs): EU and WMM. We design an active connection component within EU. It can actively send request for connection (RFC) messages to the server. The Plug-and-Play component within the server will do the authentication and authorization upon request. After the security check is passed, the server connects with the device and adds its information into the EU management list. In addition, we add a socket on WMM. After the plug of the equipment is inserted into the socket on WMM, and the user inputs a few parameters via Web browser, the system can begin to monitor and control the electricity usage of the equipment.

The System Security component plays an important role of protecting the system. It does not allow unauthorized users to use the system, or unauthorized devices to connect to the system. Its components include user authentication and authorization, EU device authentication and authorization as well as a Web application security mechanism to fulfill requirement (4). To meet requirement (5), we design Electric Power Signal Handler (EPSH) component within EU. It utilizes multifunction MEPT to retrieve the electric parameters (including V, A, W, VAR, PF, WH, Hz, etc.) of facilities. The EPSH obtains electric signals through RS-232 or RS-485 communication interface and Modbus [26] transfer protocols. The processed electricity information is then sent to the database on the Server Side via calling the DAWS. For requirement (6), we design the Power Demand Forecast (PDF) component based on the cost function of the best contract capacity [27]. This component can predict the optimal electricity consumption based on the power consuming parameters of the current year. Enterprises can then sign the contract capacity with the power utility provider according the estimated power usage.

Regarding requirement (7), we have designed the Power Demand Control (PDC) component, which is able to proactively monitor power consumption, convey real-time warning messages, and directly control loads. These functions can be used to inhibit the peak electricity usage to avoid the over-usage penalty. For requirement (8), we have designed the Node Detection component. This component will proactively scan all remote power handlers. The monitoring point will be removed from the user interface temporarily if the monitoring point cannot be detected, and will be added to the system if it is detected again. To conform to requirement (9), we design the Data Management component to manage the users of the system, EU, WMM, and historical power usage data. To meet requirement (10), we design a variety of graphical user interfaces to facilitate the user to browse the power usage, and to help the system administrator to manage system operations. In order to meet requirement (11), we design the System Transplantation component. When the system administrator needs to transplant the system to another server, all he or she has to do is to change the parameters in the System Transplantation component to let the system operate on the target server immediately. Finally, to strengthen the system information security, we install firewall in front of the MMS to prevent vandalism from unauthorized access.

In order to construct the DPMS, we first adopt Web service technology to build the communication infrastructure and to replace the traditional distributed object technology. It can also integrate heterogeneous systems and data over the Internet. The components can then be able to communicate with each other automatically. Then, the MMS connects to the distributed EUs and WMMs through the Internet. This can not only enable the easy deployment of the RPH but also flexibly extend the monitoring distance of the system. The next thing we do is to design the Plug-and-Play EU to replace the Ethernet-ready I/O Module. The administrator can connect to the server initiatively and transmit power information to the database server by doing simple setting on the EU. Meanwhile, we design the WMM which contains a power socket. For a piece of equipment to be monitored and managed by the MMS, we just need to insert the plug of the equipment into the socket of a WMM, and to key in basic data related to the equipment through the designed Web-based GUI for this

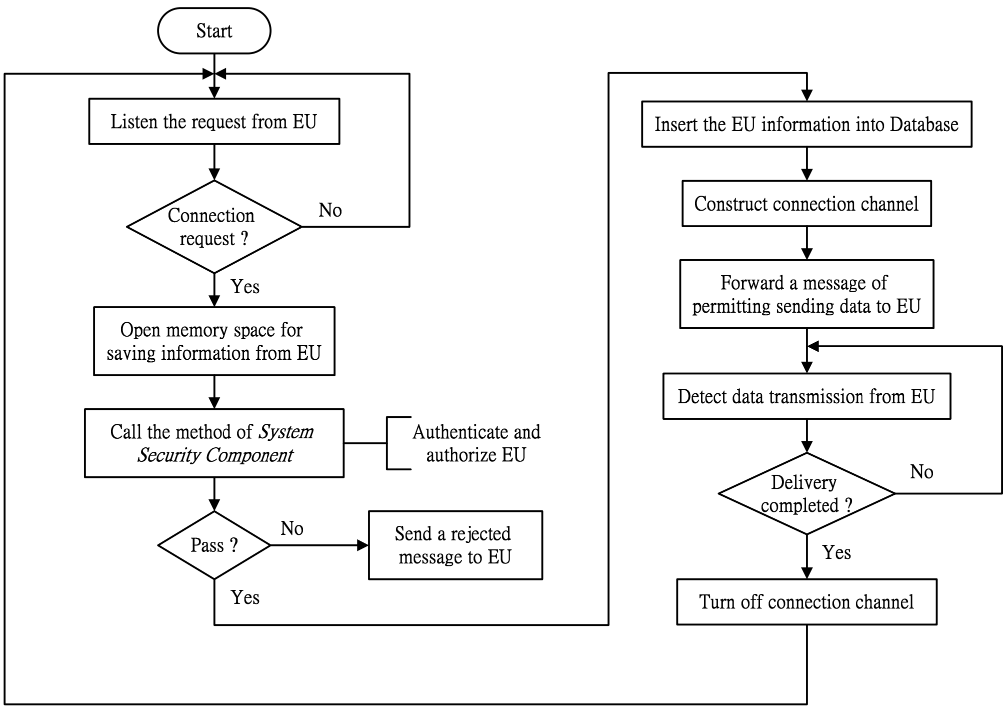


Fig. 2. The operation flow of the Plug-and-Play component.

function. The MMS can allow the administrator to manage the electricity usage conveniently and enable the users to remotely use the system resources any time from any places via the Internet as long as they pass the authentication and authorization of the MMS. The detailed design of the MMS will be explained in the next Section.

Ⅲ. Design OF THE MMS

Due to the page limitation, we only explain the design of major components in the MMS and EU, and the message transmission between some components. Detailed introduction can be found in [28].

3.1 The Plug-and-Play Component

The Plug-and-Play component can assist the administrator to add new EU into the power monitoring system. The operational mechanism of this component is shown in Figure 2 and explained below.

As the new EU tries to establish connection with the MMS, the Active Connection component in the EU will send a series of information to the Plug-and-Play component, including a unique identification code of the EU, the name and password of EU, the location of power monitoring point, and the facility to be monitored. All of the information is input by the user except the identification code of EU, which is embedded into the device and cannot be changed by the user. If the EU is lost, the system administrator can simply delete the unique identification of the EU from the database. Once this is done, the EU cannot convey any data to the MMS anymore.

Once the Plug-and-Play component receives the information from an EU, it calls the System Security component to perform the authentication and authorization process. If the information is sent from an illegal device, the component will reply with the "connection refused" message. On the contrary, if the device sending the information is legal, the component will add the information of the device to the management list, allowing the device to send the acquired power information to the database in the MMS. By this way, the power monitoring point can be easily included into the power monitoring system. The system administrator can then manage the device through the Web-based GUI.

By using Web services as the communication infrastructure, data can be transmitted between the EU and the MMS in loosely-coupled way. In other words, the connection is established only when there is a message to be delivered. Once the message transmission is complete, the connection between EU and MMS will be terminated. This way can not only reduce the bandwidth required for communication, but also increase the system stability. After a newly deployed power monitoring point is included in the system, the MMS begins to acquire the power usage information from it and display the acquired information on the Web-based GUI, while saving the information into the database at the same time for future reference.

3.2 The Power Demand Forecast Component

The Power Demand Forecast component is designed based on the cost function of optimal contract capacity and the sequential search rule [26]. This component is mainly used for predicting the best contract capacity, and to get the lowest fix electric rate. Equation (1) is a cost function for the best contract capacity:

$$OCC = Minimum\left\{\sum_{m=1}^{12}\left[\left(BPF\right)_m + \left(OCF\right)_m\right]\right\} \quad (1)$$

where OCC is the yearly cost of the optimal contract capacity, $(BPF)_m$ is the basic power fee of the m-th month, and $(OCF)_m$ is the over capacity fee of the *m*th month.

The mechanism of predicting the best contract capacity is shown as in Figure 3 and described as follows. First, import the monthly peak load of the previous year, from January to December. Next, find out the maximum peak (Dmax, Maximum Peak Demand) and the minimum peak (Dmin, Minimum Peak Demand). Then, based on the seasonal rate announced by the electricity utility company, use the minimum peak demand to calculate and store the yearly fix electricity fee. After that, starting from the Dmin, add 1KW to it at each iteration and recalculate the yearly fixed fee until Dmin > Dmax. Finally, the optimal contract capacity is the contract capacity that produces the smallest fixed electricity fee. Based the predicted contract capacity, the administrator can stipulate next year's capacity contract with the utility company.

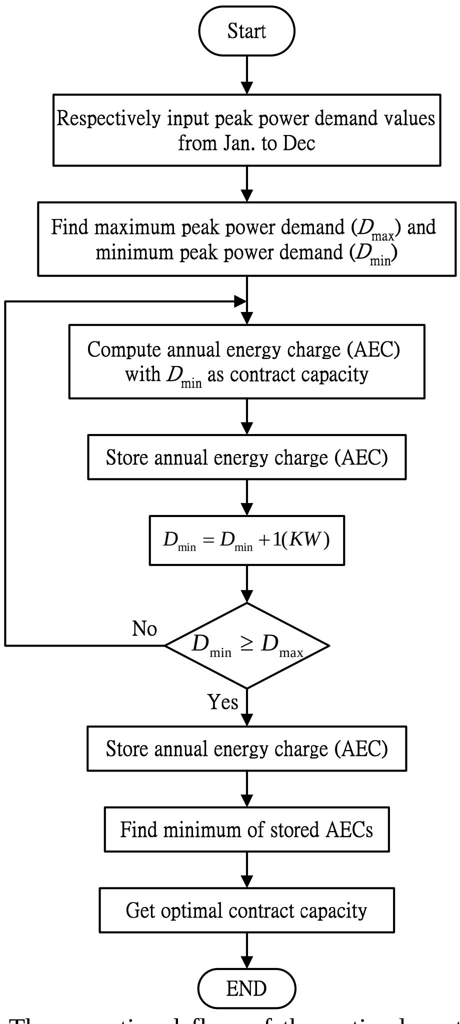


Fig. 3. The operational flow of the optimal contract capacity prediction mechanism.

3.3 Power Demand Control Component

The Power Demand Control (PDC) component is used to inhibit the peak electricity usage and to prevent the penalty due to the electricity usage over the contract capacity. This component consists of three mechanisms: mechanism of actively monitoring high power consumption, mechanism of timely conveying warning messages, and mechanism of direct loading control, which are described below.

3.3.1 Design of Actively Monitoring High Power Consumption Mechanism

The EU sends power data, acquired by the MEPT, to the database server through the DAWS component. Then, the script program in the Web-based GUI will call DAWS to get the newest power information and timely display it on the GUI.

We define two threshold values [29] to distinguish loading situations: the critical power threshold P_c and the warning power threshold P_w. If the real-time loading demand P_r is lower than P_w, the power consumption is safe. If P_r is higher than P_w and lower than P_c, We need to pay attention to the power consumption. When P_r is higher than P_c, meaning that the power consumption is in critical situation, some of power loading must be dismissed. Otherwise, the power consumption may exceed the contract capacity at any time.

In order to define P_w and P_c, We use the contract capacity as the base value, say V. Let $P_c = \alpha V$ and $P_w = \beta V$, where $0 < \alpha, \beta < 1$. The electric power administrator can setup α and β on the GUI according to practical demands. The PDC component can compare P_r with P_w and P_c to judge the status of the power consumption. Moreover, to reduce the probability of false alarms, the value of P_r is calculated using moving average as follows:

$$P_r(t) = \left(P_r(t) + P_r(t-\psi) + P_r(t-2\psi)\right)/3$$

where ψ is the sampling interval whose default value is one minute. The design of the PDC only focuses on detecting high power consumption. To predict the short term loading more accurately will need more complete loading models and advanced learning rules [30].

3.3.2 Design of Timely Conveying Warning Message Mechanism

Based on the results from the mechanism of actively monitoring high power consumption, the mechanism of timely conveying warning messages can send warning messages about critical power consumption situations to the power administrator in a timely manner. There are two ways to deliver warning messages in this work: via e-mail or mobile phone text message.

- E-mail:

In case of high power consumption state, this mechanism will send relevant information, such as time, system handling situation, and electric power information, to the power administrator's email account via Simple Mail Transfer Protocol (SMTP).

- Mobile phone text message:

Unlike email, mobile phone text messaging can accelerate the transmission of abnormal power consumption information. It allows the power administrator to take the requisite measures within the shortest time, which can avoid the penalty due to the power consumption over the contract capacity.

Because Web services are programmable components over the Internet, there are many companies offering various types of Web services already. We use the text messaging Web service offered by the ASPOnline Web Services Center [31] to deliver the warning messages. The mechanism of delivering mobile phone text messages is shown in Figure 4 and described as follows. First, the system developer needs to login to ASPOnline Web service main page, apply for an account, and pay service credits. By adding the Web reference of the Web service in the system program, the developer can create the service proxy in the system. Then, the PDC component is able to send warning messages about abnormal power consumption to the administrator's mobile phone by calling the service proxy, which in turn calls the text message delivery Web service. After the Web service sends the warning message, ASPOnline will deduct credits from the user account.

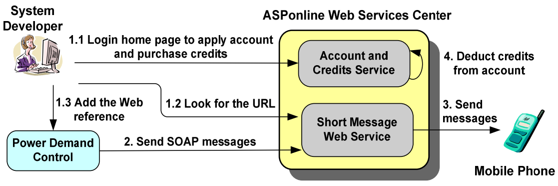


Fig. 4. Mobile phone text message delivery mechanism based on Web service technology.

3.3.3 Design of Direct Loading Control Mechanism

The direct loading control mechanism is designed to get rid of power loading on demand. As the power administrator receives a warning message regarding to the power consumption, he can use this mechanism to unload some pieces of controlled equipment. If the power consumption status is critical, this mechanism will unload the controlled equipment either sequentially or from the ones with maximum power consumption according to the pre-determined rules. This mechanism lets the PDC component call the MCWS to turn on/off the controlled equipment directly.

3.4 Design of System Security Component

We design three mechanisms in the system security component to ensure the safety of system's operations, including user authentication and authorization, device authentication and authorization, and website access control, which are described below.

- User authentication and authorization:

To prevent the system from invaders' attacks, the user must pass this mechanism in order to operate the functions of the system. The user authentication mechanism uses the user's account number and password to verify the user's identity. Once a user passes the authentication process, the system will assign the proper authorization level to the user according to his role.

- Device authentication and authorization:

New EU must pass the authentication and authorization mechanism before connecting with the system. When the power administrator deploys a new EU, she or he has to enter essential EU information via the GUI. This information includes the EU's name and password, server IP address, the location of power monitoring point, and the name of the monitored facilities. Then the EU's information will be sent to the MMS for authentication and authorization. If the name, password, and the embedded unique identification number of the EU match with those in the system's database, the system security component will send an authorization message back to the EU. The EU cannot convey electric information to the system's database until it receives the authorization message.

- Website access control:

To strengthen the website security, we adopt the form verification technology in ASP.NET. It can filter out the unauthorized website access from the input field of the URL. If an attacker obtains the URL of the Web-based GUI from the record of the browser and wishes to access the GUI, the system security component will automatically re-direct the access request to the system login page. Therefore, this mechanism ensures that only authorized user can access the system's resources.

3.5 Design of Watchdog Component

The watchdog component is designed to be embedded in the EU. It plays the role of facilitating the PDC component in the power management server. The administrator can choose to turn on or off the watchdog function on demand. The default state of the watchdog component is off. Once the watchdog component is turned on, the active connection component in EU will extract essential parameters in the PDC and store them in the EU database. These parameters include P_c, P_w, power factor *PF*, and the power administrator's email account and mobile phone number. This component will take over important functions of the PDC in case of MMS failure or network interruption. It is also responsible for monitoring power consumption and delivering warning messages. First, the active connection component wakes up the watchdog component. As long as the watchdog component detects that the PF of power loading is too low or the power consumption is too high, it will notify the power administrator to handle the abnormal situation as soon as possible. Finally, after the MMS is back to normal operation or the network connection is re-established, the active connection component will stop the functionality of watchdog and give the control back to the PDC component.

3.6 Message Transmission between EU and MMS

Due to the space limit, this section only describes the operational flow of transmitting power information from EU to MMS, as shown in Figure 5.

(1) The serial port of the embedded unit sends a Modbus-format query message to MEPT and requests for power data.
(2) When MEPT receives the query message, it will compile the measured power data in Modbus format and send a response message back to EU.
(3) When EU receives the response message, it will do error checking first. If the result is correct, it will decode the message into power information, such as V, A, W, VAR, PF, WH, VARH, Hz, and show these information on the screen of EU.
(4) EU calls the DAWS in MMS to transmit power information to MMS, which is then stored into the system's database.
(5) After the DAWS stores the data into the database, it will reply a "success" message to EU. Once EU receives the reply message, it can transmit the next power information again.

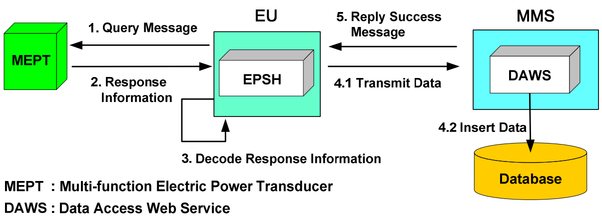


Fig. 5. Message transmission between an embedded unit and the MMS.

Ⅳ. SYSTEM ANALYSIS AND DESIGN

We adopt Web service technology to construct the communication infrastructure of the system. In addition, we use object oriented methodology to develop the system components, utilizing UML (Unified Modeling Language) [32] for modeling the system. Due to limited space, this section only explains the object oriented analysis and design issues regarding to MMS's components.

4.1 Object Oriented Analysis

During the object oriented analysis phase, the use case diagram, sequence diagram, and class diagram of the MMS are drawn up, described as follows.

4.1.1 Use case diagram

The use case diagram of requirements analysis is shown in Figure 6. The actors and use cases are explained as follows.

Actor:

- User: It can be system user, power administrator, or system administrator.
- EU: Embedded Unit. It can read MEPT's power information and send it to the system's

database.

- Database: It stands for the system's database, which is used to store the system information, user information, and electricity information.
- WMM: It is the acronym of Wireless Monitoring Module, which is used to monitor the power consumption of facilities. It can also turn on/off the power of monitored facilities.
- MMS: It represents the monitoring and management server, which is the kernel of the entire system. It can carry out power monitoring and control, as well as detect the connection of remote power monitoring modules. Therefore, MMS can be treated as an actor.

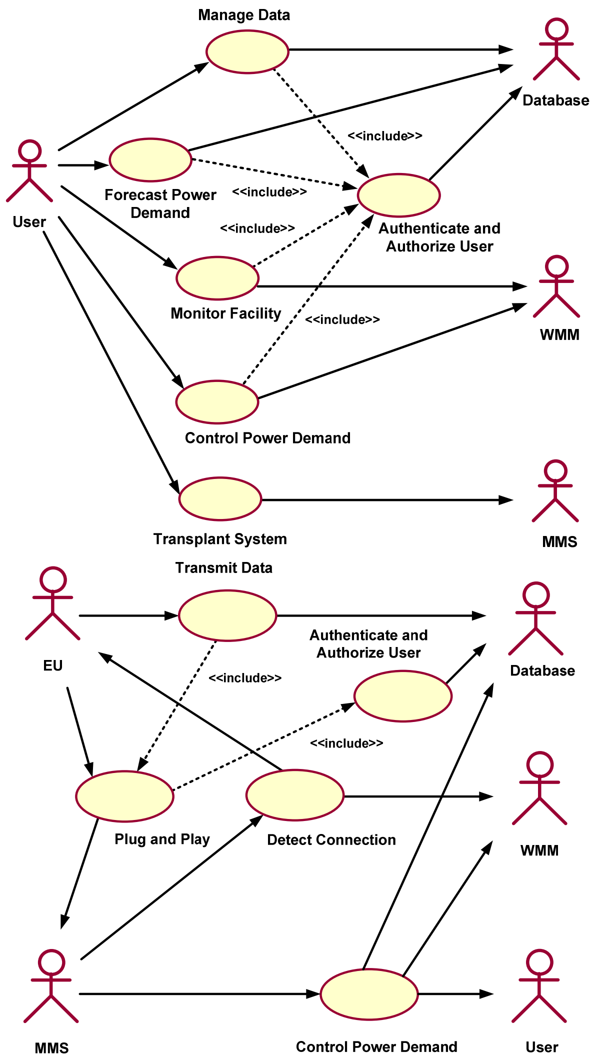


Fig. 6. Use case diagrams for the MMS.

Use Cases:

- Authenticate and Authorize User: In this case, the system verifies an user's identity according to the account number and password provided by the user. It then authorizes appropriate access privilege to the authenticated user. Similarly, the EU has to pass the authentication and authorization of this use case before connecting with the system.
- Manage Data: This use case allows general users to manage their personal data and the system administrator to manage the system's information. Because an user must pass the authentication and authorization before using this use case, this use case includes the use case of "Authenticate and Authorize User."
- Forecast Power Demand: The user can carry out this use case to analyze the yearly optimal contract capacity. Similarly, this use case includes the use case of "Authenticate and Authorize User."
- Monitor Facility: The user can apply this use case to monitor the power consumption of facilities. Similarly, it includes the use case of "Authenticate and Authorize User."
- Control Power Demand: This use case allows the power administrator to manually turn on/off the monitored facilities. It can also actively monitor the loading of total power consumption. If the power loading is entering into warning or critical conditions, a warning message will be sent to the power administrator. Similarly, it needs to include the "Authenticate and Authorize User" use case.
- Transmit Data: This use case is for EU to send power information to the database in MMS. Similarly, it includes the "Authenticate and Authorize User" use case.
- Transplant System: The system administrator can apply this use case to transplant the MMS to another server.
- Plug and Play: This use case allows the EU to be included into the system and to be managed easily. Similarly, this use case must include the "Authenticate and Authorize User" use case.
- Detect Connection: This use case is for actively detecting the connection statuses of all the underlying EUs and WMMs. If a power monitor point cannot be detected, it will be removed from the system temporarily. It will be brought back into the system once

the connection is reestablished.

4.1.2 Sequence diagram and class diagram

After completing the use case diagram of the MMS, we further describe every use case to generate the corresponding scenarios. According to these scenarios, we can create the sequence diagrams of the object-oriented analysis phase. Then, combining all of the sequence diagrams, we can generate the class diagram of the object-oriented analysis phase. Due to the page limitation, we do not list the sequence diagrams and class diagrams here.

4.2 Object-Oriented Design

According to the sequence diagrams and class diagrams obtained in the object-oriented analysis phase, we can conduct object-oriented design of the MMS to generate the sequence diagrams and class diagrams of the design phase.

V. DESIGN OF POWER MONITORING MODULES

We use off-the-shelf hardware devices to design and develop the portable power monitoring modules for achieving mobile deployment of the power monitoring points. Specifically, we adopt a MEPT to extract the power signals of PDB through RS-232 or RS-485 interface using Modbus transfer protocol. Moreover, to reach plug-and-play RPH and real-time electric signal transmission, we employ a 3.5-inch single board computer, called EU in this paper, to transmit the command string of the Modbus transfer protocol through serial port. It can read the power information measured by MEPT and send it to the remote system's database. In addition, we design a portable wireless monitoring module, which is easily to be deployed on demand for monitoring the power of facilities and equipment. The power monitoring modules adopted in this work are described as follows.

5.1 Multi-function Electric Power Transducer

The multi-function electric power transducer, a.k.a. MEPT, is developed by Chitai Electronic Corporation [33]. It has 16-bit microprocessor and 16 MHz working pulse. All of the measurements, display, correction and output are digitalized. In addition, its communication interfaces include RS-232 and RS-485. It utilizes Modbus transfer protocol to deliver the measured electric power information.

5.2 Embedded Unit

In this study, EU is a single board computer designed by ADVANTECH [34]. It integrates Intel Strong ARM CPU and Microsoft Windows CE operating system. It is a compact and complete platform for the embedded application. In addition, it contains a CPU which is a Reduced Instruction Set Computing (RISC) microprocessor, and it does not use hard drive as the storage. This design makes the EU especially applicable to serve as an embedded platform operating in harsh environments. Other specifications of the EU include three serial ports, one Ethernet port, touch-screen LCD, IrDA interface, and sound output.

5.3 Wireless Monitoring Module

We design a wireless monitoring module (WMM), which includes a socket and a plug [29]. After the plug of an apparatus is inserted into the socket of WMM, and the plug of WMM is inserted into the socket on the wall, the WMM can send the root mean square of the acquired voltage and current to the MMS. The design of WMM is shown in Figure 7, which is made up of a set of relays and four units, i.e. Voltage/Current Transformation Unit (VCTU), Ethernet-Ready I/O Unit, Wireless Adapter, and Power Supply Unit (PSU). First, the actual AC voltage and current signals are converted to DC analog signals by the VCTU. Then, the DC signals are converted to digital packet signals by Ethernet-ready I/O unit. The digital packet signals are then conveyed to the wireless access point by wireless adapter, and then to the Internet. On the contrary, wireless adapter can receive control commands and send them to the Ethernet-ready I/O unit, which can then turn on/off the monitored apparatuses through the relays.

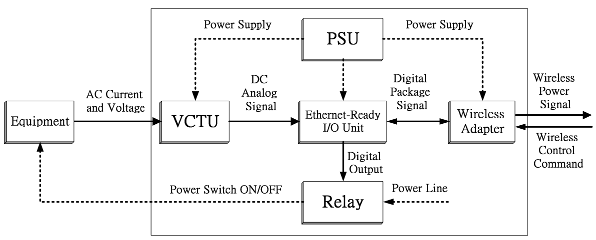


Fig. 7. Functional blocks of the Wireless Monitoring Module (WMM) [29].

5.3.1 Voltage/Current Transformation Unit

We design the VCTU to extract the root mean square value of the AC voltage and current of the facilities. The VCTU is composed of Voltage Transformation Unit (VTU) and Current Transformation Unit (CTU). VTU is formed by AC2DC Transformer and Voltage Divider. The working principle is that $110V_{AC}$ is transformed to 15 V_{DC} by the AC2DC transformer. Then, $15V_{DC}$ is scaled down to a value that the Ethernet-Ready I/O unit can read. The circuit design of the current transformation unit (CTU) can be referred to [29].

5.3.2 Other Units

We adopt the Smart Web I/O module produced by ADVANTECH [34] as the Ethernet-ready I/O unit. The Smart Web I/O module has the advantages of long transmission distance, low cost, and high mobility. By using the digital output port connected with the relay, this I/O unit can turn on/off the monitored facilities. Also, it can extract the current and voltage signals of the monitored facilities by using its analog input port.

We use ICPDAS' Wi-Fi Ethernet Smart Client [35] as the wireless adapter. The Ethernet-ready I/O unit can connect with the access point via this wireless adapter using IEEE 802.11g protocol. This increases the mobility of deploying power monitoring points.

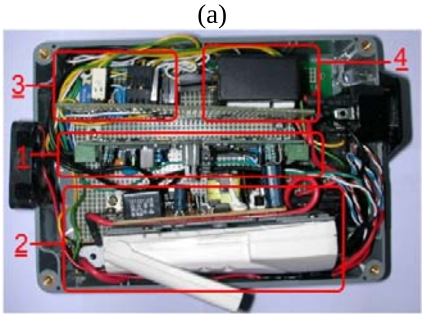
PSU is used to offer DC power to the Ethernet-ready I/O unit, wireless adapter, and VCTU. We use AD6 vertical power supply produced by Kwang Hwa Electronic, Material Co., LTD [36] in this work.

5.3.3 Construction of WMM

According to the design for each unit, we construct a WMM, which can match the system's requirements. Figure 8(a) is the physical appearance of WMM. The number 1 in the figure is the power plug of WMM which must be plugged into the socket on wall for this module to be operational. The number 2 in Figure 8(a) is the power socket of the WMM. To monitor and control an apparatus, we only need to insert the plug of the apparatus into the power socket of the WMM.

Figure 8(b) is the inner view of WMM. The number 1 in Figure 8(b) is the real circuit of Ethernet-ready I/O unit. It is responsible for the communication between the WMM and the MMS. Mark number 2 is the wireless adapter. It is the bridge between Ethernet and wireless networks. Mark number 3 is VCTU, which is responsible for extracting the root mean square of DC voltage and currents. Mark number 4 is the power supply unit and transducer, which is responsible for providing enough operational power to the WMM.

(a)



(b)

Fig. 8. (a) Outer appearance of WMM, (b) Inner connection of the units in WMM.

Ⅵ. PROTOTYPE SYSTEM CONSTRUCTION AND INTEGRATION TEST

We constructed a prototype of the demand-side power monitoring system (DSPMS) with mobility consideration according to the framework in Figure 1. The system implementation and the integration test of the prototype DSPMS are described as follows.

6.1 System Implementation

We adopt Microsoft 0 .NET Framework plus .NET Compact Framework as the execution environment, and use Windows 2003 as the development platform. For the software, we use Microsoft Visual Studio .NET as the development tool, and use C#, Java Script, and VB 6.0 as programming languages to develop the system. At the same time, we adopt ASP.NET to build the Web-based GUIs. The Smart Device Extension (SDE) is applied to the development of EU application programs.

Internet Information Services (IIS) is employed as the Web server. The database on the Web server is constructed by using Microsoft SQL Server.

For the hardware, we use two personal computers, one for constructing the MMS on the server side and the other for being as the client computer. We deploy a MEPT to detect the power signals of a PDB. Moreover, we utilize a 3.5-inch single board computer as the EU. Furthermore, we deploy the designed portable WMM to detect the voltage and current of the monitored equipment, as well as to turn on/off monitored equipment. The WMM makes the installation of the power monitoring points very easy.

6.2 Integration Test

Figure 9 shows a snapshot of the integration test of the prototype DSPMS. The server side shows the GUIs of Login, Main Menu, Forecast Power Demand, Power Demand Control Setting, Manage User, Manage EU, EU Real Time Monitor, Manage WMM, and WMM Real Time Monitor and Control. Also, the EU operation GUIs, including Information List, MEPT Display, Active Connect, and Alert Setting, are shown at the bottom of the left hand side of Fig. 9. Moreover, the physical diagram of MEPT, Power Distribution Box, WMM, Air Conditioner, and Equipment are shown at the bottom of Fig. 9 as well. Due to limited space, we only describe the results of two testing scenarios: “adopting EU to deploy power monitoring point” and “managing EU.”

6.2.1 Adopting EU to deploy the power monitoring point

Figure 10 demonstrates the steps for the power administrator to deploy a new power monitoring point for the PDB. First, the CT and PT signal lines of RS-232 communication interface and PDB are pulled out and fixed to the connection point of MEPT, as shown in Mark (1) in Fig. 10. The MEPT will convert the power signals into various power data. Then, the EU uses the RS-232 interface to send Modbus commands and retrieve power data. The Mark (2) in Fig. 10 is the RS-232 interface of the MEPT. Then, the user needs to input some information about the power monitoring point via the GUI of EU, including the name and password of the EU, the name and location of the monitored facility,

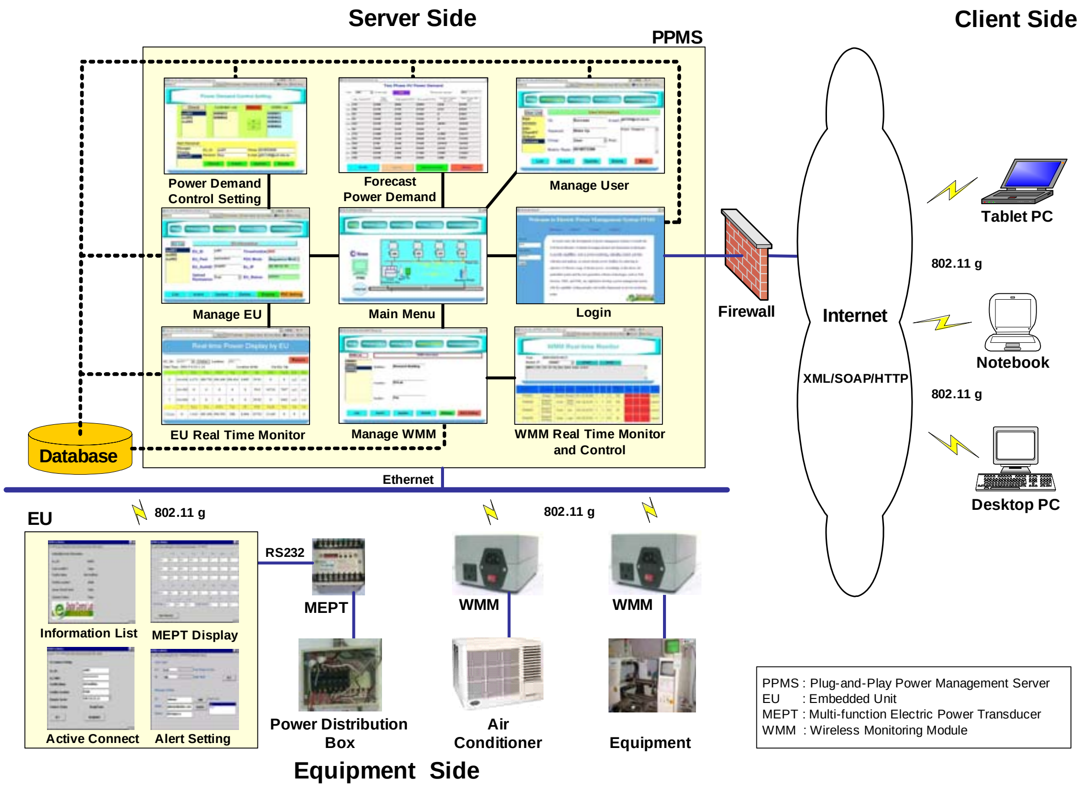


Fig. 9. Snapshot of the integration test of the prototype DSPMS.

and the IP address of the remote server. After the user presses the SET button, as marked (3) in the figure, EU will send the information to the MMS through WMM for authentication and authorization. If the TRANSMIT button is pressed, EU will send the acquired power information to the MMS, which will store the power data into the system's database. The above steps have demonstrated that the power monitoring system can easily bring power monitoring points into management and begin to timely monitor their power consumption.

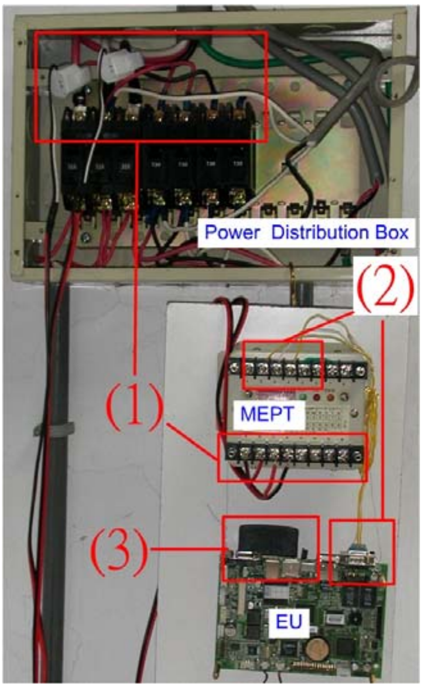
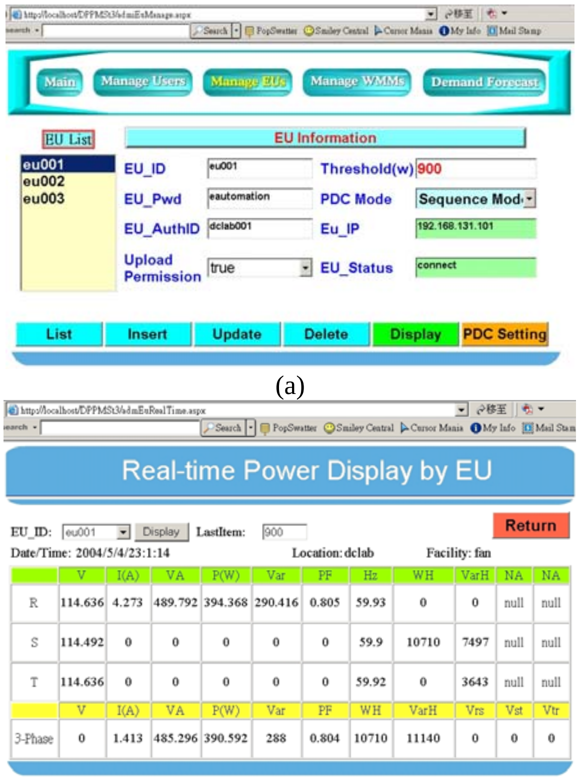


Fig. 10. Photo showing the deployed EU and MEPT for monitoring the power consumption of a power distribution box.

6.2.2 Managing EU

If a user login the system as the system administrator, the main GUI will show four buttons: Manage User, Manage EU, Manage WMM, and Forecast Power Consumption. When the Manage EU button is pressed, the GUI shown in Fig. 11(a) will pop up. The GUI displays the available EU list and the selected EU information, including the EU's name, password, and identification number, upload permission status, power threshold, PDC mode (either sequential or maximum loading), IP address of the EU, and the connection status between the EU and the MMS. The six buttons at the bottom of the GUI are to list all EUs, insert, update, delete, and display the selected EU's power information, as well as to do PDC setting.

If the Display button is pressed, the GUI as Figure 11(b) shows up. The GUI will display the power information regarding the power monitoring point selected by the Eu_ID value. The displayed information includes single-phase (R, S, T) and three-phase voltage (V), current (I), apparent power (VA), effective power (W), ineffective power (Var), power factor (PF), watts per hour (WH), varhour (VarH), and frequency (Hz).



(a)

(b)

Fig. 11. (a) EU management GUI, (b) EU real time monitoring screen.

Ⅶ. CONCLUSIONS

In this paper, we propose a framework of the demand-side power monitoring system (DSPMS) with mobile deployment consideration. Specifically, we adopt Web service technology to construct the system's communication infrastructure. Consequently, the proposed DSPMS is able to collect, exchange, integrate, and share power information easily over the Internet. Besides, we design a type of wireless power monitoring module which can facilitate the mobile deployment of distributed power monitoring points. Also, we develop a power monitoring server (PMS) which provides various Web services for power monitoring and management. In addition, we design an embedded unit which can operate standalone and actively acquire power data from the power monitoring points and then send the power information to the PMS. Finally, we construct a prototype of DSPMS and conduct integration tests. The testing results have validated the effectiveness of the proposed DSPMS and our designs. The research results can be a useful reference for industrial practitioners to develop power monitoring and management systems.

ACKNOWLEDGEMENTS

The authors would like to thank the National Science Council and Chinese Culture University, Taiwan (R.O.C.) for financially supporting this research under the contract NSC 98-2221-E-606-019 and the Flying Geese Program of Chinese Culture University, respectively.

REFERENCES

[1] Blonbou, R., “Very short-term wind power forecasting with neural networks and adaptive Bayesian learning,” Renewable Energy, Vol. 36, pp. 1118-1124, March 2011.
[2] Gang, Z., Tomiyama, H., Takada, H., and Ishihara, T., “A Generalized Framework for System-Wide Energy Savings in Hard Real-Time Embedded Systems,” in Embedded and Ubiquitous Computing, 2008. EUC '08. IEEE/IFIP International Conference on, pp. 206-213, 2008.
[3] Bin, H., Dazong, Z., and Tao, Y., “Energy consumption analysis and energy management strategy for sensor node,” in Information and Automation, 2008. ICIA 2008. International Conference on, pp. 211-214, 2008.
[4] Nicholson, K. E., Doughty, R. L., Mane, L., Miranda, G., and Pulaski, F. D., “Cost effective power management systems,” Industry Applications Magazine, IEEE, Vol. 6, pp. 23-33, 2000.
[5] Seki, T., Kubota, K., Tsuchiya, T., Tamura, S., Watanabe, H., and Tanaka, T., “Power systems information delivering system using Internet technology,” in Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES, Vol. 1, pp. 12-17, 2002.
[6] Balen, H., Elenko, M., Jones, J., and Palumbo, G., “Distributed Object Architectures with CORBA (SIGS: Managing Object Technology)”, 2000.
[7] Leinmiller, M. W., “Total power management for the cement industry,” in Cement Industry Technical Conference, 2003. Conference Record. IEEE-IAS/PCA 2003, pp. 97-107, 2003.
[8] Xiaobing, Q. and Wimmer, W., “Applying object-orientation and component technology to architecture design of power system monitoring,” in Power System Technology, 2000. Proceedings. PowerCon 2000. International Conference on, Vol.2, pp. 589-594, 2000.
[9] Sessions, R., COM and DCOM: Microsoft's vision for distributed objects: John Wiley & Sons, Inc., 1998.
[10] Forth, B. and Tobin, T., “Right power, right price [enterprise energy management systems],” Computer Applications in Power, IEEE, Vol. 15, pp. 22-27, 2002.
[11] Chik, W. A. W., Yusof, M. I., and Rahman, T.K.A., “Web based application for energy management system in UiTM,” 2002 Student Conference on Research and Development (SCOReD 2002), pp. 444-447, 2002.
[12] Sarkinen, J. and Lundin, O., “Integrate Internet solutions into your energy management network,” in Telecommunications Energy Conference, 1998. INTELEC. Twentieth International, pp. 623-629, 1998.
[13] Wang, C.-M., “Development of a Electric Power Management System Architecture with Mobile Deployment Capabilities,” Master Thesis, Chung Cheng Institute of Technology, National Defense University, Tao-Yuan, Taiwan, 2003.
[14] Webservices Web Site: http://www.webservices.org/
[15] Kumar, C. M., Sindhwani, M., and Srikanthan, T., “Profile-based technique for Dynamic Power Management in embedded

systems," in Electronic Design, 2008. ICED 2008. International Conference on, pp. 1-6, 2008.

[16] Ibrahim, H., Ghandour, M., Dimitrova, M., Ilinca, A., and Perron, J., "Integration of Wind Energy into Electricity Systems: Technical Challenges and Actual Solutions," Energy Procedia, Vol. 6, pp. 815-824, 2011.

[17] Ituero, P., Ayala, J. L., and Lopez-Vallejo, M., "A Nanowatt Smart Temperature Sensor for Dynamic Thermal Management," Sensors Journal, IEEE, Vol. 8, pp. 2036-2043, 2008.

[18] Li, Y., Lence, B. J., and Calisal, S. M., "An integrated model for estimating energy cost of a tidal current turbine farm," Energy Conversion and Management, Vol. 52, pp. 1677–1687, 2011.

[19] Roy, J. and Ramanujan, A., "Understanding Web services," IT Professional, Vol. 3, pp. 69-73, 2001.

[20] SOAP Specifications, W3C. http://www.w3.org/TR/soap/

[21] Mahdoum, A., Hamimed, L., Louzri, M., and Saadaoui, M., "Data coding methods for low-power aided design of submicron interconnects," in Faible Tension Faible Consommation (FTFC), pp. 51-54, 2011.

[22] Cattell, R., Inscore, J., and Partners, E., J2EE Technology in Practice: Building Business Applications with the Java 2 Platform, Pearson Education, 2001.

[23] Extensible Markup Language (XML), W3C. http://www.w3.org/XML

[24] Jepsen T., "SOAP cleans up interoperability problems on the Web," IT Professional, Vol. 3, pp. 52-55, 2001.

[25] OMG Web Site. http://www.omg.org

[26] Chang, L.-Y., "The Study of Multi-Medium Electrical Energy Management for Academic Distribution Systems," Master Thesis, Feng Chia University, Seatwen, Taichung, Taiwan, 2001.

[27] Lee, T.-Y. and Chen, N., "Optimal utility contracts for time-of-use rates industrial customers," Journal of the Chinese Institute of Electrical Engineering, Vol. 1, pp. 247-257, 1994.

[28] Chen, P.-Y., "A Power Management System with the Capabilities of Plug-and-Play," Master Thesis, Chung Chen Institute of Technology, National Defense University, Tao-Yuan, Taiwan, 2004.

[29] Hung, M.-H., Chen, K.-Y., and Lin, S.-S, "A Web-Services-based Remote Monitoring and Control System Architecture with the Capability of Protecting Appliance Safety," Journal of Chung Cheng Institute of Technology, Vol. 34, No. 1, pp. 385-402, 2005.

[30] Abdel-Aal, R. E., "Short-term hourly load forecasting using abductive networks," Power Systems, IEEE Transactions on, Vol. 19, pp. 164-173, 2004.

[31] ASPonline Web Services Center. http://www.asponline.com.tw/wsps/desktop default.aspx

[32] Fowler, M. and Scott, K., UML Distilled: A Brief Guide to the Standard Object Modeling Language, 2 ed.: Addison-Wesley, 1999.

[33] Chi Tai Electronic Corp. (October 2, 2011). Web Site: http://www.chitai.com.tw/

[34] ADVANTECH Web Site. http://www.advantech.com.tw/

[35] ICPDAS Web Site. http://www.icpdas.com.tw/

[36] Kwang-Hwa Web Site. http://www.cpu.com.tw/kh/index.html
Microsoft Web Site: http://www.microsoft.com/