Development of Customer Oriented Load Management Software for Savings on Utility Bills in the Electricity Market

Koo-Hyung Chung†, Chan-Joo Lee*, Jin-Ho Kim, Don Hur***, Balho H. Kim**** and Jong-Bae Park***

Abstract - For electricity markets to function in a truly competitive and efficient manner, it is not enough to focus solely on improving the efficiencies of power supply. To recognize price-responsive load as a reliability resource, the customer must be provided with price signals and an instrument to respond to these signals, preferably automatically. This paper attempts to develop the Windows-based load management system in competitive electricity markets, allowing the user to monitor the current energy consumption or billing information, to analyze the historical data, and to implement the consumption strategy for cost savings with nine possible scenarios adopted. Finally, this modeling framework will serve as a template containing the basic concepts that any load management system should address.

Keywords: Competitive electricity market, Consumption strategy, Demand scheduling, Electric charges savings, Windows-based load management software

1. Introduction

Dramatic changes are now taking place in the structure of electric power sectors around the world. These changes are aimed at the expansion of decentralized competition in the supply of generation services in a positive way that preserves the operating and investment efficiencies while mitigating the significant costs that the institution of regulated monopoly has created [1]. Ideally, the restructured electricity marketplace consists of not a few technical and business parties independently making decisions such as power generators (GENCOs), transmission providers (TRANSCOs), distribution companies (DISCOs), retail companies (RETAILCOs), and customers [2]. With the introduction of restructuring into the electric power industry, the price of electricity has become a particularly challenging problem because of the properties of electricity. By far the most distinct feature of electricity price is the potential for its volatility [3]. On the demand side, customers articulate their willingness to pay for electricity, which includes their willingness to contract or expand their uses at different times as price varies. This unpredictable environment results in greater uncertainty in both consumers' costs and electricity service providers' expected profits. In practice, consumers may be responsible for higher electric rates in the absence of enough information related to their own historical consumption patterns and well-organized strategies. It stands to reason that an effective load management mechanism is required to intelligently respond to more volatile electricity prices.

This paper presents the Windows-based load management system (shortly, LMS) in competitive electricity markets. This software is intended to be a tool that will provide market participants, policy-makers, and permitting authorities with the information necessary to make informed decisions when constructing the energy consumption scheduling and the best behavioral strategy for cost savings. It should help reduce the consumers' fiscal burden while calling on them to actively respond to time-of-use rates for an arbitrary time period.

The Windows-based LMS we propose here offers five major enhancements to traditional load management [4] so that our methodology can be sufficiently general in application:

- Efficient database design to facilitate an enormous amount of data exchange
- Description of historical electricity consumption patterns and electric charges

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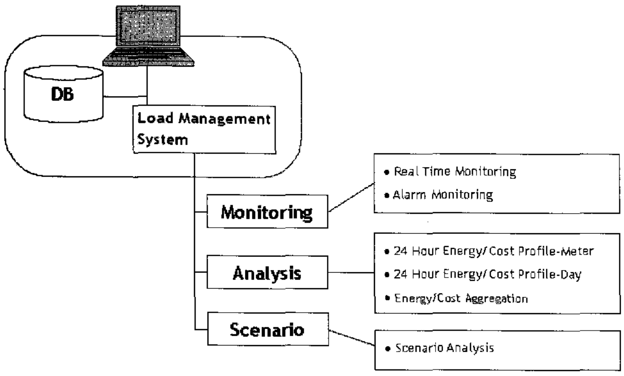

Fig. 1. Function structures of Windows-based load management system

- Real-time monitoring for energy usage and pertinent billing
- Various "What-if" scenarios of load management
- Regular update on electricity price information

This Windows-based program was essentially written in the Java programming language and the database was also implemented using Microsoft Corp.'s Access software for more reliable, flexible, rapid, and efficient data processing.

2. Organization of the Windows-Based Load Management System

2.1 Overview of Windows-Based Load Management

As shown in Fig. 1, the Windows-based LMS has two fundamental components: One is the part of the database used to manage large amounts of data collected from individual consumers' metering facilities [5] and the other is a graphical user interface used to vividly display a meaningful output through direct manipulation of appropriate inputs. Fig. 1 depicts practical functions of the Windows-based LMS. The 'real-time monitoring and alerting' technologies will track the current energy usage and corresponding billing information, and the 'energy/cost analysis' function will in turn indicate energy consumption patterns as well as the payment records in the past. Additionally, the 'scenario analysis' function will enable the users to reduce their energy uses and save on their utility bills by making the most out of the experience.

2.2 Classes of Windows-Based Load Management

Fig. 2 presents the overall architecture for the Windows-based LMS. This diagram is generally divided into three chief groups: 'monitoring', 'energy/cost analysis', and 'scenario analysis'. In Fig. 3, the 'real-time monitoring'

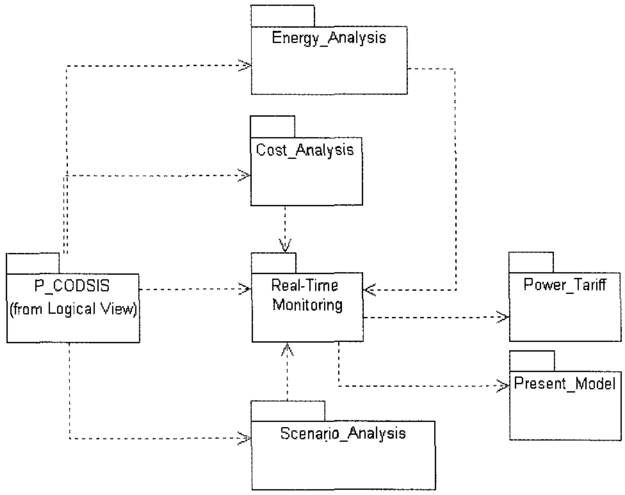

Fig. 2. Schematic of Windows-based load management system

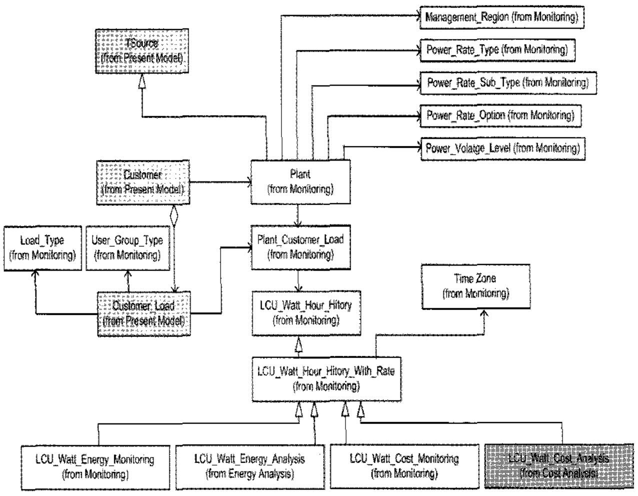

Fig. 3. Class diagram of 'real-time monitoring' package

package is the set of classes that may need to monitor a one-hour record for energy usage and electric charges in real-time. The 'Plant' class is intimately linked to the user's basic configuration. The 'Power_Rate_Type' class is classified into industrial, residential, and educational types. The 'Power_Rate_Sub_Type' class means the profiles of load while 'Power_Rate_Option' and 'Power_Voltage_Level' are respectively affected by the options of electricity charges according to the usages and voltage levels of load. The 'Plant_Customer_Load' class is used to register all loads in a plant. Notably, the 'LCU_Watt_Hour_History' class collects detailed end-use metering data at 30 minute intervals and the 'LCU_Watt_Hour_History_With_Rate' class calculates the true electricity costs based on the actual measures. 'Energy analysis and cost analysis' packages are the set of classes that are required to make a quantitative analysis of historical statistics associated with electricity consumption and bills for a considerable span of time. The 'Scenario analysis' package is the set of classes that make

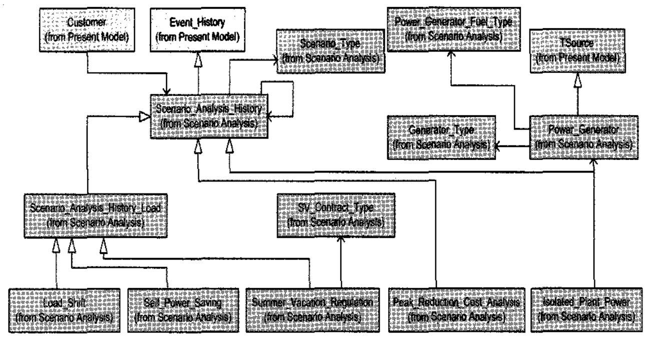

Fig. 4. Class diagram of 'scenario analysis' package

it possible to provide the user with the simulations on optimal consumption schedules by adopting comprehensive energy efficiency portfolios, which is illustrated in Fig. 4. 'Load_Shift', 'Self_Power_Saving', 'Summer_ Vacation_Regulation', 'Peak_Reduction_Cost_Analysis', and 'Isolated_Plant_ Power' are general-purpose classes to implement system wide direct load management programs that will provide a solid foundation for reducing peak electrical demand and provide their customers new choices for reducing electricity costs. In Korea, the rates applicable to electric services are subject to not simply profiles but voltage levels, and the two-part tariff is officially determined by the sum of capacity [kW] rates and electric energy usage [kWh] rates. The 'Power tariff' package serves to make up a table for the electric rates in Korea. The 'Present model' package plays a critical role in a buffer against user's query, thus leading to the real-time operation of the Windows-based LMS without any troubles.

3. The Function of the Windows-Based Load Management System

3.1 Monitoring

This section of the paper presents a brief overview of established technologies that can be used for monitoring end-use energy consumption and billing information on a particular day. Through this monitoring function, the users can accurately identify the load in small commercial buildings, which has tremendous influence on total energy consumption and billing. On the other hand, the unusual load is duly found by detecting sudden changes in energy consumption. Moreover, a dummy load may be assigned by grouping several loads of great interest.

To obtain monitoring results, the user should type in seamless information with respect to a plant and some loads adjunct to this plant, respectively, In accordance with this activity, the electric rates applied to this plant are revealed and electric charges of individual loads are accordingly imposed. The energy consumption at every load is posted onto the screen of the LMS as well. The Windows-based LMS collects energy consumption at periodic intervals (typically, 30 minutes to one hour), but this time interval can be adjusted according to the reading interval of on-site equipment.

The electric charges (U_c) of each load are mathematically derived as follows:

$$U_c = \sum_{t=t_0}^{t_f} (P_t \cdot R_t) \tag{1}$$

where,
t_0: initial reading time
t_f: final reading time
P_t: electricity consumption measured at fixed time interval t
R_t: electric rates applied at fixed time interval t.

Furthermore, total electric charges (U_t) in a whole plant are estimated by:

$$U_t = \sum_{i=1}^{N} \sum_{t=t_0}^{t_f} (P_{it} \cdot R_t) \tag{2}$$

where,
P_{it}: electricity consumption of load i measured at fixed time interval t
N: total number of loads in a whole plant.

Alternatively, the monitoring results are being offered in text format or in graph form for the user's convenience.

3.2 Energy/Cost analysis

The energy/cost analysis functions demonstrate the historical trend of energy consumption and corresponding payment of a specified load. Keep in mind that the user should input the information separately since the energy analysis and the cost analysis are entirely independent functions. The Windows-based LMS sponsors three types of analysis to allow for more customized and interactive services.

3.2.1 24-Hour Energy/Cost Profile-Point

As outlined previously, a plant has a host of loads and consumer's billing accounts for the energy consumption of these loads. In those cases where only a few loads have a marked impact on a consumer's bill, the user is greatly concerned about how much is the demand for electricity at these loads during a particular period. Perhaps, the user can conduct a comparative analysis on the past and current energy consumption or billing of a specific load through the '24-hour energy/cost profile-point' command.

3.2.2 24-Hour Energy/Cost Profile-Day

If the total energy consumption increased one day, the user would desire to capture how much each load or specific loads contribute to the total energy consumption of that day. Given that energy consumption of each load happens at a particular time, the user will have to make a decision on whether the peak demand exceeds the quantity of contracts. The analysis of these events is fully realized by the '24-hour energy/cost profile-day' command. In other words, the Windows-based LMS can analyze the energy consumption or billing of loads that the user selected on a particular day.

3.2.3 Energy/Cost Aggregation

The consumer's energy consumption or billing is vastly different day after day due to the changes of certain externalities such as weather, temperature, and humidity. The consumer's payment is expected to be higher in step according to their energy consumption. Therefore, the consumer would like to know a substantial portion of total electricity usage by each load on a given day so that the control of each load can be available. With the 'energy/cost aggregation' command, the user can discover the daily cumulative energy consumption and billing of specific loads.

3.3 Scenario Analysis

When the retail price of a kilowatt rises during periods of peak demand, electricity customers reduce their consumption in response to market prices. Rate reduction is a cornerstone of the LMS. It appears that LMS programs allow energy customers to participate in reducing usage during peak hours in exchange for a favorable rate class or bill rebate. As program structures and technologies vary, advances in communications and program development have helped to make the LMS one of the responsible choices for any utility seeking to achieve the best balance of portfolio resources.

What-if scenarios allow the user to create and save the most versatile and rapid-responding programs by comparing cost savings against multiple available programs in this Windows-based LMS. After running the What-if scenario, the rate-payers can make all-out efforts to excavate excellent alternatives to reduce rates and costs.

This Windows-based LMS program supports nine scenarios that will be later discussed in detail. The Scenario analysis function will be executed by choosing one or more scenarios and the simulation cases can be stored for future use.

3.3.1 Load Shift

Customers must be able to respond to changing supply conditions by modifying their demand for electricity. To the extent that this demand is flexible for an individual customer, he or she will buy less electricity when it is more expensive and shift demand to periods when electricity is cheaper [6]. However, it is worthy of note that working with customers to shift demand to off-peak times is not necessarily an optimal consumption schedule since a great many constraints should be taken into account. The user can determine whether the hypothetical scenario is improved in terms of cost savings by calculating the following formula:

$$AR = BR - \sum_{s=st_0}^{st_S}(P_s \cdot R_s) + \sum_{e=et_0}^{et_E}(P_e \cdot R_e) \tag{3}$$

where,
AR: electric rates after the load shift scenario is applied
BR: electric rates before the load shift scenario is applied
s: index of time when the load is moved from
e: index of time when the load is moved to
P: energy consumption
R: electric usage rates per each kWh consumed.

3.3.2 Peak Demand Reduction

This Windows-based LMS reflects the actual reduction in annual peak load (measured in kilowatts) achieved by consumers that participate in the peak demand reduction program during crunch times, especially during hot summer weekday afternoons [7]. Today, the electric rates in Korea are roughly composed of the capacity rates and the usage rates. The basic capacity rates are computed by the product of the consumer's peak demand times and fixed unit rates. Owing to this peak demand reduction program, the user will benefit from shaking off both the capacity rates and the energy usage rates.

3.3.3 Real-Time Electricity Pricing

In preparing for the day as if electricity systems were to transfer from billing large commercial and industrial customers under the simple retail pricing structures currently in use to billing them under a time sensitive pricing structure, it seems apparent that the user would compare the energy usage rates under the different tariffs via the real-time electricity pricing program.

3.3.4 Bilateral Contract Tariff

Pool-type power dispatch and bilateral contract transactions invariably exist at the same time in any modern deregulated electricity supply system. In a bilateral contract setting, a buyer and a seller agree on a certain amount to be transferred through the network at a certain fixed price to hedge against the risk of daily price volatility or even price spikes of the electricity market. The user can draw a clear comparison between the hourly energy usage rates under each pricing mechanism by looking at a chart involved with the bilateral contract tariff program.

3.3.5 Alternative Power Suppliers

Customer choice offers the expanding electric utility industry the opportunity to choose the power suppliers in a competitive environment. As straightforward as it should be, a business can select its power suppliers based on their quality of service, reliability, load management incentives, and current and future rate structures. Using the alternative power suppliers program, seeking for an economical power supplier is crucial, especially if a consumer's operation is energy intensive. Even if it isn't, the power supplier can still have a major impact on production efficiency and profitability.

3.3.6 Voluntary Load Curtailment

If an appeal has been made by the Korea Electric Power Corporation through appropriate news media or by direct appeal to the customer for voluntary electric energy reduction because of an impending capacity shortage, the utility will reward those customers who reduce their electrical consumption for the period of the requested voluntary curtailment. An incentive payment (*IP*) will be made to the customer or applied to the customer's account and determined by:

$$IP = \sum_{s=st_0}^{st_s} \left(P_s \cdot Rates \cdot N\right) \tag{4}$$

where,

P_s: amount of interruptible demand for any period of continuous interruption

Rates: utility's payment per kilowatt that is cut off

N: total number of load curtailment activities undertaken on a voluntary basis.

But in real life, the customer's business can receive substantial compensation for reducing electrical load or running back-up generators during periods of peak demand for electricity.

3.3.7 Regulation of Schedules for Summer Breaks

The users can take advantage of the regulation of schedules for a summer vacation program designed to help them in cutting the cost of their bills. If the customers sign contracts with the Korea Electric Power Corporation to reduce their usage by as much as the contracted amount during the summer vacation, they will be eligible for a rebate on their electricity accounts. There are two different rebate rates throughout the summer season, depending on the month (July or August). The rebate (*RB*) payments will appear on the electricity bill as follows:

$$RB = P_{adj} \times Rates \times d \tag{5}$$

where,

P_{adj}: demand adjustments, i.e., peak demand minus the kW demand as specified in the contract that the customer expects to reduce during the summer vacation

Rates: electric rates that apply to the residential, commer-cial, and industrial customers

d: total period of contract for this program.

3.3.8 Direct Load Control

Direct load control is defined as load that can be curtailed directly by a utility or dispatcher, without intervention of an operator at the end-use customer premises [8]. The direct load control program deals with the incentives paid to the customers participating in this program, or the cost-effectiveness of cycling some consumer appliances such as air conditioning and water heaters to reduce their load during the peak hours, and shifting some of the water pumping system load from peak to off-peak hours. Consequently, this program can be, at the user's sole discretion, combined with the load shift program or self-generation program.

3.3.9 Self-Generation

The commercial or industrial customers can in part lower the costs of electricity by operating their privately-owned generating facilities, not by purchasing it through the wholesale marketplace. The Windows-based LMS has the self-generation scenario and calculates the costs (*SC*) due to the self-generation given by:

$$SC = \sum_{j=1}^{m} \sum_{s=st_0}^{st_s} \left(P_{Gj} \cdot C_{jf}\right) \tag{6}$$

where,

P_{Gf}: real power generation of the privately-owned unit j

C_{jf}: fuel costs of the privately-owned unit j.

The user can put in the input regarding the fuel type, amount of self-generation, and a date when this program comes into effect, thereby focusing on achieving a user-centered design or usability.

4. Illustrative Example

Suppose that a licensed power plant has 19 load points. In particular, loads 1, 3, and 7 are grouped to create a dummy load. As of August 21, 2006, the hourly energy consumption in these loads is monitored in Fig. 5. From the results of surveillance, the peak demand typically occurs on a day between the hours of 3 and 5 p.m. The tabular form in Fig. 5 indicates the amount of electricity used at each load, usually integrated over one clock hour. As shown in Fig. 6, historical electricity consumption trends at each load during a specified period of time are retrieved by the 'energy aggregation' analysis. When the users want to sketch out the electricity consumption patterns of some loads on July 28, 2001, they should perform the '24-hour energy profile-day' command as depicted in Fig. 7. In case that the user's greatest concern is to demonstrate the energy usage of load-14 by date since this load strongly influences the total electricity consumption, the user will use the '24-hour energy profile-point' command in Fig. 8. In a similar fashion, the user can review the costs of electricity paid to each load by cost analysis.

At this stage, the scenario analysis function of load shift program and voluntary load curtailment program in the Windows-based LMS will be discussed. One can see from Fig. 9 that the customer might shift 1,000 kW of load-3 at the time of system peak (2 to 4 p.m.) to lower-cost hours (5:30 to 7:30 a.m.) on July 28, 2001, producing collective benefits in that the demand is redistributed away from the current peaks and in return this scenario has the potential for saving ₩222,800 expressed in Korean currency, per day.

Next, the key assumption is that a voluntary load curtail program is offered by the Korea Electric Power Corporation to this business that can willingly reduce their peak load usage by 1,000 kW during peak times (2 to 4 p.m.) on July 22 and July 25, 2001. In addition to saving money through reduced power consumption during peak demand periods, this load curtailment program rewards customers a guaranteed $ per kWh of pre-negotiated load reduction. Obviously, this plant can save a total of ₩1,393,100 by participating in this program as observed in Fig. 10.

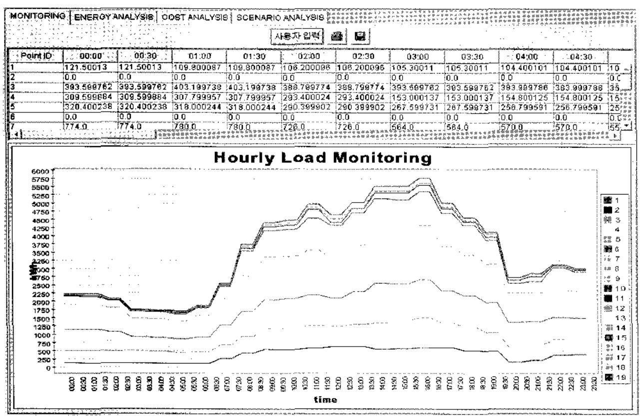

Fig. 5. Real-time monitoring result of hourly energy consumption

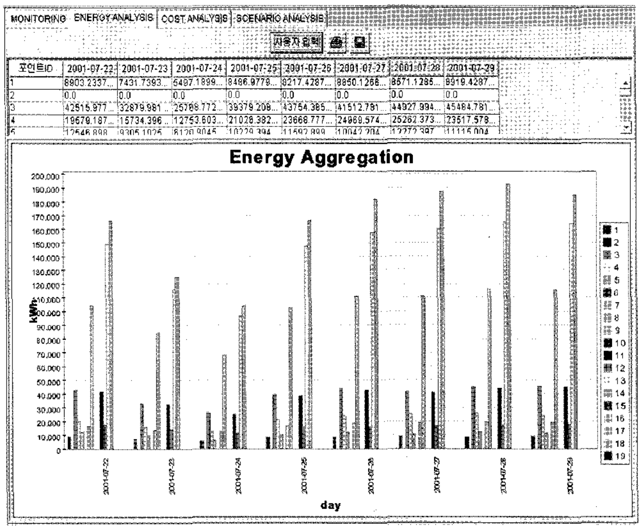

Fig. 6. Energy aggregation result of historical energy consumption

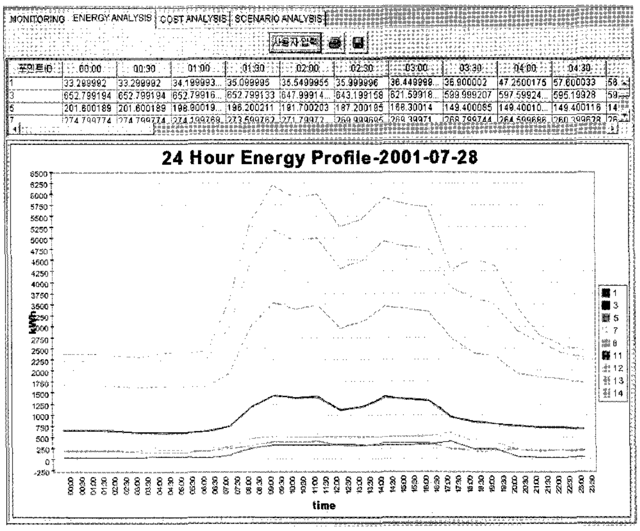

Fig. 7. Historical energy consumption trends on a particular day

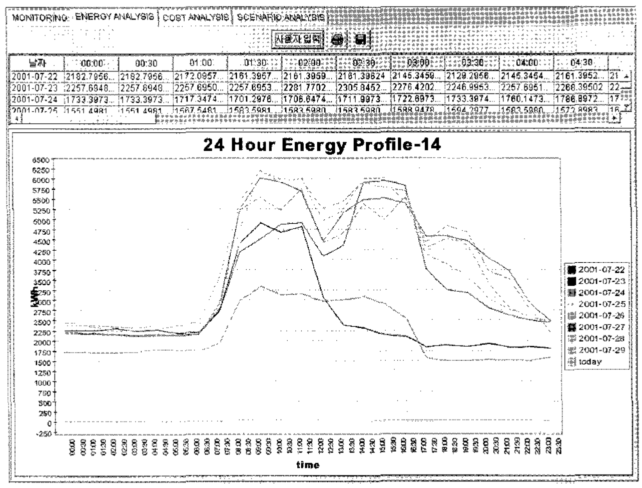

Fig. 8. Historical energy consumption trends of a specific load by date

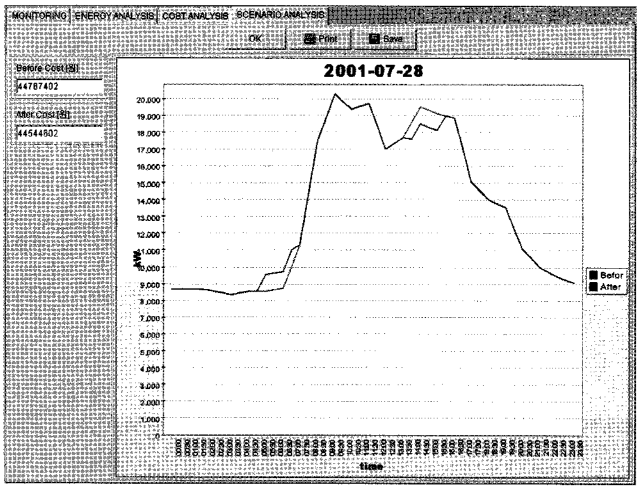

Fig. 9. Cost savings achieved by a load shift scenario

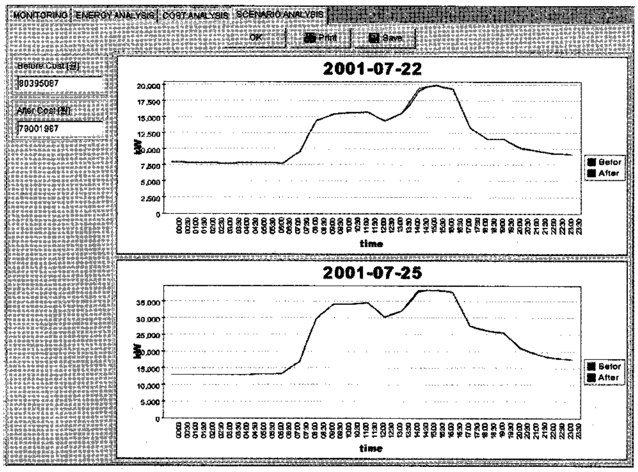

Fig. 10. Cost savings achieved by a voluntary load curtailment scenario

5. Concluding Remarks

As we have seen, the main purpose of this paper has been to explore the Windows-based LMS that may encourage at least some customers to see and respond to time-varying electricity prices by reducing demand when prices are high or by increasing demand when prices are low. From the above, additional economic benefit enjoyed by all electricity consumers is a consequence of the fact that reduced consumption when prices are high may contribute to keeping the cost of electricity down. In sum, the Windows-based LMS was developed to rapidly screen the energy consumption with meter data collection, to have access to historical electricity usage and electricity bills, and to study the acceptable effects of ongoing load management programs on significant power cost savings.

To a certain extent, the success of the Windows-based LMS is attributed to fast and reliable data communications between each metering device and this web-based software, and offers wide applications suitable for the forthcoming drastic changes in the environment of electricity markets.

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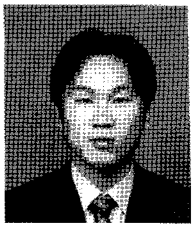

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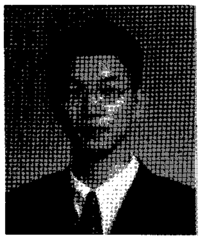

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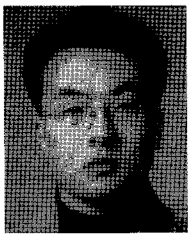

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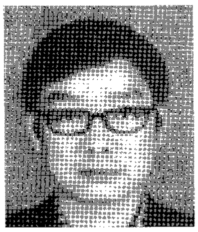

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