Microprocessor-Based Electrical Energy Cost and Consumption Monitors *

Barney L. Capehart
Department of Industrial and Systems Engineering
University of Florida
Gainesville, FL 32611

Sanford V. Berg
Department of Economics
Director, Public Utilities Research Center
University of Florida
Gaineville, FL 32611

Robert L. Sullivan
Department of Electrical Engineering
University of Florida
Gainesville, FL 32611

ABSTRACT

Digital cost and consumption monitoring devices are recent products which have found a growing market in response to greatly increased electric rates and the appearance of complex rate structures such as those based on time of use. These monitors can aid customers to reduce their consumption and cost of electrical energy. This paper discusses the capabilities and limitations of present microprocessor-based digital energy monitors, describes results of the available utility monitor tests, presents some monitor design considerations, and discusses a combined function product to perform the general tasks of energy metering, monitoring, direct load control, and management of energy cost and consumption.

INTRODUCTION

Rapidly escalating electricity prices and the desire to conserve energy and scarce petroleum fuels have resulted in new electric rate structures which consider time-of-use, demand levels and increasing cost with increased consumption [1]. Previous declining block rates have been replaced by flat rates in almost every state, and the move to more complex energy conservation rates is following close behind. Technological advances, increased electric energy costs, and the emergence of new rate structures have created a market for digital cost and consumption monitors using modern microprocessor technology. The primary function of such monitors is to display the quantity and cost of energy used by a building, residence or individual energy consuming device, thereby helping customers making cost-effective decisions to conserve home energy and save money. Besides being relatively expensive, available electrical energy cost and consumption monitoring devices are generally quite limited in the functions they perform. However, the state of the art in microprocessor technology is such that highly sophisticated monitoring devices which perform a wide variety of tasks could be available at relatively low cost.

The purpose of this paper is to describe the functions desired for residential digital cost and consumption monitors, to provide a survey and evaluation of devices currently being marketed and performance tested, and to discuss what will likely comprise the future technology for such monitors. The necessary cost monitor functions are identified in the context of potential innovative electric rate structures. In addition, manufacturer's data are presented for cost and performance functions of electrical energy monitors that are now available for purchase. The functions of existing devices are examined using human engineering principles. Finally, the design of highly flexible cost monitors is discussed in terms of a proposed integrated function device which can perform general tasks of energy metering, monitoring, direct load control, and energy management.

ELECTRIC RATE STRUCTURES

A knowledge of electric rate structures is necessary to design and evaluate digital cost monitors, since a given rate structure defines the relationship between time patterns of energy consumption and the cost to customers. Past rate structures facing residential customers have been rather simple, while prospective rates take a number of dimensions into account, making them fairly complex. In the wake of the energy crisis, federal policies such as those embodied in the Public Utility Regulatory Policy Act have served as a catalyst for the exploration of rate structures which provide more efficient price signals to customers [2].

The basic elements in any electric rate structure are 1) the customer charge, 2) the KWH energy charge, 3) the instantaneous KW demand charge, and 4) the fuel adjustment charge [3]. The customer charge is a fixed cost which is independent of the level of consumption, and usually reflects the utility's cost of reading the customer's meter and mailing out a bill. Typical customer costs are usually in the range of three to seven dollars per month. The energy charge is a fixed cost per KWH which can vary widely depending on how much of the fuel cost is included as a base value. Typical costs per KWH are two to ten cents. A typical component for industrial and large commercial customers is a demand charge: a fixed cost per KW of customer demand. Demand values are always given for an averaging period, usually 15, 30, or 60 minute intervals. Sometimes a ratchet is in effect, so the bill reflects the maximum KW for a season or year. Typical costs are \$3 - \$7 per KW, on a monthly basis. Finally, the fuel adjustment is a cost that is apportioned over the KWH consumed, and is thus a cost per KWH which varies, depending on the particular formula used. Many utilities continually adjust their base KWH charges in order to minimize the size of the fuel adjustment; others leave their base cost per KWH at a low level for extended periods, with a substantial adjustment reflecting changes in the mix of generating units and/or the cost of fuel. The four factors, along with time-of-use, provide the basis for all electric rate structures commonly used today [4]. Some typical rate structures include:

- •FLAT RATES
- •BLOCK RATES
  - DECLINING
  - INVERTED
- •DEMAND RATES
- •TIME-OF-DAY-RATES
- •LIFELINE RATES

Probably the most common structure for residential customers is a flat rate where the energy cost is a constant value per KWH, independent of the level of consumption. In the past, a declining block rate was very common, so

* This paper is based on work funded by the United States Department of Energy and the Florida Public Service Commission and performed through the Public Utilities Research Center at the University of Florida. The views and opinions of authors expressed herein do not necessarily state or reflect those of sponsoring organizations.

the cost per KWH declined in a series of steps (or blocks) to reflect a lower cost with greater consumption levels. Increasingly, we are now seeing an inverted block rate where the price per KWH increases in steps or blocks, perhaps reflecting marginal production costs which are greater than average KWH costs. A typical rate structure for such factors in residential consumption is illustrated for the City of Gainesville (Florida) Regional Utilities [5]:

City of Gainesville Standard Residential Rate

Customer Charge	$4.35 per month
Energy Charge	
First 750 KWH	$0.06 per KWH
All KWH over 750	$0.0636 per KWH
Plus Fuel Adjustment	Cost varies each month

A lifeline rate is an example of an inverted block rate where an initial quantity of KWH is priced substantially lower than subsequent KWH's, even below cost in some cases. The idea behind a lifeline rate is that all customers have some minimum requirements for electricity to sustain necessary services such as lighting and refrigeration, and that the cost of this amount of electricity should be kept artificially low for social ratemaking (income redistribution purposes).

So far in this discussion of rates, time of consumption has not been a factor. However, utilities with extreme peaks due to electric heating and air conditioning have begun to recognize time-of-use as a determinant of the cost of electricity [6]. Utility costs of producing power at peak load times can vary from a factor of two to ten quite easily, especially if base load plants must be supplemented with expensive oil fired gas turbines at the time of high load. In addition, capacity expansion is driven by peak demands. These factors are beginning to be reflected in the price to customers through a time-of-day or time-of-use rate structure. Here, the price of electricity is given at least two values, one for on-peak times and another for off-peak times. A mid-range (or shoulder) period may be involved, in addition to seasonal factors. An example is the Time-of-Use Rate for the City of Gainesville [7]:

City of Gainesville Time-of-Use Rate
Customer charge..........$7.33 per month
Off-peak energy..........$0.0429 per KWH
On-peak energy...........$0.1082 per KWH
On-peak hours are defined as follows:
Summer: May 15 to October 15
Noon to 9 pm
Winter: January 2 to February 28,
excluding weekends 7-11 AM & 6-10 PM
All other times are considered off-peak, and the lower charge applies.

One of the problems with fixed time-of-use rates and rating periods is that the actual periods of high cost for the utility depend on the weather and other utility status factors. Introducing the idea of variable peak periods leads to a flexible time-of-use rate, where the utility must send out a message to a customer to inform them that peak load rates are in effect. This variable time price signal has some obvious economic benefits, but it requires a costly communication link from the utility to each customer and pushes some of the risk (associated with reliability problems and fluctuating prices) onto customers.

Very few residential customers are faced with demand rates, although recently the Arizona Public Service Company implemented a mandatory demand rate for all new residential customers [8]. Their rate is based on a 60 minute averaged KW value and is charged each month at a cost of $6.80 per KW in the Winter (November through April) and $9.11 per KW in the Summer (May through October). Time of day could also be applied to a demand rate since consumption at times other than those of the utility's peak load is not as costly.

Another form of demand rates (via fuses), long available in Europe, is now being used by Southern California Edison Company [9]. Under their "Demand Subscription Service," a customer has a special meter with a radio controlled demand limiter which the utility activates during peak load times. If the customer's demand exceeds the value of demand contracted for, the limiter disconnects electric service. The customer must then turn the appliances off to reduce demand, and then go to the meter and reset the demand limiter. If the customer continually exceeds the present demand limit they can contract with the utility for an increased limit. Such a device has higher metering costs than the European fuse limits, but they are better able to cut back demand during key periods, without limiting economic consumption.

DESIRED MONITORING FUNCTIONS

The advent of more complicated rate structures has spurred interest in feedback devices which provide information to electricity users. The basic purpose for any digital monitor is to display energy cost and energy consumption data. The simplest digital cost monitors display a single cost number which is proportional to the total KWH consumption or consumption rate, and must be set by the manufacturer or by the customer for a specific cost per KWH. The simplest digital consumption monitors display the accumulated KWH used since the beginning of a billing period. The most comprehensive monitors are ones which display a variety of cost and consumption data, and which can reflect time-of-use and demand rates.

Additional data can be computed and displayed in order to provide information on projected costs and consumption for the next hour, day, and billing period. Here, future costs and consumption are estimated based on the current rate of consumption, and are extrapolated for the desired period of time. Also, summary data can be shown for the energy used and its cost for the current day or billing cycle. Stored data on last month's energy consumption and cost could also be displayed, as well as the current price per KWH, the current date and time, and a target KWH and target cost for the current month.

With an internal construction of electronic components such as a microprocessor chip, read only memory chips and random access memory chips, a digital monitor could offer a wide range of functions which could easily be expanded. As more complex rates are introduced, and as more customers become aware of the benefits of energy monitors, these devices will be expected to perform more and more sophisticated functions. Customer demand for these monitors should also lower production costs, given economies of scale in manufacturing and the learning curve for producers. Like personal computers, digital energy monitors should become more powerful and less costly with each year of maturity.

HUMAN ENGINEERING CONSIDERATIONS

The use of a digital energy monitor is intended to alter a customer's behavior by providing immediate feedback on the amount or cost of energy consumed [10]. Recently, Feldman discussed the psychological factors involved in altering customer behavior with energy cost and consumption information [11]. Reinforcement techniques and the form of information feedback are particularly important, with the reinforcement immediate if it is to be effective. In addition, setting a goal for an energy cost or consumption reduction is necessary in achieving the maximum behavioral change for a customer. The location of the energy monitor is also very important in that it must be placed where the display is prominent, thus showing the immediate effects of customer energy consumption decisions.

Since the optimum form of cost or consumption feedback to customers is not generally known, the best energy monitor design may be one that provides a range of displays which consist of both accumulated quantities and rate of use quantities. The display of accumulated cost and KWH, and the display of cost per hour or KWH per hour are each effective for certain groups of customers. Another important design feature of an energy monitor is the ability to set a maximum cost or KWH value for a billing period, and to have a warning alarm when this goal is exceeded. Display of projected cost and KWH is also effective in helping customers meet their goals.

If a customer is on a time of use rate, Feldman points out that the energy monitor must provide a clear signal of both the arrival of peak load periods and the arrival of off peak periods. This signal should include an auditory indication as well as a visual indication so that the customer is aware of the onset of a high cost or low cost period. Following the signal for the customer to alter his energy use pattern, the display provides positive reinforcement for consumption in low cost periods and negative reinforcement for consumption in high cost periods.

AVAILABLE MONITORING DEVICES

While the technology for producing digital cost and consumption indicators for energy use is well known, and the customer interest in having these monitors is quite high, there are relatively few manufacturers who are presently satisfying this new and growing market. Highly complex products such as personal computers are being offered by dozens of companies, but the energy monitor, which is simply a special purpose microcomputer, does not seem to attract the same corporate interest. Less than a half dozen companies offer digital energy monitors which can be purchased and used for residential, commercial and small business oriented needs. These monitors range in price from $80 - $700 and vary greatly in their capabilities, with the least expensive models providing only single function displays and the most expensive models offering an array of cost and consumption displays.

A survey conducted in 1980 showed six companies manufacturing and selling digital energy monitors [12]. Since then, only one new company is known to have entered the marketplace, and four companies which had been among the group of suppliers in 1980 are no longer in this business. Prices for the energy monitors have remained constant in current dollars over the past two to four years, reflecting a reduction in the prices when computed in constant dollars. Much greater price reductions should be expected when comparing monitors to products like personal computers. A digital energy monitor is quite comparable to a computer since its components consist of highly sophisticated electronic devices. Costs of personal computers have fallen by about a factor of five in the last four years, and similar economies are possible for digital energy monitors if the scale of production and sales increased substantially. The only new product, the Energy Teller, does substantially reflect this cost reduction potential. Table 1 below lists the manufacturers of digital cost and consumption monitors, and briefly lists the capabilities, applications and costs of each model.

Table 1

Available Digital Energy Monitors

Company/ Device Name	Capabilities and Applications	Cost
DuPont Energy Management Co. P.O. Box 2543 Baton Rouge, LA 70821 "EM-10-KL" Single Phase	For house or single small Building. Displays accumulated cost and consumption to date, projected cost and consumption, and last month's cost. Will handle	EM-10-KL $525

Table 1, continued

"EM-30-KL" Three Phase	time of use rates, and has an over budget alarm.	EM-30-KL $695
Watt Clock Co. P.O. Box 697 Stratford, Conn. 06497	For a single appliance or device.	
"Watt Miser"	Displays accumulated cost in dollars.	$449.00
Advanced Micro Products, Inc 150 N Meramec Suite 205 St Louis, MO 63105 "Energy Teller"	For a single appliance or device. Displays accumulated cost in dollars or accumulated KWH	$79.95
Fitch Creations Chapel Hill, N.C. "Energy Monitor"	For house or small building. Displays rate of use in dollars per hour. Model EM05 has a budget alarm and will shed one load.	Company no longer sells monitors. EM05 ($149.50) EM3 ($89.50)
TAD Tech Co. Chandler, AZ. "Watts Happening"	For house or small Building. Displays rate of use in cents per hour.	Company has gone out of business. ($104.00)
Energy Conservation Systems, Inc. Costa Mesa, Calif. "Energy Economizer System"	For house or small building. Displays accumulated cost. Part of a larger system for recording customer consumption data. Used by Southern California Edison Co.	Company has gone out of business ($500 - $2000)
Honeywell Corp. Minneapolis, Minn. "ECI"	For house or small building. Displays accumulated cost, projected cost next hour, and projected cost today.	Cost unknown. Available only for for DOE cost monitor project.

UTILITY TEST PROGRAMS

Determination of any benefits of reduced energy consumption and cost due to the use of a digital energy monitor can only be found from actual utility test program data. Academic research on the usefulness of consumption feedback for conservation purposes has been conducted with funding from the U.S. Department of Energy, and the results of that research show a savings of 10% is reasonably available for customers receiving energy cost and consumption feedback [13]. However, the verification of these results requires one or more well-designed experiments involving electric utilities and customers in several different geographic areas.

Several utilities initiated their own energy display monitor test programs in 1978 and 1979, but small samples, equipment problems and weather variations made the conclusions very unclear. In order to provide good data on the effects of monitors, the U.S. Department of Energy initiated a study in late 1979 which involved a sample size of 600 customers from six electric utilities in six major metropolitan areas. This DOE Demonstration Program for Energy Cost Indicators was expected to start in early 1980, conclude in late 1980, and have final results by mid 1981. The six utilities chosen to participate in this study were:

- Tennessee Valley Authority (TVA)
- Pacific Gas and Electric Co. (PG&E)
- Boston Edison Co. (BE)
- Dallas Power and Light Co. (DPL)
- Quebec Hydro (QH)
- British Columbia Hydro (BCH)

However, the DOE Demonstration Program was plagued with initial equipment problems, and fell over three years behind schedule. Final results were not available until 1984 [14]. Of the six utilities involved, Boston Edison withdrew its participation completely and Dallas Power and Light had only 36 customers left on their test program as the test year came to an end. TVA and PG&E were able to complete their test years with about 100 customers each. TVA issued a separate report since their test project involved a combination of both ECI's and time-of-use rates [15]. ECI's that were used in the TVA test were subsequently shipped to Canada and used in their test programs, which were then completed by early 1983.

Results from the two Canadian utility test programs showed a statistically significant reduction in KWH use of 3.5% - 5.1%. The TVA results were not statistically significant, but did show an average 5.1% reduction in KWH use. The PG&E and DP&L test programs did not show any significant reductions in KWH use. The primary implications of these ECI test programs is that there is evidence to support the energy conservation potential of energy cost monitors. However the energy savings appear to be less than the 10% previously projected. Another conclusion from the test programs is that consumers have a very positive attitude toward the cost monitors, and that the monitors greatly enhance awareness of household energy use. This result is leading to a new area of customer education by utility marketing departments.

Dayton Power and Light Company (DP&L) and Wisconsin Power and Light Company (WP&L) are both using energy cost monitors in widespread customer education programs. The cost monitors are loaned to customers with high bill complaints and customers who simply want to understand where their electric costs are occurring [16, 17]. Customers can borrow a small ECI for a period of two weeks in order to calculate the operating costs of single appliances or devices such as refrigerators or electrically heated water beds. Customer responses have been very enthusiastic, and WP&L plans to have 6000 ECI's available for loan by the end of 1985. These DP&L and WP&L programs suggest that the greatest utility of energy cost monitors may be in general customer energy use education rather than as devices which are used continually for cost feedback.

PROBLEMS WITH DISPLAY DEVICES

Even though the technology for designing and building energy cost and consumption monitors is well understood, and such devices have been in use for several years, there are still some major problems with their use. Complex rate structures are difficult to apply to digital display devices without costly communication ties between the utility and the customer. In addition, the customers with a display device must be educated as to the capabilities and limitations of the actual monitors they have.

One major problem in providing a display with meaningful cost data that is directly related to energy consumption is when and how to include the fixed customer charge. This cost varies from around $3 - $7 for most residential customers, and is large enough to distort the cost feedback information if it is added at the start of a billing cycle or at the end of a billing cycle. One reasonable solution is to divide the customer cost by the number of days in the billing cycle and add this cost at the end of each day. Hourly increments could be made, but this begins to reach a point of diminishing value since the marginal price signal is distorted.

Addition of a fuel adjustment charge is also a problem since this charge is usually not known in advance. When the utility calculates a customer's bill, the fuel adjustment is added in at that time. In order to include the fuel adjustment in a cost display, the utility would have to be able to send information (or an estimate) to each customer at the start of a billing cycle. Since the fuel adjustment is included as a cost per KWH, the display would then provide realistic cost feedback proportional to consumption. Without some form of communication system, either electrical or by mail, the customer would have to use an old value of fuel adjustment to allow estimation of the actual cost.

Another problem requiring some communication from the utility to the customer is associated with the use of flexible time-of-use rates. By definition, flexible time-of-use rates involve time periods for peak and off-peak rates that are not known in advance by the customer. Thus, the utility must have a mechanism for sending the customer (and the display device) a signal which specifies that a higher or lower rate is in effect. The technology for such a communication system is readily available, but the cost factor is such that the communication system would easily have a price per customer that exceeds that of the basic display device.

Two other problems involve the ability to handle changing rates and how to reconcile actual billing costs with displayed costs. The cost display requires a computation where the electric energy consumption is translated into a dollar cost through the use of the rate structure in effect at that time. Most likely, the rate structure would be put into a ROM (read only memory) chip in the display device. A change in rate structure would then require changing this ROM chip. A plug-in cartridge similar to those used in video games and home computers might make an acceptable approach to solving this problem. Before a rate change went into effect, a cost display owner could go down to the local utility and swap the old ROM cartridge for a new, updated cartridge. The problem of reconciling the cost shown on the display and the cost shown on the utility bill is mostly one of customer education. A difference of several percent would not be unexpected because of different accuracies of the electric meter and the cost monitor. Large discrepancies would obviously give rise to problems.

A PROPOSED COMBINED FUNCTION DEVICE

A digital energy monitor that contains a microprocessor, memory and energy use sensors is a highly capable and sophisticated device that could easily be expanded to provide a wide array of energy metering and control functions. Individual devices to meter electrical energy, monitor cost and consumption, perform direct load control functions, and to manage overall energy consumption are readily available, and are in use by many large customers. Recently, a combined function device has been proposed, in which all of these energy metering, monitoring and control functions are performed by one integrated control-display device [18]. Such a combined function device offers the potential to have a low cost, highly sophisticated product for supplying the data and functions required by customers faced with complex modern utility rates. In addition to the components needed to provide energy cost and consumption monitoring functions, an integrated device to perform these more general functions would need to include more memory, a receiver to pick up the utility direct load control signals, a collection of switches or relays to control appliances and devices, and a set of keyboard buttons to enter data for energy management functions. The cost of such a control display product should not be greater than that of present personal computers or home video tape recorders. Exclusive of installation cost, the price should be within the range $400 - $500 maximum, with installation costs depending on whether it is retrofitted into an existing house or building or is included as part of the original construction.

CONCLUSION

The future for microcomputer-based electrical energy monitors is unclear. Large customers (particularly industrial and commercial users) must have sophisticated display devices in order to respond to increasing electric rates and more complex rate structures. The potential market for residential customers is substantial. The technology for producing very sophisticated digital energy monitors exists, with costs dropping. However, more tests and evaluations of energy cost and consumption monitors are needed to identify the optimum form of feedback to promote conservation, and more data is needed to clearly establish the cost-effectiveness of these monitors. For example, as an add-on to a time-of-use system, the additional cost might be relatively low, but as a stand alone system, alternative investments (like insulation) might be more economic. Thus, the complexity of future rate structures will affect the penetration rate of monitors.

In the near future, more companies should be entering the marketplace for digital energy monitors, with the costs of these devices dropping substantially. With lower prices, and evidence on cost-effectiveness, these energy cost and consumption monitors could be selling in high volumes, and may be helping many customers reduce their cost and consumption of electrical energy. The fundamental problems are not technological, but institutional (regulatory) and behavioral in nature. As households become more aware of opportunities to reduce bills and/or use electricity more wisely, some monitoring devices are likely to become as common as thermostats are now.

REFERENCES

[1] Berg, Sanford V., editor, Innovative Electric Rates: Issues in Cost-Benefit Analysis, Lexington Press, 1982.

[2] Berg, Sanford V., "PURPA: Benefit-Benefit Analysis for Innovative Rates," Public Utilities Fortnightly, December 4, 1980, pp 19-22.

[3] Bonbright, James C., Principles of Public Utility Rates, Columbia University Press, New York, 1961.

[4] Berg, Sanford V., editor, Innovative Electric Rates: Issues in Cost-Benefit Analysis, Lexington Press, 1982.

[5] Gainesville Regional Utilities Rates and Charges for Electric Utility Service, January 1985, Gainesville, Florida 32601

[6] Acton, J.P. and Mitchell, B.M., "The Effect of Time-of-Use Rates: Facts Versus Opinions," Public Utilities Fortnightly, April 23, 1981, pp 19-25.

[7] Gainesville Regional Utilities, Op. cit.

[8] "Residential Demand Energy and Time-of-Day-with-Demand Rate Programs Cost/Benefits Economic Analysis," Rate Department, Arizona Public Service Company, Phoenix, Arizona, September, 1980.

[9] "The Load Management Decision," EPRI Journal, Vol. 7, No. 4, May, 1982, pp. 14-19.

[10] Ramey-Smith, Ann and Gagnon, J.L., "An Investigation of Preferences For Various Types of Energy Cost Feedback," NBSIR 79-1771, National Bureau of Standards, Washington, D.C., February, 1979.

[11] Feldman, Jack M., "A Theoretical Analysis of Energy Cost Indicator Impacts on Energy Consumption," unpublished research paper, Public Utilities Research Center, University of Florida, Gainesville, Florida, Spring, 1982.

[12] Capehart, Barney L. and Storin, Michael O., "Metering Technology for Innovative Electric Rates," Final Report to the Florida Public Service Commission and the U.S. Department of Energy, Public Utility Research Center, University of Florida, September 1, 1981.

[13] U.S. Department of Energy Press Release, "A Demonstration Program for Energy Cost Indicators," January, 1980. Prepared by the Conservation Solar Energy Office of Building and Community Systems, U.S. Department of Energy.

[14] Filiatrault, P., Hutton, R.B. and Mauser, G.A., "Energy Cost Indicator Demonstration Program: A Report on Canadian and United States Field Experiments," Communications Branch, Consumer and Corporate Affairs Canada, Ottawa, Canada, 1984.

[15] "Energy Use Display Meter Field Test," Final Report, Load Management Branch, Tennessee Valley Authority, Chattanooga, Tenn., Spring, 1984.

[16] "Energy Teller Program," Marketing Department, Dayton Power and Light Co., Madison, Wis., 1984.

[17] "Energy Teller Loan Programs," Marketing Department, Wisconsin Power and Light Co., Madison, Wis., 1984.

[18] Capehart, Barney L. and Storin, Michael O., "Technological Advances in Metering," Chapter 15 in Innovative Electric Rates: Issues in Cost-Benefit Analysis, Sanford V. Berg, editor, Lexington Press, 1982.