DIRECT WATER HEATER LOAD CONTROL - ESTIMATING PROGRAM EFFECTIVENESS USING AN ENGINEERING MODEL

M.W. Gustafson, Senior Member, IEEE
Stone & Webster Engineering Corporation
P.O. Box 5406
Denver, Colorado 80217

J.S. Baylor, Senior Member, IEEE
Stone & Webster Management Consultants, Inc.
P.O. Box 5406
Denver, CO 80217

Gary Epstein
XENERGY, Inc.
Executive Place V 60 Mall Road
Burlington, MA 01803

ABSTRACT

Most utility demand-side management strategies that involve direct load control have been developed using a pilot testing or demonstration program. Two appliances, electric water heaters and air conditioners, are the primary candidates for direct utility control. A utility can avoid pilot testing programs and proceed directly to program implementation if it designs and conducts a proper load research program in which average customer usage and instantaneous demand are determined as a function of the variables that affect each of them.

This paper describes a method to evaluate the potential effectiveness of a direct water heater load control program. Developed through a comprehensive load research program coupled with engineering insights into the energy use of the residential hot water systems, this method results in an algorithm that has been utilized to evaluate the potential for load control on three utility systems in the western U.S.

Variables to be monitored through the load research are presented and a procedure is developed that will allow the system planner to determine if such a program will be cost-effective and successful compared to a program developed through a more traditional pilot or demonstration approach. This paper also outlines how the same methodology can be used for determining a procedure for the dispatcher to properly initiate and terminate a load control program without hot water recovery problems.

KEYWORDS

Least Cost Utility Planning (LCUP)
Load Management
Integrated Resource Planning
Demand-Side Management (DSM)
Direct Load Control
Water Heaters
Pilot DSM Programs

INTRODUCTION

Utilities realize that there are potential benefits of controlling customer appliance loads by direct load control. The two primary residential appliance candidates for direct utility control are air conditioners and electric water heaters. Water heater direct load control amounted to about 42 percent of all control points with approximately 300 different utility programs by 1988 [1]. If a utility has not already investigated the costs versus benefits of these types of control, it should consider doing so as part of its integrated resource planning or least-cost utility planning.

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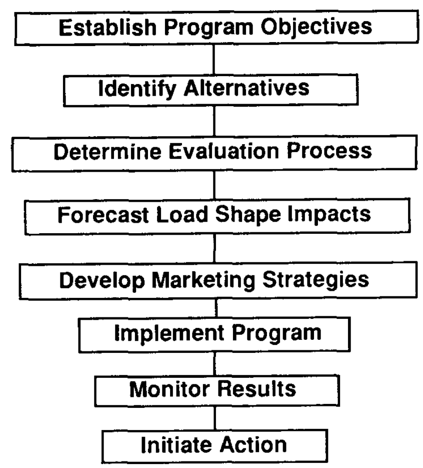
Demand-side management programs are generally planned, developed, and monitored using the first seven steps of the eight-step procedure outlined by the Electric Power Research Institute (EPRI) [2]. The procedure presented in this paper follows these same first seven steps. Figure 1 depicts the process.

Figure 1
Demand-Side Management Process



Traditionally, utilities have conducted a demonstration or pilot test program to verify the cost, control strategy, equipment technology, customer acceptance, market penetration, customer interest, ability to administer, and reliability of a direct control program as well as its demand and energy impacts. A pilot test program allows the utility to forecast load shape impacts (the fourth step) and may help it develop marketing strategies. Two sets of customers are normally selected - one to test the program and another to serve as the control group. The differences in demand and energy uses between the two groups give an indication of the amount of control achieved by the cycling or control strategy under the specific conditions at the time the control is implemented. As part of the pilot program, load research data for both participants and the control group are collected. The load research equipment and funds required to accomplish this evaluation could better be applied to a continuous load research program as proposed in this paper. In addition, monitoring results (the seventh step) requires that load research be undertaken throughout the program's life in both the demonstration and commercial phases. In effect, our approach contains many of the components of a pilot program.

Since load control will only be activated for a few hours in any day during the demonstration program, there may not be sufficient data collected to forecast with confidence the control effects during different conditions and times outside of the test hours. In addition, this type of testing is costly, may not produce accurate results, and may not generate the necessary information that will tell a dispatcher in which hour load control should be initiated and in which hour it should be discontinued. This is because the test is usually designed to demonstrate the impacts of the specific control strategy, not the hour-by-hour impacts of the control on the total system load. Determining the electric system losses impacts is also more difficult because of the limited load research data collected.

The more accurate the daily load projection, the more opportunity the dispatcher has to ensure that the most economic mix of generation is used with DSM options properly addressed. This is because a dispatcher is responsible for ensuring that sufficient resources - including demand-side management (DSM) options - are available to meet the expected load and that operating requirements for parameters such as spinning reserve are met. Generator start-up times, ramp rates, outages, and performance as well as potential purchases and sales, the outside temperature, and the season must also be considered in the process of conducting the utility's dispatch. The daily forecasting program must include the load control effects of each DSM option available for dispatching. Both the proposed method and the traditional demonstration program method require that results be monitored. Load research plays an important role in each method.

This paper provides information on the variables that have the most impact on average use and instantaneous demand for water heaters. Using this information and appropriate load research data, a utility planning engineer can develop a forecasting package that will quantify expected impacts of direct load control strategies. These strategies can be utilized during on-peak hours as well as off-peak hours as the load research data are recorded over each hour of the year. Including electric system losses in the evaluation process and the forecast of the load shape is more readily accommodated through usage of such an engineering model approach.

INTEGRATED RESOURCE PLANNING

Until recently, most utilities did not consider DSM options in their system planning process because efficient control technologies were not developed to a state where they were reliable and economic. DSM options including programs to actively reduce load by utility control, installation of efficient appliances, insulation, and lighting, and rate mechanisms (time-of-use) have surfaced primarily within the last decade. Now the emphasis of utility planners across the country is to examine all alternatives, both supply-side and demand-side, in order to develop an integrated resource plan or perform least-cost utility planning. Tools such as generation expansion models, with special capabilities to treat DSM options on the same basis as supply-side management (SSM) options, and load shape models, which modify the hourly load shape as a function of the direct or indirect control strategies, are now commonplace.

In conducting least-cost planning, utilities need to ensure that DSM options are given the same treatment as SSM options. All of the costs associated with both DSM and SSM options need to be factored into the evaluation. For an SSM option, the costs include capital, fuel, and fixed and variable operating and maintenance costs. For a DSM option, costs may include installation costs, incentive rates, lost energy, rebates, losses savings (demand and energy), transmission and distribution effects, and others [3].

Another factor which must also be considered is the reliability level associated with a DSM or SSM option. A coal-fired generating unit will experience forced outages of various pieces of plant equipment such as feed water pumps. These failures might require that the entire plant be taken out of service or that the output be reduced (called a partial outage). Similarly, a direct load control program will have component failures associated with the involved equipment. These could include the controller outage which shuts down the entire system or a local transmitter outage which would result in a local area being out of service, a partial outage.

DEMONSTRATION PROGRAMS

Examination of the cost-effectiveness of the array of DSM programs is necessary. Demonstration programs were often the only means of evaluating the economics of direct control of appliances in the 1970s when the control hardware and software required to implement DSM options were still being developed and were not standardized. Demonstration or pilot programs were implemented, usually on a reduced scale, to show the effectiveness of the control strategy and other parameters prior to large scale implementation. The reasons for conducting a pilot program include: (1) developing engineering parameters for evaluation, (2) providing sufficient data for evaluation, and (3) determining the level of investment in resources (personnel, cost, and time).

Evaluating the cost effectiveness of these kinds of programs required two groups of customers - one set to test the program and the other set to serve as the control group. Reliability of the control hardware and software was often only estimated.

To conduct its direct load control test program, a utility would equip a statistically determined number of randomly selected households with a controlling device. An equal number of randomly selected households would be used to provide data reflecting uncontrolled usage. The savings attributable to direct load control result from the differences between the non-controlled load and the controlled load in each time increment. An indication of utilization factors would also be derived from this program. Many of the earlier test programs could only measure total household energy usage at prespecified intervals; individual appliances as well as the total residential load can now be measured.

A demonstration program does not provide answers to all of the questions that a utility might ask. Only a limited number of hours, days of the week, ambient temperatures, hours of initiation, lengths of control periods, and specific control strategies can be tested during the trial period. Thus with a demonstration program, the dispatcher has a high degree of uncertainty regarding both control program peak reduction and recovery impacts.

Further, it is frequently very difficult to obtain a truly random sample of residential customers as participants in appliance direct control pilot programs. Customers volunteering for such pilot programs may be biased in that they may have goals of reducing costs, energy use, or environmental impacts; therefore they may not be representative of the general residential population. With this in mind, it becomes difficult to make comparisons with a control group unless it also represents the same subset of the population. There may be considerable uncertainty in projecting the impacts and strategies developed through the pilot program to other customers when the direct load control program is offered more widely.

If the control equipment is assumed to be reasonably reliable and economical to purchase, install, and operate, a load research effort would be recommended instead of a demonstration program. From the load research data, the cost-effectiveness of direct load control DSM programs can be evaluated by building algorithms which capture the impacts of basic parameters and simulate usage patterns of the appliances.

WATER HEATER CHARACTERISTICS

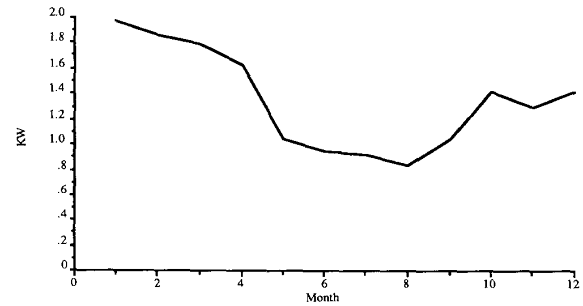
In order to develop a direct load control program without first using a costly pilot or demonstration approach, a thorough understanding of the engineering algorithms that govern water heater energy use is required. Customer demographic factors that influence levels of usage for water heaters are equally important. This knowledge, coupled with appropriate load research data, make it possible to develop equations to project the effectiveness of implementation of a direct load control program. A detailed understanding of water heater usage can also lead to effective dispatcher control strategies.

Electric water heaters exhibit usage patterns which reflect factors including element size, storage tank size, inlet and outlet water temperature, storage tank construction and insulation, household plumbing, number of bathrooms in the residence, number of residents and their ages, the price of electricity, education level, and the household income. Intuitively, the water heater usage in the home of a two-income married couple without children will show a distinctively different pattern than that in a household with a full-time parent at home and three children under the age of five. The saturation level of dishwashers and washing machines also plays a role in the amount of hot water usage for a given utility as does the saturation of solar water heating.

Domestic water heaters require energy for two reasons. First, water heaters consume electricity to heat water after hot water has been removed for such purposes as taking a shower, using the washing machine, and running the dishwasher. Second, there are conduction and convection losses from the surface area of the hot water tank and piping: electric energy is required to maintain hot water temperature.

Figure 2 shows the monthly peak average hourly demand for a typical water heater load which uses approximately 4,300 kWh annually and has an instantaneous demand of approximately 4.5 kW. This typical water heater load comes from a southwestern utility where the ambient temperatures and the inlet water temperature are above the national average. The load shape is similar, however, to water heaters in other locations in the United States but with a lower annual usage.

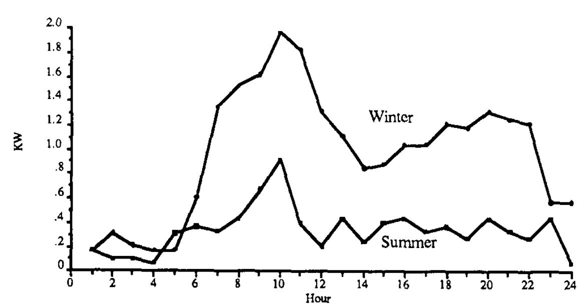
Figure 2
Monthly Integrated Peak Demand
Typical Water Heater



The monthly peak hourly demand, as reflected on Figure 2, shows a significant difference between summer and winter. This difference is caused by inlet temperatures, summer vacations, and other seasonal variables. Thus, it appears that direct water heater load control may be more productive in the winter months, but many different factors will influence whether this is, in fact, the experienced result.

Figure 3 depicts the hourly average demand for a water heater on a peak load day for summer and winter. For both of these days, the water heater peak occurred in hour 10, an hour not normally associated with the system peak for either a summer or winter peaking electrical system. The morning characteristic is typical of water heaters in all geographic areas of the U.S. In the hours associated with the system peak for the summer, the water heater load is low. For winter peaking systems with a morning peak, some coincidence in water heater load peak and system peak is evident, but, the water heater load is much lower for the evening hours. Thus control of water heaters at the time of the water heater's peak use may not benefit a utility's system to a large extent because the system peak and the water heater peak are not necessarily coincident.

Figure 3
Winter/Summer Peak Day
Typical Water Heater



The newer electric water heaters have two heating elements, approximately 4.5 kW each, with an interlock. The interlock allows only one element to be energized at a time. There is an inner tank to hold the water and an outer tank, with insulation between the two tanks. Table 1 shows some typical water heater dimensions.

Table 1
Electric Water Heater Dimensions

Size (gallons)	Height (inches)	Diameter (inches)	Insulation Thickness (inches)
52	59.00	20.00	1.71
82	63.25	23.50	1.71

A traditional electric resistance storage water heater has inherent heat losses through the surface area each hour in the year. This heat loss is a function of surface area, insulating materials, water temperature, temperatures of the surrounding space and materials where the water heater tank is located, thermostat off-set settings, use patterns, and plumbing fittings. The Electric Power Research Institute (EPRI) reports that the average efficiency of a 52-gallon water heater is 85 percent [4]. Electric water heater standards have been developed by The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE). Some states have also developed standards, such as the California Energy Commission's "Appliance Efficiency Standards P400-00-029" dated September 1988 [5]. The ASHRAE standards indicate that an electric water heater of 120 gallons or less should have an hourly loss of no more than 4 watts per square foot of surface area, or 43 watts per square meter of surface area with an 80°F temperature difference between the hot water and the surroundings [6].

Annual heat losses for a water heater which meets the ASHRAE standard can be calculated by determining the surface area of the water heater and multiplying that surface area times the hourly losses and by the number of hours in the year. A cylinder such as represented by a water heater has a curved surface area using diameter (d) and height (h) of $2\pi rh$ or πdh and flat surfaces (top and bottom) each of πr^2 or $(1/4)\pi d^2$. The total surface area (SA) is thus as shown in equation (1).

$$SA = \pi dh + (1/2)\pi d^2 \qquad (1)$$

This sum expressed in square feet is then multiplied by the maximum standby loss value of 4 watts/ft^2 and 8,760 hours in a year to obtain the desired result of annual heat losses in kWh. Thus, the annual heat losses for the 52-gallon and 82-gallon water heaters with dimensions as shown on Table 1 can be calculated to equal 1,055 kWh and 1,347 kWh, respectively. This represents hourly losses of 0.12 kW and 0.15 kW.

Convective heat transfer can also be calculated as a function of the thermal resistance (R) of the combined inner and outer shells and the insulation materials, the surface area of the water heater, and the temperature difference between ambient temperature and the temperature of the heated water. Equation (2) shows this relationship.

$$q = h*SA*\Delta T \qquad (2)$$

where:

- q = Convective heat transfer (Btu/hour)
- h = Convective heat transfer coefficient (1/R)
- SA = Surface area in square feet
- ΔT = Temperature difference

Assuming an insulation value R of 12, a temperature difference of 90°F, and the 52-gallon water heater with dimensions as shown on Table 1, the heat transfer losses can be calculated to equal 0.07 kW in each hour. This specific 52-gallon water heater configuration meets specifications which are more stringent than the ASHRAE standards.

An electric water heater is not a very efficient appliance because of the large surface areas from which heat losses are experienced. The smaller the capacity of the water heater, the smaller the surface area and thus the smaller the resulting losses. While the larger tank has more overall surface area than the smaller tank, it does have lower thermal losses per gallon of water storage.

The surface losses described above represent the baseline, steady-state-use of the water heater. The hourly losses calculated for the 52- and 82-gallon tanks can be compared with the hourly usage shown for a typical water heater in Figure 3. The minimum usage of the water heater from about 11 p.m. to approximately 5 a.m. represents a dormant period where losses are the primary, if not the sole, contributor to water heater energy use.

The variable component of the daily water heater use represents the energy used to heat water after hot water has been removed for domestic purposes. The energy used in a given hour can be calculated as a function of the flow rate of hot water removed from the tank, the specific heat of water, and the temperature difference between the incoming (cold) supply water and the heated water. Equation (3) shows the relationship.

$$Q = F\,(8.35)\,C_p\,\Delta T \qquad (3)$$

where:

- Q = Heat transfer for make-up water (Btu)
- F = Flow rate (lbs/hr)
- 8.35 = lbs per gallon
- C_p = Specific heat of water (1.0 Btu/hr °F)
- ΔT = Temperature difference

For an example hour where 10 gallons of hot water are used, the supply water is 60°F, and the hot water is 150°F (ΔT=90°F), the electric energy consumed is 2.2 kWh. It is important to note, however, that this energy is not necessarily consumed at a rate of 2.2 kW. Rather, the instantaneous use by the water heater is fixed by the size of the heating element. The average energy rate for a given hour is made up by the sum of the surface losses and the make-up water heating, capped by the heater element capacity (approximately 4.5 kW for a typical water heater element).

We now have developed a detailed knowledge of the ways in which water heaters use energy. With this understanding of the direct water heater engineering model, in conjunction with load research data, it will be possible to develop estimates of control program effectiveness, as well as direction towards dispatcher control strategies.

LOAD RESEARCH PROGRAM

A suitable load research program must be designed and conducted to enable a utility to bypass a demonstration program and still be able to determine a water heater control program's effectiveness. An understanding of the differences between average hourly demand and instantaneous demand for the water heater must be developed to properly implement such a program. One year of load research data should be adequate to develop a day-by-day water heater use forecast. Additional years of data increase the confidence in the forecast.

The load research program should gather hourly data on ambient air temperature, inlet water temperature, outlet water temperature, and demand for the appropriate number of residential customers for the specific utility as determined through statistical methods. Ambient air, inlet water and outlet water temperatures can be measured only at several locations within the utility's service territory. The remaining factors which influence water heater usage should be determined when the load research equipment is installed in the household. The most important of these factors is the element size of each water heater. These data will be used to correlate water heater hourly load as a function of date, time, and inlet temperature. These pieces of information will be variables that are readily available on a systemwide basis to the dispatcher via telecommunications. In addition, a utilization factor (how many water heaters operate at any specific point in time) can be developed.

The utility would then develop an algorithm for use by the dispatcher to forecast the water heater demand in each hour. This algorithm would be in the form of equation (4):

$$WH_L = \sum_{i=1}^{n} WH_i \qquad (4)$$

For this equation WH_L equals the total water heater demand (WH_i) for all of those water heaters monitored or under control (number = n) for any specific hour.

The hourly data for each water heater (WH_i) is a function of parameters which include the ambient temperature, the inlet water temperature, the outlet water temperature, the element size, and the hour of the day as shown in equation (5).

$$WH_i = f(AT, IT, OT, ES, TS, H, DP) \qquad (5)$$

- WH_i = Individual water heaters being monitored or controlled
- AT = Ambient temperature
- IT = Inlet temperature
- OT = Outlet temperature
- ES = Element size, noting if interlock system is in place
- TS = Tank size, includes surface losses
- H = Hour of the day
- DP = Demographic parameters

One additional variable would be desirable in determining instantaneous demand: the voltage profile of distribution circuits. However, this variable is difficult to establish because of its time variant nature and may not be useful in developing an appropriate algorithm.

The element size (ES) is a very important variable because it is required to determine recovery effects after the water heater control stops. The energy used during any control period is drawn from the stored energy in the tank. The majority of this energy must be replaced when the element is allowed to operate again; this causes a recovery situation.

The demographic parameters (DP) in reality would be made up of a number of variables that indicate the actual hot water usage of a given customer. The value of these parameters would be a function of socioeconomic and behavioral factors and would provide information such as number of residents in the household, showers per day, meals per day, types of appliances that use hot water (dishwashers, washing machines), etc. These parameters would also be the indicators of when hot water is used on any given day and whether use varies seasonally.

Such demographic and behavioral data would have to be collected by a carefully thought out survey tool Various survey instruments have been developed for the residential sector and have been very successful in generating extensive data bases on customer characteristics such as end use breakdown, saturation of efficient technologies, potential for conservation, as well as socioeconomic and behavioral patterns. For example, XENERGY's ReCAP™ residential analysis tool is being used very successfully with mail surveys for hundreds of thousands of utility customers. Existing survey instruments can be enhanced or new ones developed so that the collected data can be used to produce hourly hot water use profiles. Such profiles, applied to water heating engineering algorithms and calibrated with load research data, can lead to accurate predictions of customer water heater energy use and demand. This in turn will help planners develop accurate estimates of load control program potential and appropriate control strategies.

It is also important to recognize that developing dispatcher control strategies that consider these behavioral factors will lead to increased acceptance of the program. Further, it may be possible to categorize customers into characteristic behavioral or demographic groups. This may allow planners to use more aggressive control strategies for certain customer categories and still maintain a high level of satisfaction and acceptance of the program.

An algorithm in the form of equation (4) has been computerized and used to evaluate direct utility water heat load control on three utilities in the western U.S. The same algorithm would be substantially modified and its sophistication increased for dispatching purposes. Electric system losses may also be included in this algorithm (as they were for the three utilities for which the algorithm has been applied). There may be substantial demand and energy savings in addition to the control savings. We have not incorporated changes in electric system losses in this analysis, but the procedure to include these losses is demonstrated in [7].

It is important to consider the potential effectiveness and costs of developing a water heater direct control program without first using a pilot or demonstration program. Some comments can be made in this regard. First, appliance direct control programs have been around for a number of decades and a demonstration program would not be expected to yield new significant insights on program effectiveness or customer acceptance. Water heater control effectiveness certainly can vary from region to region and with different demographic groups; however, enough programs have been implemented to enable a review of the literature and discussion with other utilities to reveal details of the potential variation, limitations, and problems.

A pilot program would definitely be considerably more expensive than the cost of a load research/engineering program. The pilot program encompasses all of the load research and measurement equipment that would be used in the strictly load research approach. Therefore, the cost of the load research approach would be only a small subset of the pilot program costs (that additionally involve all of the control equipment at the residence and at the dispatcher). Since the load research approach collects data to determine water heater use patterns, there is no need to make comparisons between two sampled groups. This eliminates a control group and its associated costs. Further, it may be possible to use a smaller load research sample as long as appropriate survey data and engineering analysis are used to validate the load measurement based information and estimates. A major benefit of a load research program is the available hourly data that can be utilized to determine the positive effects on the transmission and distribution system. In addition, these hourly loads can be used to determine savings associated with changes in electric system losses.

Program planners may believe that problems will develop if a pilot program is not utilized before fully implementing the program. Again, other utilities' direct control program experience can be used to anticipate potential trouble. Conservative estimates of program effectiveness and careful implementation of control strategies should limit the possibility of utility-specific problems.

UTILIZATION OF WATER HEATER CONTROL

The dispatcher may use water heater control to aid in economic dispatch in off-peak hours or to result in demand reduction for the peak hours. However, it may not be practical to use water heater direct load control to assist in economic dispatch and result in demand reduction on the same day because there is only a finite amount of storage capacity. Water heater control could assist in economic dispatch by eliminating the need to start a fast response generation unit for a few hours. Once a utility has developed an algorithm which incorporates the load research data reflecting the manner in which water heaters are used on its system, the dispatcher will be able to use that algorithm to determine how much reduction is available in each hour and what the recovery characteristics after control will be.

It is important that the dispatcher have the water heater resource available for control in all hours, not just during system peak conditions. Delaying the startup of a unit may be as important as shaving the peak on any particular day, but over the long run, peak shaving is most likely the primary usage of water heater control. Forecasting the availability of water heater load over the next 24 hours is necessary to afford the dispatcher flexibility in scheduling the usage of all resources.

A direct utility load control program must be developed with the system dispatcher in mind. According to R.P. Schulte, a DSM program should take into account the operators, availability, monitoring, maintainability, controllability, safety, security, impacts on operation, and rate/contracts limitations [8]. The method described in this paper provides a very accurate data base so that the dispatcher can determine the controllability, impacts on operation, and monitoring. Since 8,760 hours of data are provided, these functions will be identified in a superior manner than can be achieved in a pilot program. The dispatcher needs an algorithm, preferably computerized, to determine the available load which may be controlled in any hour of the year. In addition, the dispatcher must also have available the length of time for which it is practical to control load once control is initiated in any specific hour. The engineering model approach described here provides this information.

The hourly use data for a typical water heater on a specific weekday for winter and summer were previously shown on Figure 3 and are listed in Table 2. These values incorporate energy required to heat water as well as surface losses. Forecast data of this type would be projected for each hour of the day utilizing the algorithm developed for WH_L. The summer peak day will be examined in detail with respect to instantaneous and average demand.

Table 2
Water Heater Hourly Load

Hour	Winter Load kW	Summer Load kW
1	.169	.169
2	.305	.102
3	.203	.102
4	.169	.068
5	.169	.305
6	.610	.373
7	1.355	.339
8	1.524	.440
9	1.626	.677
10	1.965	.915
11	1.829	.406
12	1.321	.203
13	1.118	.440
14	.847	.237
15	.881	.406
16	1.050	.440
17	1.050	.339
18	1.219	.373
19	1.186	.271
20	1.321	.440
21	1.253	.339
22	1.219	.271
23	.576	.440
24	.576	.068

The forecast of the water heater load profile must take into account hourly demand and how recovery will happen if control is initiated. For recovery of controlled water heater load, the instantaneous demand of the water heaters becomes very important. This instantaneous demand is a function of element size and terminal voltage. Average demand, on the other hand, is a function of instantaneous demand and time of operation.

The forecast of water heater load must thus consider maximum load (PI) in each hour and the average hourly load (PA). The PI would be almost constant over all hours, varying only with voltage. The maximum PI would be calculated as shown in equation (6) to be the sum of the element sizes for all the water heaters under control.

$$PI = \sum_{i=1}^{n} ES_i \tag{6}$$

PA would be equal to the average water heater demand of all water heaters being controlled for each hour as projected by the algorithm. Upper and lower confidence limits must also be established to bracket the expected value. This allows the dispatcher to use a conservative approach on any day if the impact of the water heater controls not meeting expectations is significant.

For one sample water heater, the PI is 4.5 kW and the PA is shown on Table 2 in the column labeled "Summer Load kW." The maximum PI for each water heater under control would be summed to obtain the total water heater load possible. Thus for a system with 30,000 units, the maximum PI is 135 MW if each element size is 4.5 kW.

The system forecast is used to determine what units must be available to meet the system peak load as well as which units are needed for operating requirements. This forecast as well as the water heater forecast will be revised as temperature and load data are updated.

The dispatcher determines when the next highest cost unit must be placed into service. The potential for direct utility water heater load control is then examined. Hours 13, 14, 15, and 16 (which correspond to the summer system peak loads) have a potential for load control. Projected water heater loads for these hours are selected from the load research data for the appropriate day (Table 2) and multiplied by the number of units to be controlled. In our example simple numbers are used. In actual practice, the data which would be used by a dispatcher to develop the control value would contain information on customer subgroups.

For the projected peak load hours (in this case hours 13, 14, 15, and 16) water heater control is initiated with the resulting lower peaks (Table 3). In this example, a maximum of 13 MW of water heater load was controlled in hour 13 and a minimum level of 7 MW was controlled in hour 14. The amount controlled in each hour is subtracted from the system load to yield the load for which generation or power purchases must be provided. The recovery occurred all in hour 17.

Table 3
Summer System Peak and Water Heater Control (MW)

Hour	System Summer Load (MW)	Water Heater-Controlled (MW)	Resulting Load (MW)	Recovery (MW)
12	706		706	
13	734	13	721	
14	758	7	751	
15	788	12	776	
16	737	12	725	
17	702		746	44
18	671		671	
		44		

With 30,000 units at 4.5 kW each, the recovery could have been as high as 135 MW. Since the water heater energy use during the summer peak hours is low, however, the projected recovery is 44 MW in hour 17. The energy deficit which was accumulated during the four hours of control can be accommodated in the first hour after cessation of control. It may have been prudent, however, for the dispatcher to initiate service to part of the water heaters in hour 16 to avoid the higher load in hour 17 than was experienced in hour 16. This is the type of problem the dispatcher must face and such problems will only be solved by the provision and proper interpretation of sufficient data.

Recovery considerations must be properly factored into the decision process. Accurate projections of load and water heater use will be important to enable the development of forecasts which the utility dispatcher will be able to use in actual practice.

CONCLUSIONS

The impacts on total system load of direct utility control of water heaters can be projected based on load research data which monitor water heater usage as a function of a variety of parameters. This process could help a utility avoid demonstration programs but still enable it to determine what will happen when control is selected as a DSM option.

This process provides four benefits to the utility. First, the process results in accurate determination of the appliance load profile and the level of capacity that can be controlled. Second, the information necessary to determine a DSM forecast for daily use by the dispatcher can be readily ascertained. Third, the necessary data to determine control strategies for all hours of the day would be developed. Since demonstration programs include collection of load research data, the process documented in this paper should be more cost-effective if the algorithms so developed are successful. Fourth, the hour-by-hour data can be utilized to determine the impacts of capacity reduction and reduced losses for the transmission and distribution systems.

A load research program should gather data for hourly (or other desired time increment) demand for the water heaters. Additional factors that require simultaneous monitoring would include inlet water temperature, outlet temperature, and the ambient temperature. The element size would be noted when the load research equipment is installed. Instantaneous demand of the water heater as well as its actual rating will be necessary data as well.

Once the data are gathered, the objective of the analysis will be to ascertain actual usage of the appliance versus projected usage based on design specifications. This comparison will provide a utilization factor - how many of the appliances are actually operating at what level during the periods of interest. If the utilization factor of water heaters on the specific utility system during the time of system peak is very low, for example, direct water heater load control may very well not be a cost-effective DSM program.

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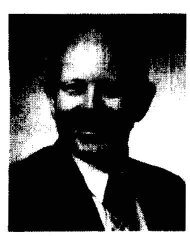

MARTIN W. GUSTAFSON (S'59-M'63-SM'72) was born in Los Angeles, California on February 4, 1939. He received his B.S.E.E. degree in 1963 from California State Polytechnic University, San Luis Obispo, California, and his M.S.E.E. degree from the University of Southern California in 1969.

He spent 15 years working for the Southern California Edison Company as a Transmission/Substation Design Engineer and as a Senior System Planning Engineer. Mr. Gustafson joined Stone & Webster Management Consultants, Inc. in 1978 as a Senior Consultant in their Denver Office and now is a Principal Electrical Engineer for Stone & Webster Engineering Corporation. He is the author or co-author of numerous IEEE papers dealing with load management and electrical system losses. His work has been published in Transmission and Distribution. He has prepared and presented DSM testimony before various state regulatory bodies including commissions.

Mr. Gustafson is a Professional Electrical Engineer registered in California and a Certified Energy Auditor in the state of Colorado. He is past Section Chairman of the Los Angeles Metropolitan Section and was Member at Large for the Los Angeles Council. He is also a Fellow of the Institute for Advancement of Engineering. Mr. Gustafson is a member of the Power Engineering Society.

JILL S. BAYLOR (M'87-SM'90) was born in Newport News, Virginia on December 20, 1954. She received her B.S. degree in Applied Mathematics (minor in Electrical Engineering) in 1976 from the University of Virginia (Tau Beta Pi, Virginia Alpha) and her M.B.A. from the University of North Carolina at Charlotte in 1979.

She spent five years working for Duke Power Company in the System Planning Department as a Planning Engineer. Ms. Baylor then joined Mobil Oil Corporation's Mining and Coal Division where she worked as a Planning Analyst. In 1984 she joined Stone & Webster Management Consultants, Inc. as a Consultant and is now an Assistant Vice President. She is the co-author of several IEEE papers dealing with electrical system losses and load management. Her work has also been published in Public Utilities Fortnightly and Transmission and Distribution.

Ms. Baylor is a Professional Engineer registered in Colorado. She is active in the Society of Women Engineers, has served as President of the Rocky Mountain Section, and is the 1991-1992 National President. Her articles have been published in the U.S. Women Engineer, Woman Engineer and Engineering Horizons. She is a member of the Power Engineering Society.

GARY EPSTEIN was born in Brooklyn, New York on January 7, 1958. He received his B.S. degree in Mechanical Engineering in 1980 from the State University of New York at Buffalo and his M.S. in Mechanical Engineering from the University of Massachusetts, Amherst in 1986.

He spent three years working for Sihi Pumps, Inc. as a Mechanical Applications Engineer. Mr. Epstein then joined the Energy Analysis and Diagnostic Center where he worked as an energy consultant. In 1988 he joined XENERGY as a senior energy engineer. He is the author or co-author of several papers dealing with energy end-use technologies, demand-side management, and the environmental impacts of energy use. His work has been published in the ASHRAE Journal and Energy Engineering.

Mr. Epstein is active in the technology committee of the Association of Demand-Side Management Professionals (ADSMP). He is also a member of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the Association of Energy Engineers.