DESIGN OF FUZZY LOGIC CONTROLLER OF RESIDENTIAL ELECTRIC WATER HEATERS

Mrs.E.Himabindu[1], Mr.D.Krishna[2]
[1]Geethanjali College of Engineering (Autonomous), Assistant Professor EEE
Cheeryal(V), Keesara(M), Medchal(D), Hyderabad
[2]Anurag Group of institutions (Autonomous), Assistant Professor, EEE
Venkatapur(V),Ghatkesar(M),Medchal(D),Hyderabad

ABSTRACT:
With the impending deregulation of electric utility industry, customer satisfaction with utility services will be crucial. Utilities will need to place a greater emphasis on their customer's preferences and desires. This paper describes a fuzzy logic-based control strategy for shifting the average power demand of residential electric water heaters from period of high demand for electricity to off-peak periods. A minimum temperature for hot water, defined as customer comfort level, is used as a control variable. Water temperature is not allowed to fall below the minimum temperature set by the customer. Simulation result show that the proposed strategy can shift the average power demand of residential water heater to improve the load factor of residential load profile.

Key words: Fuzzy Logic control, mat lab tool box, Electric water Heater.

I. Introduction:

An Englishman Benjamin Maugham, in 1868 invented the first instant water heater called "The Geyser", a device where the water was heated as it flowed into the bath. They were known to be quite dangerous.Maughn's invention influenced the designs of a Norwegian mechanical engineer by the name of Edwin Ruud, who immigrated to Pittsburg. Ruud who invented the electric water heater (automatic storage) in 1889, founded the Ruud Manufacturing Company, which is still in operation today, and pioneered the advancement of water heaters, in both the residential and commercial market.

Population growth along with technological growth force the utility companies to continue struggling to meet the ever-increasing need for electricity. With the majority of residents conforming to the 8 AM-5PM work schedule, the utility companies experience overwhelming demand peak associated with large amount of power being consumed at the same time. Complementing this effect are periods of low demand. Although over a period of time, the average amount of power consumed by community may be easily generated by a utility, that utility still has to provide enough generation to meet its highest power demand peak. It is in the best interest of the utility companies as well as the consumer to try to reduce these high peak demand periods and out their power demand profiles as much as possible.

One way this can be accomplished is by controlling residential electric water heaters. The Electric water heater accounts for the single largest contributor to the total power consumption of a residence. Existing electric water heater DSM (Demand-side management) strategies focus on on/off control of the water heater, where a group of heater are disabled during certain periods of time using a direct load control strategy [5].When water heater are energized, they are either on consuming a fixed amount of power , i.e.4.5kW,or they are off. the paper presents a fuzzy logic based variable power control strategy, where the power consumed by the water heater can be controlled based on the information available from the water heater such as water temperature, maximum and minimum water temperature allowed (or desired),and distribution level power demand. Based on the status of the above variables, the fuzzy controller will determine the percentage of maximum allowable power that the water heater should consume. Based in this information, a control signal is generated to control the voltage applied to the water heater.

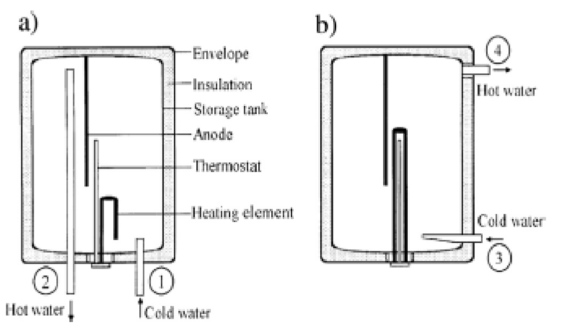


Fig.1.Conventional EWH and modified EWH.

The fuzzy controller, which can be loaded on a microprocessor chip and installed on the water heater, can be tuned interactively by the customer or be controlled directly by the utility [11] for those customers who participate in such DSM strategy. Simulation result indicate that the use of the proposed fuzzy DSM strategy can result in a flatter utility demand curve, and hence improve the utility load factor.

II: FUZZY- LOGIC BASED ELECTRIC WATER HEATER:

Fuzzy logic control is simple control strategy which works well for control of certain class of nonlinear systems that contain variable with uncertainty. this type of control strategy is suited well for control of water heater, which exbits non-linearity between the power consumed by the water heater and the water temperature [8, 10]. there is also considerable amount of uncertainty in the system variables shown in Fig.1.This figure shows the block diagram of the proposed fuzzy controller which has 22 rules, four inputs, and output signal. The rule is given in section IV, and the inputs are as follows:

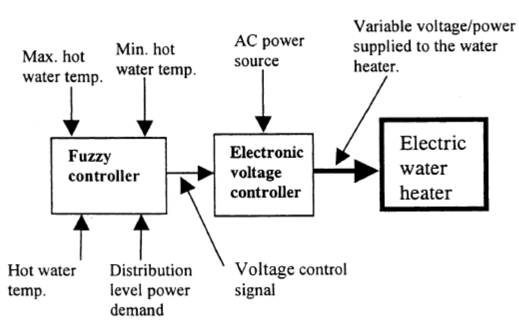


Fig.2, Fuzzy-controlled electric water-heater block diagram

1. Demand: Average residential electric water heater power demand.
2. Water_temp: Temperature of the hot water at any given time.
3. Comfort _level: A minimum temperature for hot water set by the customer. Water temperature is not to fall below this value. This temperature is set 95^0F in this study.
4. Max_Temp: Maximum water temperature allowed. This temperature is set 130^0F in this study.

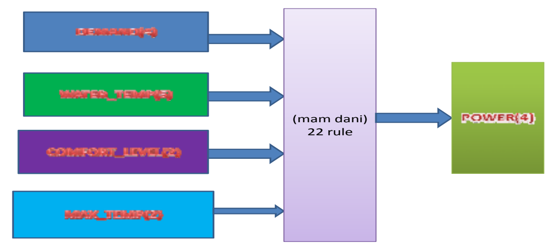


Fig.3.Block Diagram for The Fuzzy Logic Controller.

The controller takes the four crisp input values, fuzzifies them, assigns a fuzzified control signal to control the voltage applied to the water heater based on the assigned rules and membership functions. The control signal is then converted to a crisp signal through defuzzification process [12].

The decision-making process is based on a set of linguistic rules that will map each input signal to a set of membership function that correspond to that input. These signals are, in turn, mapped to an output signal.

The voltage applied to the water heater at any given time is the product of the fuzzy controller's output command, which is a number between zero and one, and the water heater's rated voltage. Assuming water heater's heating element is purely resistive; its power consumption is proportional to the square of its voltage which is now variable. Therefore, the water heater's power consumption becomes variable.

The fuzzy rule's and membership function will be explained in the next two sections.

III.MEMBERSHIP FUNCTIONS:

Fuzzy membership functions are needed for all input variables and the output variable in order to define linguistic rules that govern the relationship between them. Gaussian(bell-shape) membership functions were used for the input, demand and temperature, and the output signal(power). This type of membership function resulted in the smoothest shifted water heater demand profile, On other hand ,s sharp membership function functions were chosen for input variables, comfort level and maximum temperature because of sharp constraints on those variables. Water temperature shall not drop below the comfort level and shall not exceed the maximum temperature assigned by the customer. the range for the membership functions were chosen based on experience.Fig.3. Shows the shape, range and the linguistic terms used for the input and output variables.

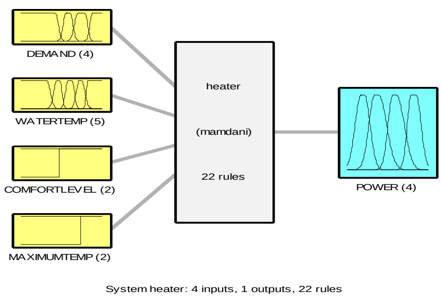
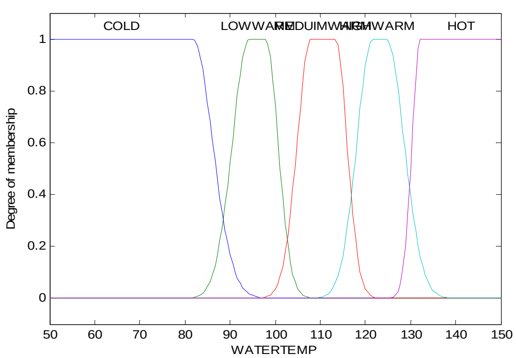
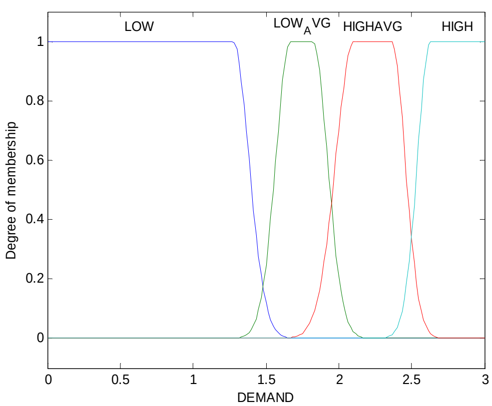
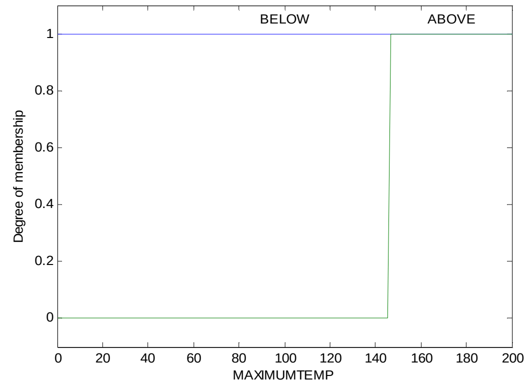


Fig.4.Fuzzy Interface System for Electric Water heater.







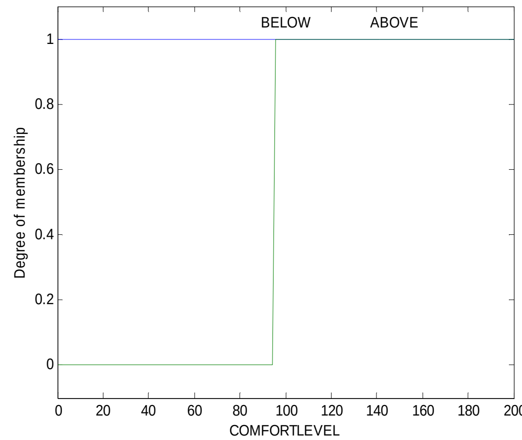


Fig.5.Membership functions for Fuzzy logic controller.

IV: Fuzzy rules:

A very important task in fuzzy controller design is the development of fuzzy rules for the problem at hand. The development of these rules depends in large on the experience and knowledge of the designer about the system. In the present case, the fuzzy controller is to shift the peak of the water heater demand profile to periods where total demand, as seen by the utility, is low. At the same time, constraints set by the customer, i.e. the maximum and minimum temperature for the hot water, should be met. Considering the desired water heater demand profile,The rules are given below.

1. If (demand is low) and (water _temp is cold) then (power is high)
2. If (demand is low) and (water _temp is Warm) then (power is high)
3. If (demand is low) and (water _temp is M_warm) then (power is avg)
4. If (demand is low) and (water _temp is H_warm) then (power is avg)
5. If (demand is low) and (water _temp is hot) then (power is low)

6. If (demand is L_avg) and (water _temp is cold) then (power is avg)
7. If (demand is L_avg) and (water _temp is L_warm) then (power is avg)
8. If (demand is L_avg) and (water _temp is m_warm) then (power is avg)
9. If (demand is L_avg) and (water _temp is H_warm) then (power is low)
10. If (demand is L_avg) and (water _temp is hot) then (power is very low)
11. If (demand is H_avg) and (water _temp is cold) then (power is low)
12. If (demand is H_avg) and (water _temp is L_warm) then (power is low)
13. If (demand is H_avg) and (water _temp is M_warm) then (power is low)
14. If (demand is H_avg) and (water _temp is H_warm) then (power is very low)
15. If (demand is H_avg) and (water _temp is hot) then (power is very low)
16. If (demand is high) and (water _temp is cold) then (power is very low)
17. If (demand is high) and (water _temp isL_warm) then (power is very low)
18. If (demand is high) and (water _temp is M_warm) then (power is very low)
19. If (demand is high) and (water _temp is H_warm) then (power is very low)
20. If (demand is high) and (water _temp is hot) then (power is very low)
21. If (max_temp is above) then (power is very low)
22. If (comfort level is below) then (Power is high)

Rules 21 and 22 set the boundaries for the maximum and minimum temperature note that in this study we have assumed that the temperature cannot exceed a certain limit. Therefore, there is a limit on the amount power which can be applied to the water heater in order to heat the water during the periods where the demand for the electricity is low. Otherwise water temperature will exceed its maximum limit. Similarly, water temperature should not fall below a minimum value set by the costumer. Therefore it may not be possible to reduce the power supply to the heater all the way to zero during the periods of the high demand for electricity.

V. SIMULATION RESULT:

Simulation studies were conducted to evaluate the effectiveness of fuzzy controller to shift the average daily residential electric water heater power demand using the membership functions and rules given in the previous section. Fig 3 to 7 show a comparison fuzzy controlled and uncontrolled water heater power demand it is clear from this figure that under fuzzy control a large percentage of water heater power demand has been shifted from periods of high demand for electricity to off-peak periods . It is understood that cooperation and some planning for the use of hot water is expected from the customers participating in the proposed fuzzy logic based DSM strategy. From the figures we can define load factor is improved significantly for the average demand profile of fuzzy controlled.

$$\text{Load Factor} = \frac{\text{average demand}}{\text{peak demand}}$$

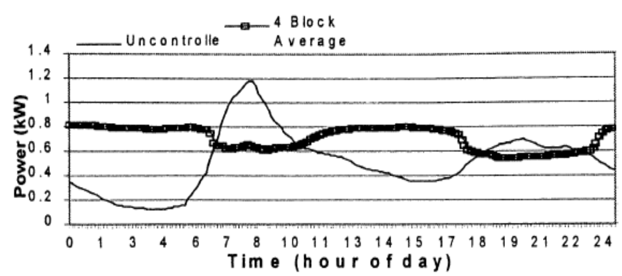


Fig.6.Power demand profile for average of four blocks of water heaters with three blocks being controlled

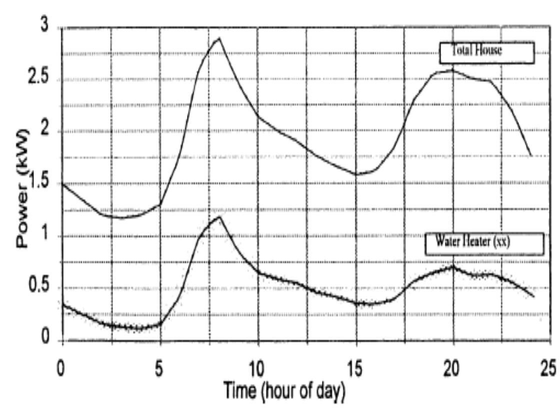


Fig.7.Daily average, total residential demand and electric waterheater demand

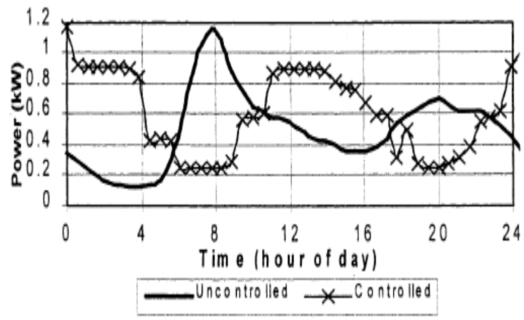


Fig.8.Daily average water-heater power demand, uncontrolled and using a single fuzzy controller

VI: Conclusion:

In this paper a fuzy logic based DSM strategy was presented for the controlling the average daily power demand of residential electric water heater. The proposed DSM strategy is based on variable power consumption of water heater by controlling its applied voltage. The fuzy logic controller uses hot water temperature, distribution level demand, and maximum and minimum allowed temperature for the hot water as input variables and outputs adecision signal which controlles the magitude of input voltage to the water heater .Simulation results show that it is possible to reduce the peaks of average residential water heater power demand profile and shift them from periods of high demand for electricity to low demand periods using the proposed customer –interactive DSM strategy. The proposed strategy can also be beneficial to the customers participating in such DSM programes, specially in a realtime pricing environment. Some cooperation and planning for use of hot water is necessary by the customers participating in such DSM program.

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