Demand Side Load Management for Residential Buildings

PL. Somasundaram, R. Kaviya, K. Sundararaju

Abstract: ***Demand-side load management is essential for controlling loads inside the residential buildings to satisfy the user requirement at low cost. This paper presents a Fuzzy inference model to be evaluated with four linguistic variables namely the power consumption of the appliances, its time of utilization, electrical power utilization in kWh and also the user satisfaction on each electrical appliances at each hour of the day. From the user data, the system can provide an energy utilization design, which in turn gives maximum satisfaction at a predefined user budget to the user. In this work the function of cost is based on the user expenditure and the cost function is predefined as Rs3/day. Randomly selected appliances can be utilized by the user based on the predefined cost. Result of the work provides maximum user satisfaction and minimum cost at the value of predefined cost function.***

Keyword's: Fuzzy inference model to be evaluated with four linguistic variables namely the power consumption of the appliances,

I. INTRODUCTION

In upcoming years, the power consumption has drastically increased worldwide, causing power outages. Due to the sudden increases in peak demand of power. One of the solution for this issue is the incorporation of demand-side management systems that helps to decreases the peak power and encourage effective power utilization with demand reaction (DR) control. In recent year development on demand-side management systems, in which computerized planning scheme is established on the consumer residential buildings.

The main consideration is to concentrate on the comfort level of the consumer, as the utilization of electronic product for most applications leads to huge rise in energy demand, which results in substantial power cut in peak hours. To overcome the power outage, effective power utilization by means of energy consideration helps to decrease the energy consumption and increase the performance of the power system.

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The demand side management strategy can be connected to a residential building, it reduces the over-burdening, conductor failure, transformer failure, and hardware failure. The demand-side management is suitable for load controlling, so that the user satisfaction is maximized at least expense,[1] in this work genetic algorithm is used for load satisfaction which results maximum user satisfaction at minimum cost. Ravibabu P [2] this paper introduces the fuzzy logic application and DSM systems to the household loads, while consumption of power can be restricted during the peak hours thereby it accomplice power protection. According to Yun GY, Kong HJ [3], their investigation uncovers the elements in lighting energy utilization of open plan workplaces which emphasis on the roles of resident adaptable activities, results shows that direct connections between comfort illuminance levels and luminous comfort on the work plane. Ogunjuyigbe ASO [4], the investigation performed of Mixed Integer Linear Programming (MILP) reveals that the plan and load assignment based on user priority of load provides a moderate energy utilization. Missaoui R, Joumaa H [5] proposed a performance of global model based anticipative building energy management system (GMBA-BEMS), the outcome of this work gives daily minimum energy cost for managing the household energy. P.Ravi Babu [6], in this paper he concentrates on reducing the power consumption of air conditioner by using fuzzy controller with PV. This work provides reduction of over load and saving electricity bill. Another direct load control model in view of the fuzzy logic system [7] as it results reduction in electrical energy utilization and payback period. El-Baz Wessam [8], the aim of DSM is to control the loads at peak hours or to change the usage of time to off-peak hours or night times or week off. DSM has a cost-effective technique, and suitable for large-scale energy consumption. The DSM has numerous effective techniques for power consumption reduction namely [9] load shifting, peak clipping, valley filling, end-use equipment control and differential tariff. The applications of demand side load management has different comfort conditions and considerations, user satisfaction of this paper is considered with two constraints, namely time based satisfaction and device based satisfaction, on equalizing these two constraint satisfaction, user's absolute satisfaction is estimated. Generally, electricity consumers are trying to accept various constraints for power utilization. Important of these constraints is to calculate the user satisfaction from power utilization and the user should utilize power within the predefined budget. The DSM program affect the energy cost of consumer and load utilization pattern, it influence the user comfort level and maximum user satisfaction.

The DSM provides effective load utilization technique to satisfy the power requirement of the user with an aim to increase the user satisfaction and reduce the cost rate in energy utilization. The proposed fuzzy inference system is suitable for producing energy utilizing pattern and reveals maximum user satisfaction at a predefined user budget.

II. DEMAND SIDE LOAD MANAGEMENT

Demand-side load management (DSM) is also called as demand-side response (DSR), it is the modification of consumer demand for energy through various methods such as financial incentives and behavioral change. By using DSM, load to be controlled by assigning load priority, to fulfil the power requirement of a user and also reduce the cost function. DSM proceeds control action to balance the energy demand and supply between the consumer and supplier in the system. The balancing of energy is to establish real-time and an efficient relation between consumer and supplier. By using DSM technique maximum satisfaction to be achieved at minimum user cost.

The proposed model express the DSM technique for effective power utilization to reduce the cost without affecting user satisfaction. This is achieved by the demand side load management technique of shifting the load during peak utilization hours to satisfy the user requirement and demand market. The proposed model provides an effective DSM technique by using fuzzy inference system for energy schedule. Based on the energy demand the priority to load and operation of household appliances are planned for each and every hour of the day.

In our proposal, fuzzification is used to convert crisp values into fuzzy value. The input and output linguistic variables are selected from the DSM system and the membership function is used to represent the linguistic ranges in the fuzzy inference system. By using linguistic ranges, the fuzzy rules are formed according to user satisfaction and user cost function. The center of mass defuzzification technique is used to convert a fuzzy value into human understandable crisp value.

III. THE FUZZY LOGIC DSM SYSTEM

Fuzzy logic is a logical operation which helps the system to operate the human-basic decision approach. Fuzzy manages vague and imprecise information of data. In this paper a fuzzy inference system can decrease the cost of power utilization and gives more satisfaction for the user by balancing the load. The fuzzy system allocates predefined priority control over the loads according to the usage of the user. The design of fuzzy inference system is used to turn off the interruptible loads during peak hours automatically.

This system calculates a value at each hour of the day. The main goal of fuzzy model is that reducing the energy demand during peak hours and saving energy by balancing the load. The proposed fuzzy system model is user helpful to turn off and turn on the loads when power exceeds the priority level.

The proposed fuzzy inference system provides more satisfaction for the user by minimizing the cost with help of all the parameters which are listed below:

Power consumption
Time
Satisfaction
Cost

The input variables are declared as three linguistic ranges Low, Medium, High and the output variable is taken five linguistic ranges Very Low, Low, Medium, High, and Very High. The contribution work is characterized to as triangular and trapezoidal.

A. Fuzzy Logic Controller

Fuzzy inference (reasoning) is the direct procedure of mapping the output from a given input using fuzzy logic. The controller has input as crisp value, using fuzzification crisp input value converted into fuzzy value. The output obtained from set of fuzzy rules is based on the combination of input and output sets. The Mamdani Fuzzy inference system is performed by following steps: determine set of fuzzy rules, fuzzification, output aggregation and defuzzification using center of mass technique.

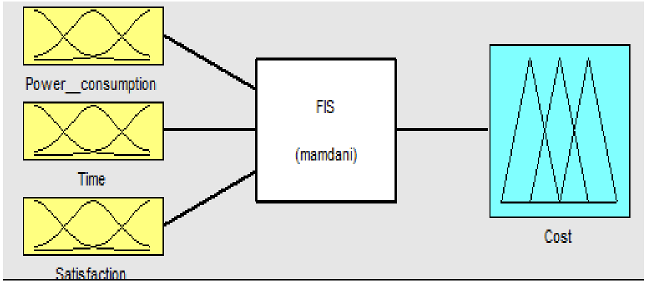

Figure1: Fuzzy inference system

B. Fuzzy Membership Function

To define fuzzy rules the fuzzy membership function gives a relation between input and output variables. The membership function is a curve that establish mapping of input and output variables in the range between 0 and 1.

a) Power consumption

The fuzzy linguistic value ranges from 0 to 1. The power consumption has 3 linguistic values namely low, medium and high. Where low ranges from 0 to 1700 and medium ranges from 1000 reach top heap at 2150 to end 3000. The overlapping between the low and medium level at the point 1000. Similarly, high ranges from 2500 and reaches 4000, its overlapping point at 3000. The trapezoidal membership function is used by low and high whereas medium supplies triangular membership function.

$$\mu_l(x) = \begin{cases} 1, & \mathrm{x} \in 1000; \\ (1700 - x)/200, & \mathrm{x} \in (1000, 1700); \\ 0, & \mathrm{x} \geq 1700. \end{cases}$$

$$\mu_m(x) = \begin{cases} (x - 1000)/1150, & \mathrm{x} \in (1000, 2150); \\ (3000 - x)/1850, & \mathrm{x} \in (2150, 3000); \\ 0, & \mathrm{x} \geq 3000. \end{cases}$$

$$\mu_h(x)=\begin{cases}(x-2500)/500, & x\in(2500,3000);\\ 1, & x\in(3000,4000);\\ 0, & x>4000.\end{cases}$$

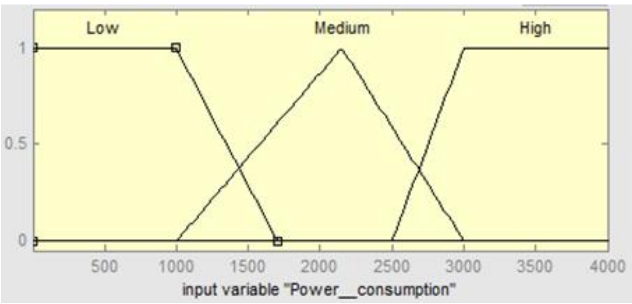

Figure 2: Membership function for power consumption

b) Time

Let the time is taken by 24 hours per day. Where low ranges start from 0 to 11 and medium ranges from 7 reaches top heap at 12.5 to end 18. The overlapping between the low and medium level at the point 7. Similarly, high ranges from 14 and reaches 24, its overlapping point at 18.

$$\mu_l(x)=\begin{cases}1, & x\in 7;\\ (11-x)/4, & x\in(7,11);\\ 0, & x\geq 11.\end{cases}$$

$$\mu_m(x)=\begin{cases}(x-7)/5.5, & x\in(7,12.5);\\ (18-x)/5.5, & x\in(12.5,18);\\ 0, & x\geq 18.\end{cases}$$

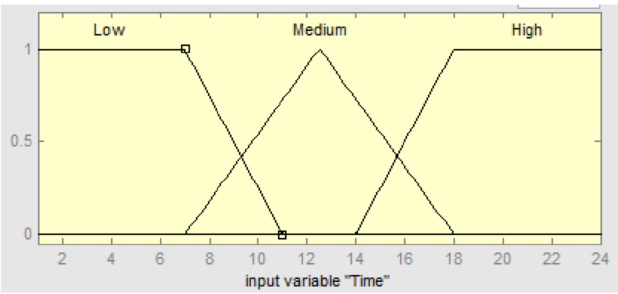

Figure 3: Membership function for time

$$\mu_h(x)=\begin{cases}(x-14)/4, & x\in(14,18);\\ 1, & x\in(18,24);\\ 0, & x>24.\end{cases}$$

c) Satisfaction

The satisfaction announcement is [0 – 100%]. Where low ranges begin from 0 to 40% and medium ranges from 25% reaches top heap at 50% to end 75%. The overlapping between the low and medium level at the point 25%. Similarly, high ranges from 60% and reach 100%, its overlapping point at 75%.

$$\mu_l(x)=\begin{cases}1, & x\in 25;\\ (40-x)/15, & x\in(25,40);\\ 0, & x\geq 40.\end{cases}$$

$$\mu_m(x)=\begin{cases}(x-25)/25, & x\in(25,50);\\ (75-x)/25, & x\in(50,75);\\ 0, & x\geq 75.\end{cases}$$

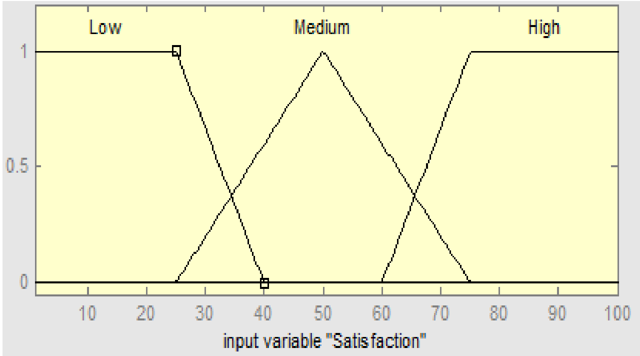

Figure 4: Membership function for satisfaction

$$\mu_h(x)=\begin{cases}(x-60)/15, & x\in(60,75);\\ 1, & x\in(75,100);\\ 0, & x>100.\end{cases}$$

a) Cost

The fuzzy very low ranges begin at 0 and end with 400, overlap with a low-level at 200. At that point the low range starts from 200 to 650, it achieves a heap point at 425 similarly overlapping with a medium at the point of 500. The fuzzy medium level begins 500 to 950 and has a peak point of 725, overlap with high at 800. The high range begins at 800 to 1400.

$$\mu_{vl}(x)=\begin{cases}x, & x\in 200;\\ (400-x)/200, & x\in(200,400);\\ 0, & x\geq 400.\end{cases}$$

$$\mu_l(x)=\begin{cases}(x-200)/225, & x\in(200,425);\\ (650-x)/225, & x\in(425,650);\\ 0, & x\geq 650.\end{cases}$$

$$\mu_m(x)=\begin{cases}(x-500)/225, & x\in(500,725);\\ (950-x)/225 & x\in(725,950);\\ 0, & x\geq 950.\end{cases}$$

$$\mu_h(x)=\begin{cases}(x-800)/250, & x\in(800,1050);\\ (1300-x)/250, & x\in(1050,1300);\\ 0, & x\geq 1300.\end{cases}$$

$$\mu_{vh}(x)=\begin{cases}(x-1050)/250, & x\in(1050,1300);\\ 1, & x\in(1300,1500);\\ 0, & x>1500.\end{cases}$$

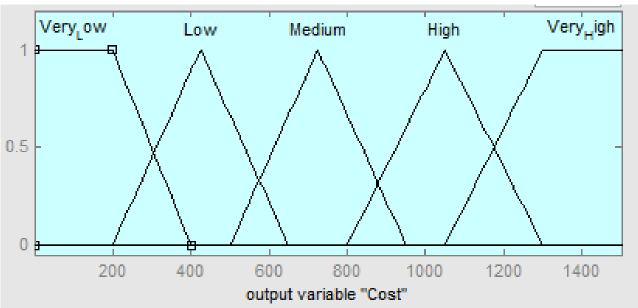

Figure 4: Membership function for cost

C. Fuzzy Rules

Fuzzy rules used to connect input and output variables through the fuzzy set activity utilizing t-norm. T-norms are utilized as an AND connector. The number of rules depends on the membership function to examine input and output variables. The system efficiency depends on the number of rules. If rules become more the output gets exact value. Fuzzy logic rules assist load transfer between high priority to low priority. The rules are created depends on consumer restraint. The linguistic variables are implemented in the form of IF-theory and, THEN-resultant, here theory specifies collected input variable (power consumption, time, satisfaction) and the resultant specifies collected output variable (cost). The fuzzy rules are used to get a required output (maximum satisfaction at minimum cost). After the fuzzy output defuzzification is performed to have a crisp value of output.

Table 1. Fuzzy rules

Consumption	Time	Satisfaction	Cost
Low	Low	Low	Very Low
Low	Low	Medium	Low
Low	Low	High	Medium
Low	Medium	Low	Low
Low	Medium	Medium	Medium
Low	Medium	High	High
Low	High	Low	Low
Low	High	Medium	High
Low	High	High	High
Medium	Low	Low	Very Low
Medium	Low	Medium	Low
Medium	Low	High	Low
Medium	Medium	Low	Medium
Medium	Medium	Medium	Medium
Medium	Medium	High	High
Medium	High	Low	High
Medium	High	Medium	High
Medium	High	High	Very High
High	Low	Low	Low
High	Low	Medium	Low
High	Low	High	Low
High	Medium	Low	Low
High	Medium	Medium	Medium
High	Medium	High	Medium
High	High	Low	Medium
High	High	Medium	Very High
High	High	High	Very High

IV. RESULTS AND DISCUSSION

The result of fuzzy inference system in the demand side load management of residential building was derived from the utilization data user. The investigation of load management was conducted to analyze a proposed maximum user satisfaction and minimum cost function. A predefined budget was considered at all hours of the day, peak loads are shifted to the off peak hours. During the system design, assign priority to electrical appliances that user wanted to spend on energy at every hour. The required input data was obtained from user load audit and the user satisfaction audit. The satisfaction table and the load table data are to be continued.

A. Load calculation

The load table data was selected by the following consideration: the rooms accessible on the consumer household, the user utilized electrical appliances, the rating of every appliance and time taken by, it may be ON or OFF. The cost of each electrical appliances is calculated and the budget of electrical energy is Rs3/day. A Cost/unit estimation relates the user power utilization and required satisfaction got from the table.

Table 2: Load table of an electricity user

S/N	Appliance	Unit Wattage [W]	Quantity
1	Lighting	40	1
2	Fan	60	1
3	Television	150	1
4	Refrigerator	150	1
5	Water Heater	4000	1

B. User satisfaction tabulation

The user satisfaction table is collected by the user satisfaction audit, it is discovered by three different tables (time-based, device based and absolute satisfaction). These satisfactions depend on the user utilizing electrical appliances at various time of the day. The table containing data is a numerical value somewhere in the range of '0' and '1' for every electrical appliance. By utilizing this data with time based and device based satisfaction was computed. An absolute satisfaction table is obtained from time and device based satisfaction table.

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Table 3: Time-based satisfaction table

HOURS	EQUIPMENT				
	Lighting	Fan	Television	Refrigerator	Water Heater
1	0.0	1.0	0.0	0.1	0.0
2	0.0	1.0	0.0	0.1	0.0
3	0.0	1.0	0.0	0.1	0.0
4	0.0	1.0	0.0	0.1	0.0
5	0.7	1.0	0.0	0.1	0.7
6	0.8	1.0	0.0	0.1	0.8
7	1.0	0.8	0.6	0.4	1.0
8	0.7	0.5	0.3	0.4	1.0
9	0.4	0.1	0.1	0.5	0.2
10	0.0	0.0	0.0	0.2	0.0
11	0.0	0.0	0.0	0.3	0.0
12	0.0	0.6	0.0	0.5	0.0
13	0.0	0.8	0.0	0.5	0.0
14	0.0	0.8	0.0	0.5	0.0
15	0.0	0.0	0.0	0.1	0.0
16	0.0	0.0	0.1	0.1	0.0
17	0.0	0.1	0.1	0.1	0.1
18	0.8	0.3	0.3	0.3	0.1
19	1.0	0.4	0.8	0.3	0.3
20	1.0	0.6	1.0	0.3	0.3
21	1.0	1.0	1.0	0.2	0.2
22	1.0	1.0	0.8	0.1	0.0
23	0.8	1.0	0.6	0.1	0.0
24	0.3	1.0	0.4	0.1	0.0

C. Time-based satisfaction

The time-based satisfaction table is drawn by the connection between electrical appliances utilization of this model and each hour of the day. Here the satisfaction is denoted as 'α' and additionally allocate the maximum user (crest) satisfaction hour is, α (tmax) =1. Alternate hours of the day are taken from an amount of satisfaction by user utilized. The user will not utilize any appliances at a specific time it is noted as α (tmin) =0. Table 2 demonstrates the entire time-based satisfaction of usage of the average user. The time-based satisfaction is computed to find which device will be ON at a specific time and the data's are filled depending on the device rating with the amount of time the device is used.

For every time interval of the day, the customer chooses if appliance #A would yield how much level of satisfaction is utilized. At the end of the day, the satisfaction expected from appliance #A utilization at different hours (ti) to the maximum satisfaction at hour tmax is compared. This estimation results the user satisfaction at different hours ti (αA(ti)) ranges from 0 (zero level of satisfaction) to 1 (maximum satisfaction)

$$0 \leq \alpha\,(ti) \leq 1 \quad ; \quad i = 1, 2, 3, \ldots, 24$$

D. Device-based satisfaction

The device based satisfaction table is computed based on priority of appliances, that is switched ON or OFF at a specific time interval. The device based satisfaction table data is derived from the connection between time and appliances need level (which appliance yield a maximum satisfaction at particular hour ti). The level of user satisfaction is represented as 'β' and the maximum satisfaction hour is, β (tmax) =1. In table 3 maximum satisfaction intervals are noted as '1', Alternate segments are filled by the priority of appliances. The device based satisfaction is, β (tmin) =0. Table 3 demonstrates the entire device based satisfaction of the average user. For one of the appliances utilized at hour ti, the user calculates satisfaction level of other appliances (i.e. βA(ti), βB(ti), and so on.) it would be compared with the other appliances in respect to the satisfaction got from device #A. This estimation results the user satisfaction range from 0 (zero level of satisfaction) and 1 (maximum satisfaction).

Table 4: Device-based satisfaction table

HOURS	EQUIPMENT				
	Lighting	Fan	Television	Refrigerator	Water Heater
1	0.0	1.0	0.0	0.1	0.0
2	0.0	1.0	0.0	0.1	0.0
3	0.0	1.0	0.0	0.1	0.0
4	0.0	1.0	0.0	0.1	0.0
5	0.7	0.8	0.0	0.1	0.1
6	1.0	0.8	0.0	0.1	0.6
7	0.8	0.8	0.6	0.2	1.0
8	0.6	0.6	0.8	0.4	1.0
9	0.2	0.2	0.6	0.4	0.4
10	0.0	0.0	0.0	0.1	0.0
11	0.0	0.0	0.0	0.1	0.0
12	0.0	0.6	0.0	0.1	0.0
13	0.0	0.6	0.0	0.1	0.0
14	0.0	0.5	0.0	0.1	0.0
15	0.0	0.0	0.1	0.1	0.0
16	0.0	0.0	0.1	0.1	0.0
17	0.0	0.0	0.1	0.1	0.0
18	0.2	0.1	0.2	0.1	0.0
19	1.0	0.8	0.4	0.6	0.4
20	1.0	0.8	0.6	0.8	0.4
21	1.0	1.0	1.0	0.4	0.3
22	1.0	1.0	1.0	0.2	0.0
23	0.8	1.0	0.4	0.1	0.0
24	0.4	1.0	0.2	0.1	0.0

E. Absolute satisfaction

The equalization of above two satisfaction results in absolute satisfaction. The overall user satisfaction was derived from the resultant effects of time-based and device based satisfaction of a user.

The total satisfaction of a device at the hour it is given as:

$$\gamma(ti) = \frac{\sqrt{(\alpha\,(ti))^2 + (\beta\,(ti))^2}}{\sqrt{2}}$$

where α(ti) is the time-based satisfaction of one appliance at time interval ti and also β (ti) is the device based satisfaction of same appliance at time interval ti. The time and device based satisfaction to be equalized by utilizing the denominator '√2', the satisfaction reaches maximum of value

1. For example, an hour t = 8, Table 2 shows the time-based satisfaction of the television is 0.3 while Table 3 shows the device based satisfaction at the same time is 0.8.

Subsequently the absolute satisfaction of the television at hour 8 can be determined as

$$\gamma(t8) = \frac{\sqrt{(0.3)^2 + (0.8)^2}}{\sqrt{2}} = 0.85/1.414 = 0.6$$

The absolute satisfaction of all the appliances utilized in a system was calculated and shown in Table 5.

F. Scenario budget = Rs3/day

In this current budget Rs3/day was considered every day for the unaffordable family. Based on the budget, to calculate the energy allocation design the fuzzy inference system was executed that would submit the satisfaction as maximum at minimum cost to the medium earner household. The fuzzy inference system assigns energy to support low rating devices and maximum satisfaction of user. The main reason to introduce fuzzy system in this paper to minimize the user cost.

From table 4, the Sdesired (total desired satisfaction) was determined by the summation of all the absolute satisfaction of user for all appliances at every hour of the day. The mathematical expression as follows,

Table 5: Absolute satisfaction table

HOURS	EQUIPMENT				
	Lighting	Fan	Television	Refrigerator	Water Heater
1	0	1	0	0.1	0
2	0	1	0	0.1	0
3	0	1	0	0.1	0
4	0	1	0	0.1	0
5	0.7	0.9	0	0.1	0.5
6	0.9	0.9	0	0.1	0.7
7	0.9	0.8	0.6	0.3	1
8	0.6	0.5	0.6	0.3	1
9	0.3	0.1	0.4	0.4	0.3
10	0	0	0	0.1	0
11	0	0	0	0.1	0
12	0	0.6	0	0.3	0
13	0	0.7	0	0.3	0
14	0	0. 6	0	0.3	0
15	0	0	0.1	0.1	0
16	0	0	0.1	0.1	0
17	0	0	0.1	0.1	0
18	0.5	0.1	0.2	0.2	0
1	1	0.5	0.6	0.4	0.3

9					
20	1	0.6	0.8	0.6	0.3
21	1	0.8	1	0.3	0.2
22	1	1	0.9	0.2	0
23	0.8	1	0.5	0.1	0
24	0.3	1	0.3	0.1	0

$$\text{Sdesired} = \sum_{i=1}^{24} \sum_{h=A}^{E} \gamma(ti)$$

Here 'i' represents all time of the day, it varies from 1 to 24 and h represents the appliances used in this system (A to E). Alternatively achieved satisfaction (Sacheived) is determined by fuzzy inference waveform at all time of interval for all appliances.

The result derived from the fuzzy input, output membership functions, and fuzzy rules is still vague. To make that fuzzy output, defuzzification process is needed. The maximum satisfaction at minimum cost function is analyzed by using fuzzy inference system waveform.

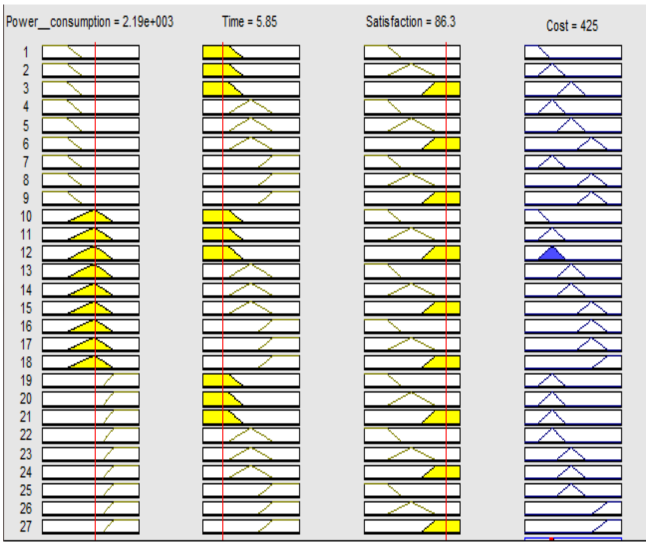

Figure 6: Aggregation of fuzzy output

The surface viewer is a good interpretation of FIS when dealing with 2 input and output model. It gives a 3D interpretation of the input-output relations in the problem domain. When using the surface viewer of MATLAB Fuzzy toolbox, limit it to only 2 inputs and 1 output thus becoming a 3D system. Get x and y and project it vertically to get z, here x-axis denotes satisfaction, y-axis denotes power consumption and z-axis denotes cost function of the system model. In this paper, any two inputs are selected to view depends on the corresponding output. Generally the fuzzy simulation has the input data as crisp set of value. In real execution, the user has the information which would be the fuzzily indicated value. Here the medium income household is taken to energy audit and determine the power utilization without fuzzy inference system.

The power utilization exceeds the maximum point at peak hours, requires utilization of electrical energy, protection is achieved.

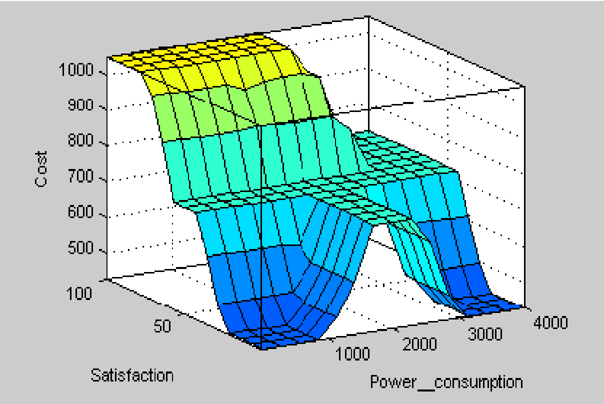

Figure 7: Surface view of fuzzy output

Fig.8 shows the diagram curved between power utilization and hour in a day. It is the hourly power consumption when the use of the fuzzy logic controller. It shows the operation of demand-side management systems before and after fuzzy logic controller modeling. By using a fuzzy system consumption of power can be reduced at every hour of the day shown in the figure.

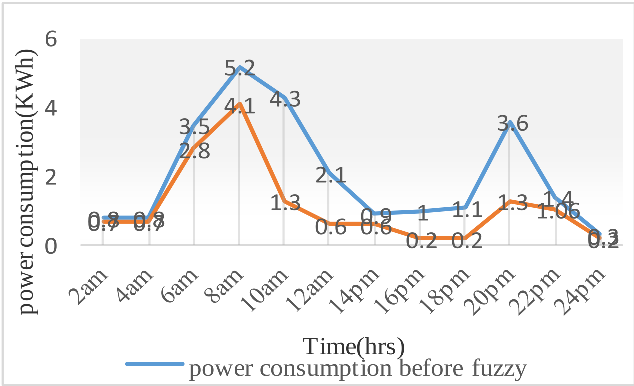

Figure 8: Energy utilization curve before and after fuzzy

V. CONCLUSION

In this study, we have investigated a demand side load management system to maximize the customer satisfaction and minimize the users power utilization cost. The DSM designed to incorporate the dynamic nature of the power consumption by applying fuzzy inference system. The user satisfaction is fuzzified to obtained a maximized performance by minimizing the power consumption and user cost with a maximum utilization time. This is achieved by adjusting the usage of energy based ON peak and OFF peak time. The experiment was conducted, demonstrates the effectiveness of the proposed fuzzy based DSM that maximizes the user satisfaction. As the extension of this work, we will use multiple linear regression and optimization algorithm to find the objective function for maximizing the other factor for better user satisfaction.

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