Energy conservation using Fuzzy logic and DSM techniques- A case study

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***Abstract*— Electrical energy is a vital source for any developing nation. To meet the growing electricity demand, power generating plants of all types are being installed; even then the gap between the supply and demand is continuously increasing due to the depletion of the natural sources. The only option left is optimal utilization of available energy sources. This paper presents the application of fuzzy logic and Demand Side Management technique to air conditioner load to achieve increase in the average turn off period of an Air Conditioner per day to meet the optimal power consumption and consumer satisfaction. Simulation results are presented to show effectiveness of the proposed DSM strategy for energy conservation.**

***Index Terms*— Air Conditioner (A/C), Business People for Outsource (BPO'S), Demand Side Management (DSM), Differential Tariff (DT), End Use Equipment Control (EUEC), Load Priority Technique (LPT).**

I. INTRODUCTION

THE most flexible, un-substitutable form of energy in the recent times is electrical energy. It is a coveted form of energy because it can be generated centrally in bulk and transmitted economically over long distances. It has been a critical resource for all nation building activities which keep the countries' wheels on progress and economy to prosper. So, demand for electricity is on the ever increasing side. As this electrical energy can be easily converted into other forms of energy, ease of its control has fed to the increase in demand in both the industrial and domestic sectors. Hence, increase in demand for electrical energy, the demand for high quality, reliable power supply has compelled the power engineers to focus their attention on the new technological developments in the power sector operation and improvement.

So, in order to overcome this ever growing demand for electricity, in general the generating plants like hydro, thermal, nuclear, diesel are being installed. But the natural fuel resources for this type of generating plants are limited and not renewable. Further, uncertainties in fuel availability, quality of fuel, high level prices and environmental barrier put a crimp on installation of new generating plants. Unfortunately, the present day technology has not yet been developed to that extent of tapping effectively and reliably the enormous amount of energy present in nature such as solar, wind, tidal, geothermal energy. Under these circumstances, one of the options left is to utilize the available electrical power very effectively by energy conservation [1].

Energy conservation is concerned with those actions which reduce the total energy consumption. Examples of energy conservation include the use of more or better loss prevention methods, better efficiency and curtailment of activities to reduce the overall consumption of electrical energy.

According to H.G.Gopal [2], it is in the best interest of the utility companies as well as the consumer to try to reduce these high peaks demand profile as much as possible. While reducing the peak demands, however, utility companies will also need to compete for new customers and ensure current customer satisfaction with their performance and services as a new model (direct load control) based on fuzzy logic technique, which shows savings in electrical energy consumption and payback period.

P.Ravibabu et al describes a fuzzy logic [3] and differential tariff technique based on demand side management (DSM) strategy showed simulation results of the proposed DSM strategy. Among the various advancements in the power sector Demand Side Management in power systems is latest technology.

This paper presents a new application of expert system techniques to an Air Conditioner. Now-a-days, AC's are of general use, energy consumed by an AC can be conserved by the application of expert system techniques using fuzzy logic. Fuzzy logic is an intelligent system which controls the AC by increasing the turn off time in a certain period [4]. The steps followed in order to increase turn off time are as follows:

1) Fuzzy logic load controller,
2) Fuzzy membership functions,
3) Fuzzy rules.

Based on the methodology, an intelligent system is developed which can be used to control the Air conditioner. The proposed intelligent system is implemented in Mat lab. Implementation issues on knowledge representation, portability of the system, and computational efficiency are discussed.

II. DSM TECHNIQUES ADOPTED

There are several reasons why utilities manage demand through special programs. The utility's reaction was the introduction of Demand Side Management programs to overcome all these problems. The concept of DSM program in power systems is to bring both supplier and consumer around a common platform for effective utilization of available electrical energy with minimum inconvenience and maximum profit. What actually DSM means is a measure taken by utilities to influence the amount of timing of customer energy demand in order to utilize scarce energy resources most efficiently [5]. These techniques are most useful in real time pricing environment. A large number of DSM Techniques are available and selecting the most suitable and appropriate technique is the most crucial part. Some of the DSM Techniques are as follows:

a) Peak clipping valley filling,
b) Differential Tariff,
c) Load priority Technique,
d) End use equipment control.

a) Peak Clipping and Valley Filling:

The consumers demand curve consists of peaks and valleys. Reduction of peak demand reduces the demand charges of the consumer. Peak clipping is achieved by direct control of equipments which are responsible for the peaks. It helps in matching the available power with the demand without going for additional generation, thereby reducing capital charges, fuel charges and operation charges.

The principle involved in valley filling is to buildup load or consume power during light load periods of supply system. This results in high efficiency and lower cost of operation because of improved load factor or energy efficiency of the system. This flattens the load curve more. In this way this technique helps in reducing the peaks and improving load factor.

b) Differential Tariff:

To implement the above mentioned method of flattening the load curve, this technique is employed. As the variable load has some peaks and valleys, the supplier must install his equipment which will be capable of supplying the peak load of consumer by which we can supply the consumer's peak. But during valley period, the equipment will be underutilized thereby decreasing the energy efficiency of equipment. Hence the supplier will insist or will try by all possible means that his equipment is utilized to its rated capacity for the entire duration whenever it is in the commissioned state. With this type of tariff, the consumer will try to consume more energy during valley periods by avoiding energy consumption during peak hours. This is the basic principle of Differential Tariff.

c) Load Priority Technique:

In developing LPT, the loads are classified into non-interruptible and interruptible loads. Non-interruptible loads are the high priority loads while the interruptible loads are the low priority loads. The priorities are assigned to the loads in discussion with the respective section supervisors giving immense importance to the production schedule.

The success of LPT is totally dependent on the development of various load priorities for operation, which will not disturb the production schedule, and gives enough scope of reduction of load demand. In order to achieve this, close interaction between the various sections of the industry is required.

d) End Use Equipment Control

It deals with the control operation of various end use appliances for better utilization of available resources without effecting the production and supply. This is one of the most active areas of DSM Technology development. This is because some of the bulk industrial loads exhibit maximum peaks and valleys in their load curves. Due to increased activities of BPO'S, from most of their consumption patterns, it is found that the electrical power consumption is exceeding beyond the permitted levels. So for these bulk consumers, there is more scope for flattening these curves.

III. FUZZY LOGIC

Fuzzy set theory was introduced by LOTFIE ZADEH in 1965. Fuzzy set theory is considered as generalization of the traditional probability set theory. Fuzzy set theory offers new methods for modeling human reasoning and for presenting and utilizing linguistic descriptions in computerized inference.

Probability theory deals with uncertainty that results from random behavior, where as fuzzy theory addresses the uncertainty resulting from boundary conditions, Figure.1 shows generalized fuzzy block diagram and tells how the fuzzy system works [6].

Matlab provides software to implement this fuzzy logic through the fuzzy toolbar. Various step to be followed.

i. Fuzzy load controller

Fuzz load controller it provides a block diagram which consists of inputs, outputs and controller block. In the case of Air Conditioner [7], the inputs and outputs are as follows:

1) Outside temperature,
2) Preferred temperature,
3) Comfort level,
4) Size of the room
5) Time (output).

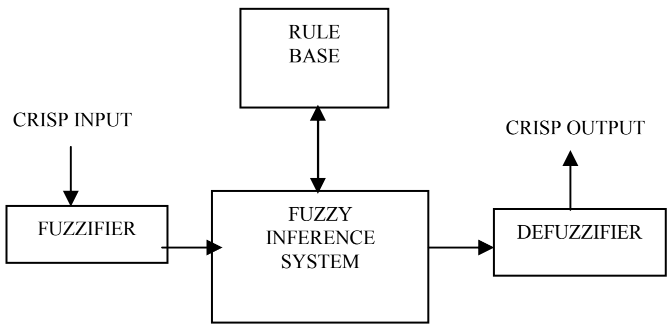

Figure.1 Fuzzy block diagram

The controller consists of Fuzzification and defuzzification. It takes four crisp input values, fuzzifies them, and assigns a fuzzified signal to control the operation of air conditioner based on the assigned rules and membership functions (MF). The control signal is then converted to one crisp signal by defuzzification process and the output is got through the output block. Figure 2 shows the block diagram of a Fuzzy controlled air conditioner.

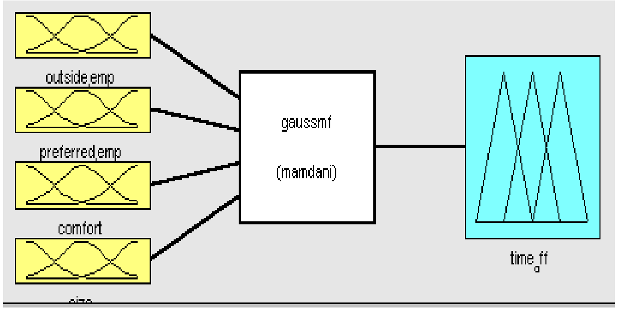

Figure.2 Fuzzy block diagram of an Air Conditioner

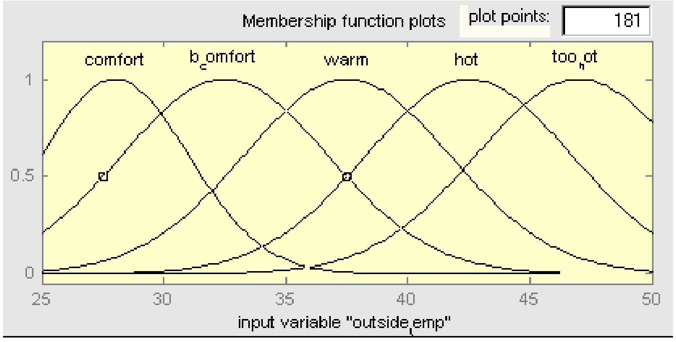

Figure.3 Member ship function of Outside temperature

ii. Fuzzy inference system (FIS)

FIS is one that uses fuzzy sets to make decisions or draw conclusions. A fuzzy set allows for an object to be a number of a set to some degree. Development of this idea led to many successful implementations of fuzzy systems / FIS. Essentially the advantage of a fuzzy set approach is that it can usefully describe imprecise, incomplete vague information. However, being able to describe such information is of little practical use unless we can infer with it. The accepted method of the application of fuzzy sets is analogous to, but different from, the way a conventional knowledge based system is organized. Assuming that there is a particular problem that can't be tackled by conventional model, after some process the 'base' fuzzy sets that describe the problems are to be determined. These rules then have to be combined which are referred to a rule composition. Finally conclusions have to be drawn by defuzzification. FIS can be defining as follows:

1. The base fuzzy sets that are to be used, as defined by their MF's.
2. The rules that combine the fuzzy sets.
3. The fuzzy composition of the rules
4. The defuzzification of the solution fuzziest

All the components of a FIS present complex, interacting choices that are to be made. Each component of the FIS presents its own problems, and all approaches to date, typically, concentrate on one (or) two areas and are domain dependent. The rest of this report describes each component in turn and discusses the approach that has been used to control the AC.

iii. Fuzzy Member ship Functions:

`Membership functions for fuzzy sets can be defined in many numbers of ways as long as they follow the rules of the definition of a fuzzy set. The shape of the MF used defines the fuzzy set and so the decision on which type to use is dependent on the purpose. The member ship function (MF) choice is the subjective aspect of fuzzy logic; it allows the desired values to be interpreted appropriately. Fuzzy MF's are needed for all input and output variables and these member ship functions are shown in Figure.3 to Figure. 7. Linguistic rules are framed for both the inputs and the output variables using the selected MF's. Selection of MF plays a major role in providing the output. All the inputs and outputs are to be defined using only one Membership Function. GAUSS MF was found to be most suitable to control the operation of an AC.

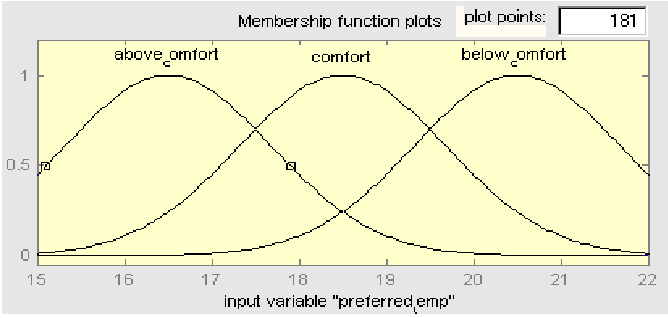

Figure.4 Member ship function of preferred temperature

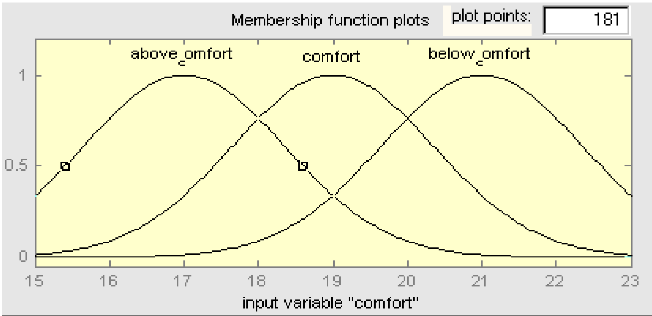

Figure.5 Member ship function of Comfort level

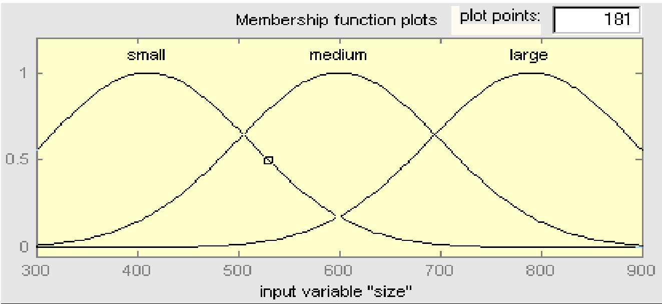

Figure.6 Member ship function of Size of the room

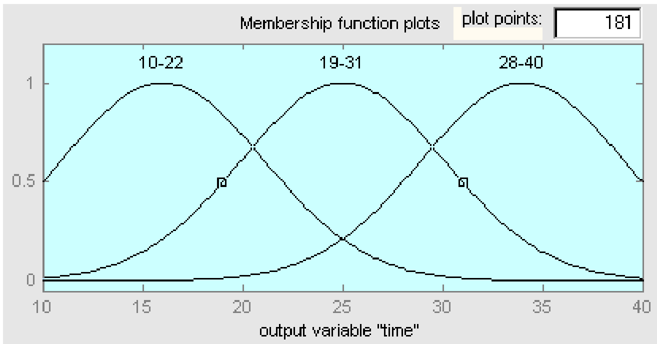

Figure.7 Member ship function of Time

IV. FUZZY RULES

Fuzzy rules formation is the vital part of the entire fuzzy logic. The fuzzy set approach offers the possibility of handling vague (or) uncertain information. Fuzzy rules can be represents in the following way:

If (x is A) AND (Y is b) …..AND…..THEN (z is C)

In the present model the fuzzy controller helps in reducing the electricity power consumption of an AC, at the same time meeting the customer satisfaction like preferred temperature in a room must be achieved. Considering these needs and constraints, fuzzy rules are defined. Rules are framed using the inputs and outputs in the particular ranges. Each input and output is divided into ranges, like outside temperature is classified into 5 ranges comfort, above comfort; warm, hot, too hot, preferred temperature to 3 ranges above comfort, comfort, below comfort, comfort level is into 3 ranges same as that of preferred temperature. Size of the room is into 3 ranges small, medium and large. And finally the output time is divided into 3 ranges. Every input and output is defined in unique FIS with corresponding MF's ranges of same type. Rules are framed linearly combining all the input ranges in different combinations according to their appropriate output range. Framing the possible number of rules will provide the best output. Fuzzy composition is the place where all the rules are composed easily and are stored. Rules are also viewed pictorially. To control A/C according to the needs and requirements of consumers 180 rules are designed. Figure.8 shows the rule viewer in mat lab, few of the rules are listed below.

Rules:

1. If (outside temp. is comfort) and (preferred temp. is above comfort), and (comfort level is comfort), and (size is small), then (time is 10-22 mins.)
2. If (outside temp. is comfort) and (preferred temp. is comfort), and (comfort level is above comfort), and (size is large), then (time is 10-22 mins.)
3. If (outside temp. is comfort) and (preferred temp. is below comfort), and (comfort level is below comfort), and (size is medium), then (time is 10-22 mins.)
4. If (outside temp. is comfort), and (comfort level is above comfort), and (size is large), then (time is 19-31 mins.)
5. If (outside temp. is below comfort) and (preferred temp. is above comfort), and (comfort level is above comfort), and (size is medium), then (time is 19-31 mins.)
6. If (outside temp. is below comfort) and (preferred temp. is above comfort), and (comfort level is comfort), and (size is large), then (time is 19-31 mins.)
7. If (outside temp. is below comfort) and (preferred temp. is below comfort), and (comfort level is below comfort), and (size is medium), then (time is 10-22 mins.)
8. If (outside temp. is below comfort), and (comfort level is below comfort), and (size is small), then (time is 10-22 mins.)
9. If (outside temp. is warm) and (preferred temp. is above comfort), and (comfort level is below comfort), and (size is medium), then (time is 19-31 mins.)
10. If (outside temp. is warm) and (preferred temp. is comfort), and (comfort level is above comfort), and (size is small), then (time is 10-22 mins.)
11. If (outside temp. is warm) and (preferred temp. is below comfort), and (comfort level is comfort), and (size is medium), then (time is 19-31 mins.)
12. If (outside temp. is warm), and (comfort level is comfort), and (size is small), then (time is 10-22 mins.)
13. If (outside temp. is hot) and (preferred temp. is above comfort), and (comfort level is below comfort), and (size is large), then (time is 28-40 mins.)
14. If (outside temp. is hot) and (preferred temp. is comfort), and (comfort level is comfort), and (size is medium), then (time is 19-31 mins.)
15. If (outside temp. is hot) and (preferred temp. is below comfort), and (comfort level is above comfort), and (size is small), then (time is 10-22 mins.)
16. If (outside temp. is hot), and (comfort level is comfort), and (size is large), then (time is 28-40 mins.)
17. If (outside temp. is too hot) and (preferred temp. is above comfort), and (comfort level is below comfort), and (size is large), then (time is 28-40 mins.)
18. If (outside temp. is too hot) and (preferred temp. is comfort), and (comfort level is comfort), and (size is medium), then (time is 19-31 mins.)
19. If (outside temp. is too hot) and (preferred temp. is below comfort), and (comfort level is above comfort), and (size is small), then (time is 10-22 mins.)
20. If (outside temp. is too hot), and (comfort level is comfort), and (size is large), then (time is 28-40 mins.)

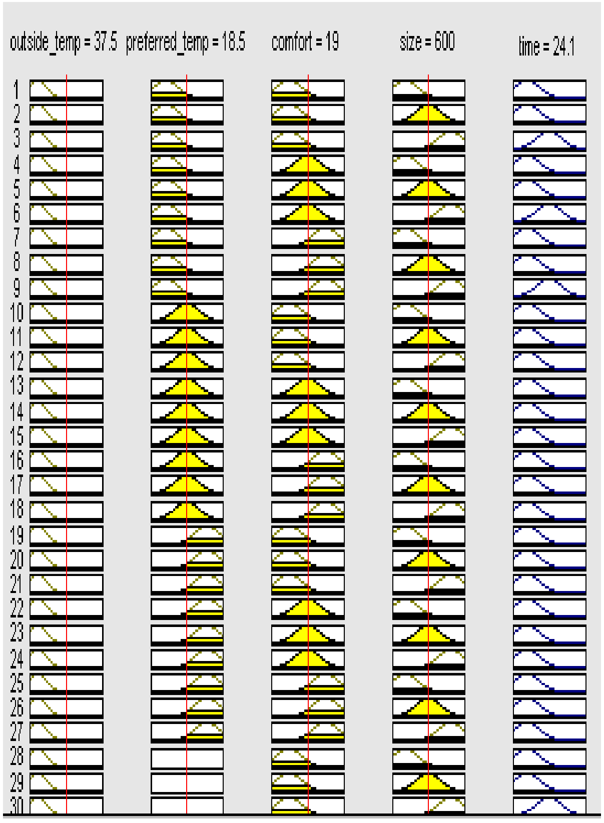

Figure.8 Fuzzy rule viewer

V. CASE STUDY

The unit selected for investigation is GENPACT; BPO'S located in Hyderabad, India. It works for 24hrs a day and 20days a month [8]. This industry is considered for case study possesses approximately 100 A/C's per floor which works for 24 hours per day. The power consumption of single AC is 58.8 kWh per day and 1764 kWh per month,(Table I, Table II) which is leading to large amount of power consumption only in case of cooling machines like A/C. A conventional air conditioner is taken for case and compared with air conditioner with Fuzzy logic.

Capacity	A/C type	Power rating
2 Ton	Conventional, single phase	2.45 kW

Table I Technical specification of A/C

Table II Energy consumption of conventional A/C

Sl. No	Period	Power consumption of 100 A/C's
1	Per hour	245kW
2	Per day	5880kWh
3	Per month	176.4MWh

Table III Fuzzy results

OT.	PT	CL	Size	Time	Time Off
21	20	18	450	0-5	18.7
27	19	20	450	5-8	18
31	18	22	450	8-10	21.7
36	17	19	450	10-14	21
44	15	17	450	14-18	19.4
25	18	20	450	18-21	17.4
21	20	18	450	21-24	20.7

VI. RESULTS AND DISCUSSIONS

A conventional air conditioner is taken for case and compared with the operation of air conditioner with operation of an air conditioner Fuzzy logic. The results like energy consumption, cost savings, payback period and rate on investment of a conventional A/C and A/C with fuzzy logic are calculated and compared. These calculated results of an A/C (before and after application of fuzzy logic is shown below. Hence, the results of the above proposed method are compared and discussed with the results of H. Salehfar et al as shown in table IV. The results highlighted in the Table IV are turn-on period, turn-off period, and energy savings. The results of the proposed method are turn-on period, turn-off period, energy savings and Payback Period. The fuzzy rules developed in the proposed method are much more efficient than the rules developed by and finally the proposed fuzzy controlled A/C is an intelligent system which full meets the customer satisfaction and results in savings in the energy bill.

The total working hours of the A/C in a day = 24 hours
Energy consumed per A/C per hour = 2.45 kWh

Energy consumption details of a conventional A/C

Energy consumption of one A/C = 58.8 kWh per day
Energy consumption of one A/C = 1176 kWh / month
Energy consumption of 100 A/C's = 117.6 MWh / month
Energy consumption of 100 A/C's = 1411.2 MWh / annum

Energy consumption details of an A/C with fuzzy logic

Energy consumption of A/C = 53.18 kWh / day
Energy consumption of A/C = 1063.6 kWh / month
Energy consumption of 100 A/C's = 106.36 MWh / month
Energy consumption of 100 A/C's = 1276.32 MWh/ annum
Net energy savings per annum = (1411.2 – 1276.32)
=134.88 MWh

i. Cost savings

$$Cost\ Savings = Energy\ saving \times Electrical\ energy\ \cos t$$

= (134880 x 5)
= Rs. 6, 74, 400 / annum
Annual savings in the electricity bill is = Rs. 6, 74,400

ii. Pay Back Period (PP) and Rate on Investment (ROI)

$$PP = \left[\frac{A}{(C \times D) - B} \right]$$

A = Capital cost of energy conservation equipment (Cost of A/C and the controlling instrument).
B = Annual Operation Cost.
C = Annual Energy Savings in kWh per year.
D = Projected energy price per kWh.

A = Rs.24, 00,000
B = Rs.1, 00,000
C = 134880 kWh,
D = Rs.6
Pay Back Period = 3 Years and 5 Months

$$ROI = \left[\frac{Net\ Annual\ returns}{Capital\ Investment} \times 100 \right]$$

ROI = 29.4 % per year

The results obtained from and from conventional A/C are discussed about control over energy consumption and maximum demand, and the results are used for comparison. Table-IV shows the maximum demand before and after DSM techniques, demand savings, load factor improvement, turn ON and OFF periods, payback period.

VII. CONCLUSION

Due to very high investments on luxury electrical appliances by every individual, the consumption of electrical energy is increasing day by day. But, the production of electricity has been constant. As a result of this, there exists a large gap between demand and production of electrical energy. The gap is very much high in summer has become a very big problem because of the fact that majority of the peak load electricity produced by hydro power plants in India. It is the greatest drawback mainly for developing countries to proceed further in its industrial development. In such a case, utilization of various loads like air conditioner load by every consumer creates a problem to the utility and if non utilization of AC causes discomfort to the consumers life. Under such circumstances, conservative measures must be initiated and implemented to decrease the gap between demand and production.

Combined application of DSM techniques and Fuzzy logic, gives rise to an intelligent system which can be applied to any A/C. This acts as a switch to the A/C by which some substantial energy can be conserved making the Air Conditioner intelligent and user friendly. Energy conservation reduces the burden on utility, and encourages new industries for coming future. It also results in reduction of electricity bills which favors the consumer.

This user friendly A/C can also be used in software industries, BPO'S or any organization with large number of servers and systems, which needs 24hr. working A/C. This leads to a huge power consumption which can be conserved by using this intelligent system as clearly shown in this paper.

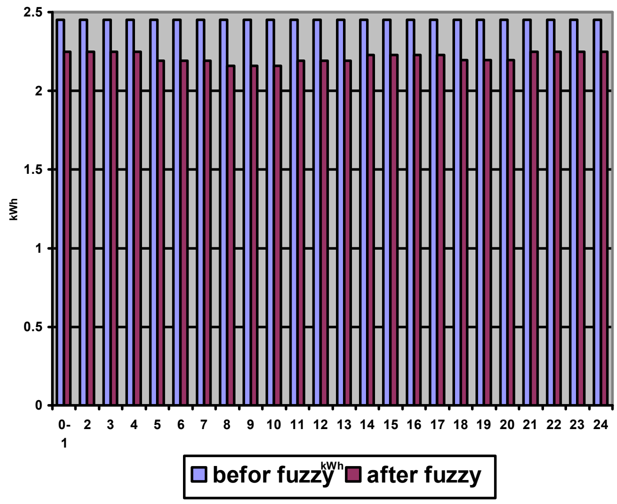

Figure.9 Hourly power consumption of A/C before and after fuzzy application

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