Load Scheduling using Fuzzy Logic in a Home Energy Management System

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Abstract: **The increase in electricity consumption and the smart grid initiative opened the door for electricity management in the consumer side or controllable load. The current situation shows that the electrical energy is not efficiently utilized due to consumers' ignorance. Overloading the grid mainly during peak hours is common which ultimately result in grid failure. Controlling the loads at the consumer end will help the consumer in proper management of energy. Initiatives from the consumer end by implementing techniques such as Demand Response could bring an efficient utilization of energy. Compared with the various methods, load scheduling from the consumer end is the best alternative through which energy management could be done. However, there is no work which proposes the frequency at which load scheduling can be done. Hence, an attempt is made to implement demand response by scheduling the loads from the user end in a Home Energy Management System using Fuzzy Logic with the target of minimizing the energy consumption and thereby reducing the cost.**

KEYWORDS – Smart Grid, Home Energy Management, Demand Side Management, Load Scheduling, Fuzzy Logic

I. Introduction

Smart grid applications are becoming popular, because they intend to supply the electricity by merging interactions and control techniques to the available grid. Adding smartness to the grid provides various options, such as demand side management, which in turn depends on real-time pricing and user preferences to support consumers to decrease their load. Demand and Supply requires a balance so that interruptions in power supply can be avoided. In grid-based systems, load sharing during the peak hours becomes a challenge to provide the required power. Due to population increase, housing areas have become a large sector for energy consumption. Energy management for the appliances used for Heating, Ventilation, and Air Conditioning (HVAC) are the main target since they contribute to a significant amount of the total power. HVAC systems also act as the major loads during peak load periods which result in electrical power short comes[1].Thus, the demand-side management (DSM) techniques for residential HVAC systems benefit both consumers and producers.

DSM is used to control the customers' load demand. Thus, it modifies the customer's energy consumption and also improves customer satisfaction. In order to implement DSM, a Home Energy Management System (HEMS) is required to flatten peak hour demand and reduce power consumption [2-5]. Residential loads are specified as room cooling, room heating, water heating, fabric drying, cooking, freezing, lighting, others. Depending on their use, the loads can be classified as critical loads and controllable loads. One of the basic requirements for the DSM is shifting the loads i.e. dish washing can be done during late night or early morning, when there is much less demand than in the peak period[6].

A genetic algorithm based technique to reduce the electrical consumption of a home is presented [7]. -Load scheduling is done to keep the power consumption below a threshold which is obtained based on consumer preferences, renewable sources and price. The approach found to provide better results than mixed integer non-linear approach. A Master Controller (MC) for HEM using an Adaptive Neuro-Fuzzy Inference System (ANFIS) is proposed [8]. The MC issues the schedule of the appliances depending on consumer priorities and convey to the appliances. The ANFIS forecast the preferences of the consumer and communicates with an aggregator.

A demand side management using load shifting technique with a large number of devices of several types is discussed [9]. An Evolutionary Algorithm (EA) was developed to solve the problem of load shifting which can be considered as a minimization problem. A novel framework for obtaining non stationary DSM strategies using game theory, in which the customers select various daily power consumption patterns depending on their priorities, cycles, and usage is proposed [10].A hierarchical DSM model is proposed which consists of three layers i.e., utility, demand response aggregator and customers[11]. The goal of the utility is to reduce the operation cost, and this is solved using artificial immune algorithm.

A lightning search algorithm (LSA) combined with artificial neural network (ANN) to forecast the ON/OFF condition for home appliances is proposed [12]. Four appliances such as water heater, air conditioner, washing machine, and refrigerator are modeled, and their activation is controlled. A scheduling algorithm to optimize the energy consumption for residential users is proposed [13]. Binary Particle Swarm Optimization (BPSO) using Time-of-Use (ToU) pricing scheme is used to solve the optimization problem. The technique of scheduling a set of appliances considering price, preference level and time is presented [14]. A Mixed Integer Linear Programming model with an algorithm using heuristics is implemented for a residential customer.

An appliance scheduling method for HEMS considering the pricing based on time for a smart grid is proposed [15]. Both the thermal and non-thermal appliances are scheduled using a model predictive control (MPC) method which implements both prediction and revised information. An approximate greedy iterative algorithm is proposed for each user to schedule appliances [16]. The consumer will identify the best start time and mode of operation for the appliances with respect to the changing electricity prices. The cost function of each user and the constraints for the appliances are modeled. Fuzzy logic systems to model the behavior of human beings for activating the appliances and lighting is presented [17]. Using this model, each appliance can be activated on hourly basis. A cooperative fuzzy model predictive control (CFMPC) for both cooling and heating of buildings is proposed [18]. The overall area of the building is divided into various regions consisting of local linear models (LLM), representing the different seasons such as summer, winter, fall and spring winter. The CFMPC achieves a good prediction with less energy consumption. An autonomous thermostat which can react to various parameters namely time-varying prices, with reduced energy consumption and preserving consumer's comfort is presented [19]. A fuzzy TOPSIS methodology to compute and assess the comfort of the consumers using electrical devices based on a real-time price scheme is discussed [20].

All the above mentioned works have not considered the number of times scheduling can be done for a day. Hence, an attempt is made to predict the frequency at which the appliances scheduling algorithm can be called to switch ON/OFF the appliances in HEMS based on the supply power available at that time. The prediction can be done using fuzzy logic since it is based on human thinking.

II. Proposed System

Demand response event is the period where the consumers need to reduce the stress level in peak hours. In proposed system, we assume that there are four different appliances with different power consuming capacity. We assume that the demand limit can vary from every 30minutes to every hour which is based on the consumer need. Here the high power consuming appliances such as air conditioner and water heater creates delay and burst in over consumption. These affects the low power consuming appliances like light and fan too. Here occurs demand in power usage. To overcome this tough condition, we are fixing certain priority levels based on the customer requirements. To reduce the peak hour demand a fuzzy logic based scheduling technique relative to human reasoning for handling the demand over the power scheduling concludes the time allocation based on shifting.

Table1. Appliances usage

S.No	Appliances	Load priority	Consumer needs	Power rating	Time of Usage
1	Light	1	4-8 Hrs per day	40 W	5 A.M -8 A.M 6 P.M – 11 P.M
2	Fan	2	4-12 Hrs per day	75 W	5 A.M - 7 P.M
3	AC (1 ton)	3	4-10 Hrs per day	1400 W	9 P.M – 7 A.M
4	Water heater	4	1-2 Hrs per day	3000 W	7 A.M – 8 A.M

The appliances scheduling is based on the following things. Monitors the appliances from its starting time. The preset priority is predicated on the basis of user behavior. Here the main thing is to analyze the peak demand that cause burst while over consumption of power takes place. Power consumption of the equipments must be noted for setting priority. Commonly Critical Peak Pricing (CPP), real time pricing and Time of Use Pricing (TOUP) are included in DR. However, the usage of Demand Response (DR) is not only to reduce the electricity requirement during peak hours but also to prevent the high power demand. There were several methods like linear programming, Particle Swarm Optimization (PSO) method and game theory has been proposed in order to solve the residential power scheduling problem.

The flowchart for the proposed system is shown in figure 1. The power level can be given as the input to the algorithm to determine the suitable switching time of appliances without affecting the comfort of consumers. The proposed HEMS algorithm is developed such that it can control and schedule the water heater, AC, fan and light, and switch customer load to base on the available input power during DR event. The HEMS algorithm starts by reading the supply power available (P_s) and computes the demand power (P_D) required by the above-mentioned appliances. If the supply power is more than the total demand power required by all the appliances, then all the appliances can be switched ON without the need for scheduling. If the supply power is less than the total demand power required by all the appliances, the appliance scheduling algorithm is initiated. The flowchart for the appliance scheduling algorithm is shown in figure 2.

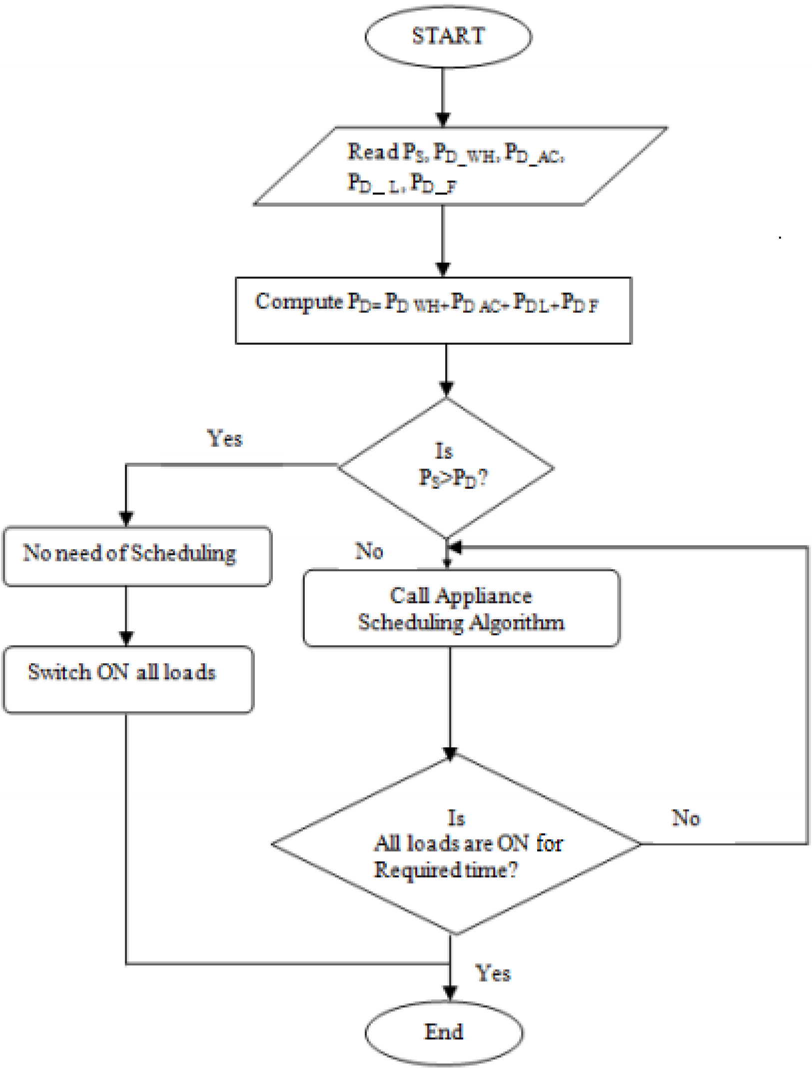

Figure 1.Flowchart for the proposed system

The appliances scheduling algorithm can be used to control the appliances in HEMS. Demand power of each appliance based on the consumer priority is compared with supply power and the particular appliance can be switched ON. The entire system is implemented in Matlab.

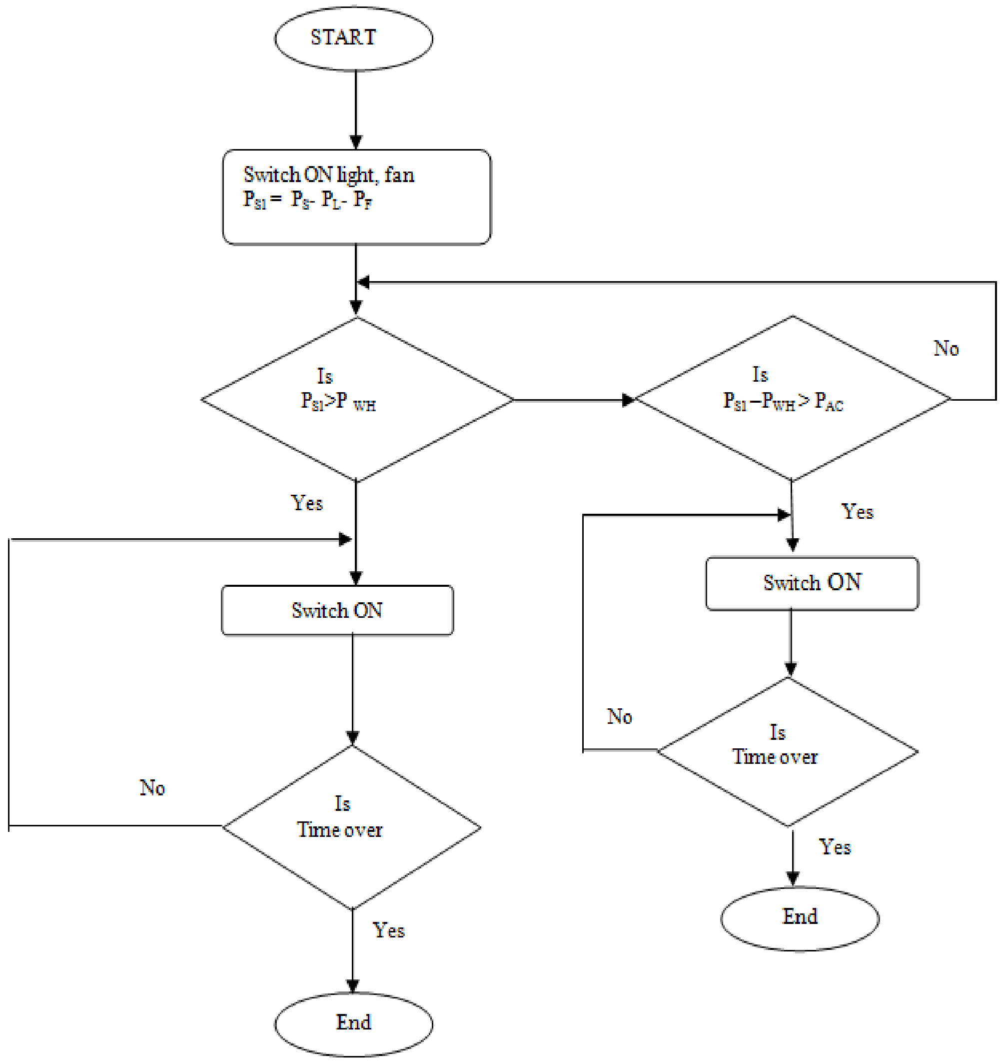

Figure 2.Flowchart for the appliance scheduling algorithm

The frequency at which the scheduling can be done is obtained using the Fuzzy logic. Once this is done, the scheduling process begins. If the scheduling commences for 6 a.m., depending on the frequency of scheduling, the loads are prioritized. The scheduling is carried out for 24 hours assuming that the grid power is available throughout the day without interruption.

III. Fuzzy Logic Control and System Design

Fuzzy logic is obtained from fuzzy set theory which basically operates based on reasoning whereas the classical set theory provides precise output. The variables used for computing the output are called fuzzy variables. The input data is first fuzzified using statically defined membership functions which generate a truth value between 0 and 1.The fuzzy logic define the relationship among different inputs in natural language through a set of fuzzy rules with the output. The system continuously estimates the given inputs and delivers outputs of the system based on the rules.

Fuzzy logic based Appliance Scheduling Scheme (ASS) is proposed to switch the appliances based on the supply power. In this, fuzzy logic based appliance scheduling is adopted whenever the supply power is lesser than the total load demand. The schematic diagram of the Fuzzy Logic Controller is depicted in figure 3.

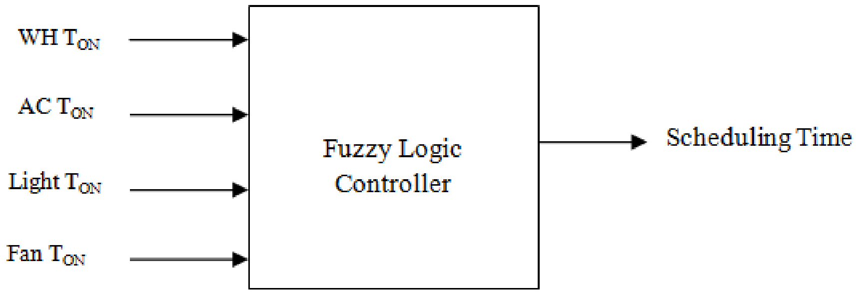

Fig.3.Schematic diagram of Fuzzy Logic Controller

The input variables of the controller are the ON times of water heater, air conditioner, fan and light. The controller takes the crisp values as inputs, fuzzified them using the membership function based on the set of rules. The output is the frequency at which the scheduling algorithm can be invoked based on the supply power. A rule-based inference engine is responsible for mapping input with the output. Thus, framing the rule depends on the knowledge and reasoning of the expert. At the end, it deffuzzifies the outputs to crisp values. The membership functions corresponding to input and output variables are tabulated in Table 2.

Triangular membership functions are selected for both inputs and output as it depicts the input and output parameters effectively. The Degree of membership shows the amount of participation of a variable in a Fuzzy set. Fuzzy rule estimation happens when the system takes fuzzified inputs and applies them to the antecedents of the Fuzzy rules. It is then applied to the consequent membership functions. The prediction of scheduling frequency based on fuzzy logic is shown in figure 4. Using the rule based structure of Fuzzy logic, a set of IF, THEN statements were framed such as, **IF** the ON time of water heater is less and AC is ***short time*** and fan is ***Less*** and Light is ***maximum***, **THEN** scheduling is ***Less frequent.*** The antecedents have 3 Fuzzy subsets. Thus the proposed Fuzzy Rule Base has 3*3*3*3=81 rules and few of them are presented in Table 3.

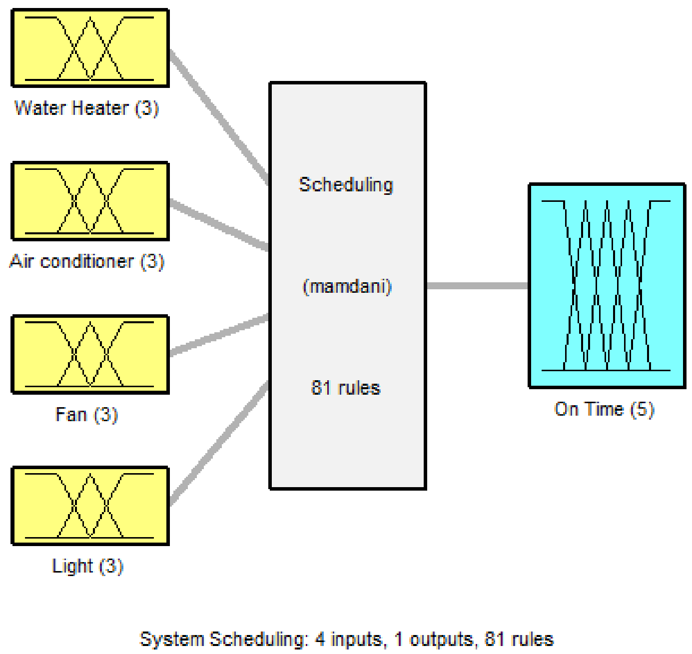

Figure.4.Schematic representation of the fuzzy input and output variables

Table 2. Membership functions

		Term Sets	Membership functions	Limits (Time periods)
Input Parameters	Water Heater (1-2 Hrs)	Less	Trapezoidal	{-0.5;0;0.5;1}
		Medium	Triangular	{0. 5;1;1.5}
		High	Trapezoidal	{1;1.5;2:2.5}
	Air Conditioner (4-10 Hrs)	Short	Trapezoidal	{2.5;4;5.5;7}
		Average	Triangular	{5.5;7;8.5}
		Long	Trapezoidal	{7;8.5;10;11.5}
	Fan (4-12 Hrs)	Less	Trapezoidal	{2;4;6;8}
		Medium	Triangular	{6;8;10}
		High	Trapezoidal	{8;10;12;14}
	Light (4-8 Hrs)	Minimum	Trapezoidal	{3;4;5;6}
		Average	Triangular	{5;6;7}
		Maximum	Trapezoidal	{6;7;8;9}
Output Parameter	On Time (Loads)	Very Less Frequent (VLF)	Trapezoidal	{3;3.5;4;4.5}
		Less Frequent (LF)	Triangular	{2.5;3;3.5}
		Little Less Frequent LLF)	Triangular	{2;2.5;3}
		More Frequent (MF)	Triangular	{1.5;2;2.5}
		Little Less Frequent (LMF)	Trapezoidal	{0.5;1;1.5;2}

Table 3.Fuzzy rule base

Rule No.	Water heater	Air conditioner	Fan	Light	Scheduling
1	Less	Short time	Less	Minimum	VLF
2	Less	Short time	Less	Average	VLF
3	Less	Short time	Less	Maximum	LF
4	Less	Short time	Medium	Minimum	VLF
5	Less	Short time	Medium	Average	LF
6	Less	Short time	Medium	Maximum	LF
7	Less	Short time	High	Minimum	LF
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76	High	Long time	Medium	Minimum	MF
77	High	Long time	Medium	Average	MF
78	High	Long time	Medium	Maximum	LMF
79	High	Long time	High	Minimum	LMF
80	High	Long time	High	Average	LMF
81	High	Long time	High	Maximum	LMF

The Fuzzy output provided by the rules is mapped with the scheduling Fuzzy set and the area for the variable, bounded by the degree of membership value is calculated. The crisp output is obtained using LOM Method.

IV. Experimentation and results

The algorithm is coded and simulated in Matlab to prove the efficiency of the approach. Initially, only four loads namely a light, a fan, an AC and a water heater are considered and the load curves obtained based on the customer preferences are shown in figure 5. Any number of loads can be added and the algorithm can be expanded**.**

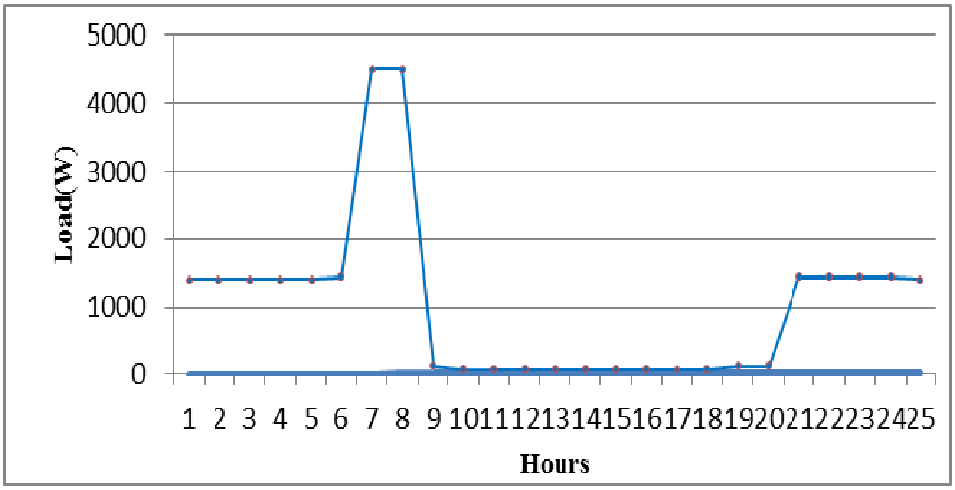

Figure 5.Load curve without scheduling

From figure 5, it can be seen that the maximum load is during the peak hours which when operated without considering supply power may result in power failure. To overcome this situation, the loads are scheduled based on the supply power available. For example, consider a scenario where the supply power varies from 1000 W to 3000 W. With the help of our algorithm, the loads are scheduled based on the supply power and consumer preferences. The load curve obtained after scheduling the appliances is shown in figure 6.

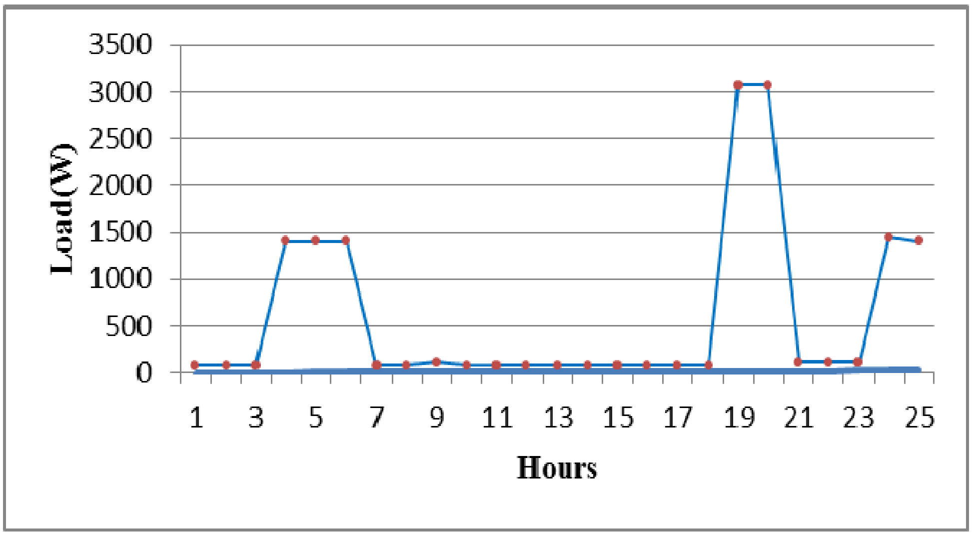

Figure 6.Load curve with scheduling

From figure 5, it is inferred that for hours from 1 to 3, the supply power is 1000W and the AC is switched OFF and fans are switched ON. For hours from 4 to 7, the supply power is enough to operate the AC and thus AC is turned ON but not enough to turn ON the water heater. Hence water heater is shifted to hours 18 to 19. Similarly, for hours from 7 to 17, the supply power is enough to turn the lights and fan and both are turned ON.

Thus scheduling the appliances depending on the supply power available at that instant effectively varies the load. However, how frequent the scheduling can be done is a big question. For, overcoming this issue, fuzzy logic is employed to determine the frequency of scheduling based on the ON time of the four appliances namely light, fan, AC and water heater. The frequency of scheduling is affected by the operating time of the appliances. To illustrate the impact of operating time on the frequency of scheduling, the appliances are switched ON one by one and the frequency of scheduling is obtained as shown in figures 7(a), (b), (c) and (d).

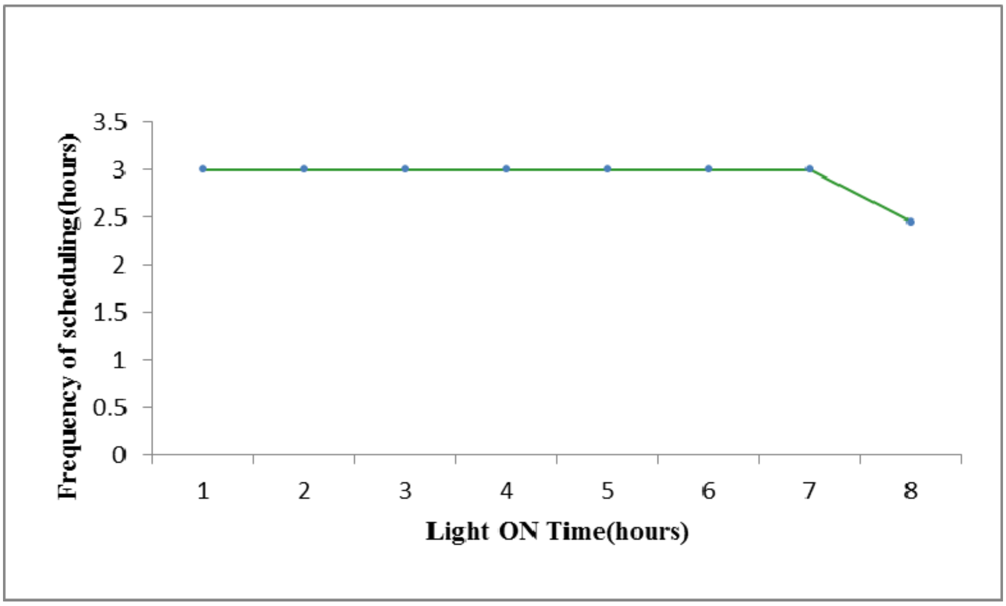

Figure 7.a.Impact of light ON Time on scheduling frequency

From figure 7(a), the impact of switching ON light alone for 4 to 8 hours is obtained by keeping other appliances OFF. The light consumes only 40W and it requires no scheduling. Hence, the scheduling required once in 3 hours for 7 hours of power consumption by light alone. In the 8th hour, the frequency of scheduling is reduced to 2.45 hours once.

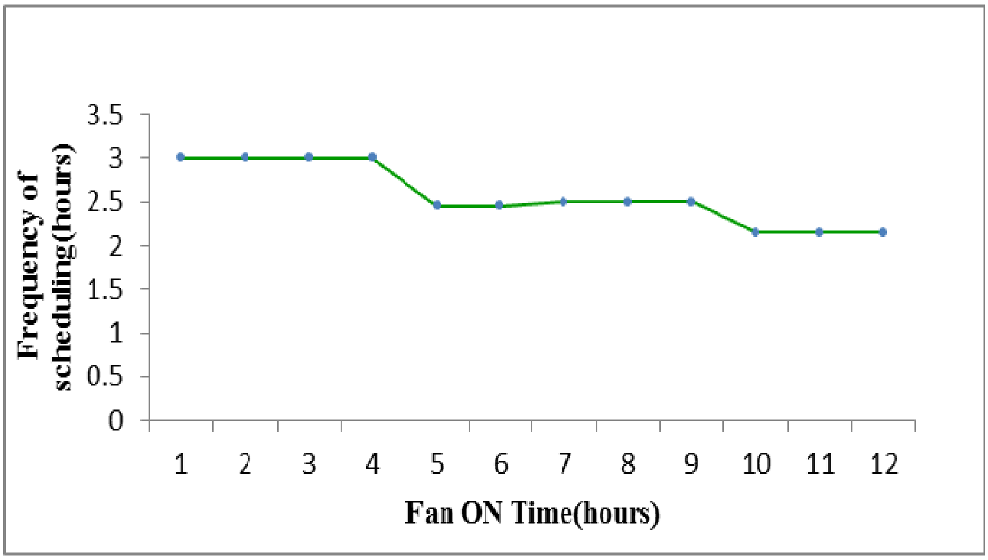

Figure 7.b.Impact of Fan ON Time on scheduling frequency

Figure 7(b) depicts the effect of power consumption by fan for 4 to 12 hours when other appliances are switched off. The power consumed by the fan is around 75 watts and this affects the scheduling frequency more compared with the effect due to light. It is found that the frequency of scheduling remains in 3hours once from 1 to 4 hours whereas it shifts to 2.5 hours once for 5th and 6th hour. Finally it reduces to 2.15 hours once during the 10th, 11th and 12th hour of power consumption by fan.

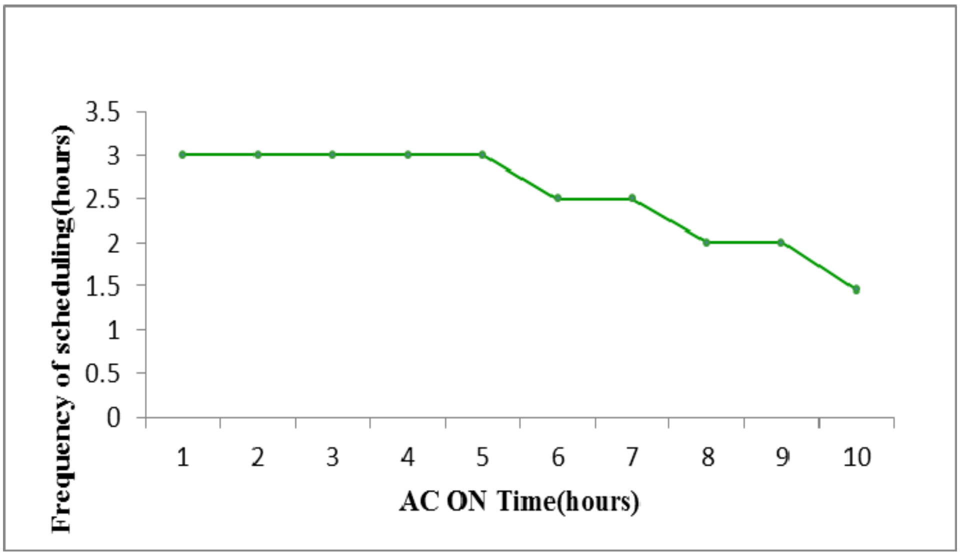

Figure 7.c.Impact of AC ON Time on scheduling frequency

From figure 7(c), it is revealed that the impact of the power consumed by AC on scheduling frequency is more compared with the power consumed by light and fan. For this case, the AC is switched On for 4 to 10 hours and the output is obtained. It is found after 5 hours of AC power consumption, the frequency at which scheduling is to be done decreases from 3 to 2.5. Further, it reduces to 2 hours and then to 1.45 hours once after 10 hours of AC power consumption.

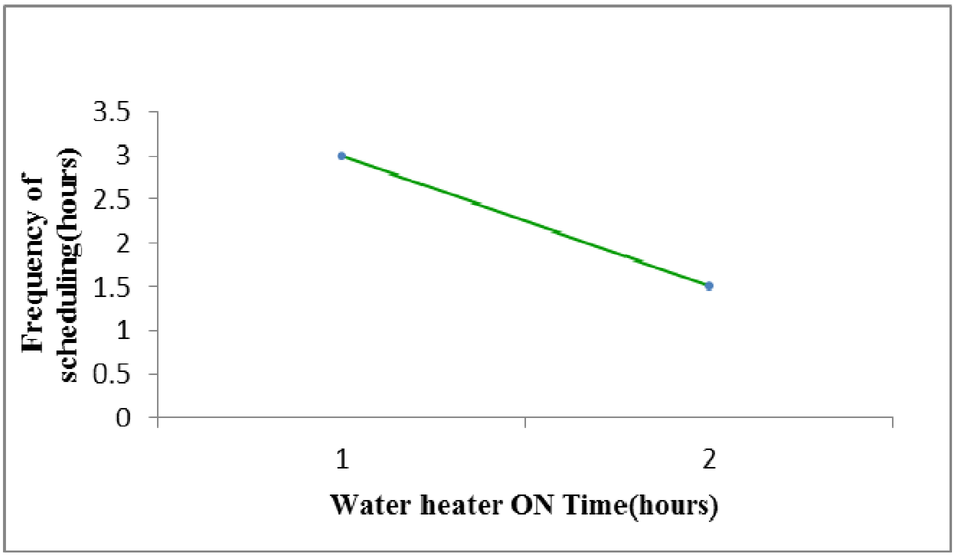

Figure 7.d.Impact of Water heater ON Time on scheduling frequency

From figure 7(d), it is found that the frequency of scheduling shifts drastically from 3 hours to 1.5 hours once when the power is consumed by water heater alone. This is because the water heater consumes the maximum power of about 3000W and this clearly affects the frequency of scheduling.

V. Conclusion

In this paper, a novel architecture for appliance scheduling load using fuzzy logic for HEMS is presented. Based on the available power, the appliances can be switched ON or OFF at that time without affecting the comfort of the consumers. The consumers can make use of this facility by means of a home energy management controller. The demand power i.e. the power required by the appliances which need to be switched at a particular instant is computed and compared with the supply power. If the supply power is more than the demand power, scheduling is not required. However, there are times when the supply power is in demand. In such scenarios, scheduling of appliances need to be done. The algorithm can also be utilized to manage the equipments consuming more power in industrial sector. The frequency at which scheduling is required is an important aspect in load scheduling. This paper proposes a fuzzy logic based load scheduling approach which provides the frequency of scheduling as output. The results prove that by predicting frequency of scheduling, loads can be balanced more appropriately.

VI. References

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