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OPTIMIZATION OF ANALYZING FUZZY CONTROL FOR SMART HOME ENERGY IN A SMART GRID ENVIRONMENT

Yazeed Ghadi

Faculty of Engineering
Al Ain University of Science and Technology
P.O.Box: 112612, Mohammed Bin Zayed City, Abu Dhabi, United Arab Emirates
yazeed.ghadi@aau.ac.ae

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Abstract. *The demand for energy efficiency has been increasing on a daily basis in order to cope up with the sustainable environment along with the enhancement in the technology. In this report, we utilize AG_0. "AG_0" makes joint decisions with respect to the user comfort and desire. The comfort level for users has a significant impact on energy savings. AG_0 based-Fuzzy Logic Controller or AG_0-FLC to facilitate the smart home energy management in the Smart Grids (SM) is discussed critically. The home automation can comprise complicated components that are distributed with distinctive behaviour and for the sake of ensuring the energy efficiency in the residential buildings, a logical control of the load can be the ideal solution that can be implemented in the load management system. In the field of smart grid type of research technique, fuzzy logic has a magnitude role because of controlling load which has a greater effect on the preferences of customers.*
Keywords: Power load management, Permanent load, Home automation, Multi-agent system modelling

1. **Introduction.** The energy can be considered as a powerful agent that can play a critical role in quotidian activities. The demand for energy efficiency has been increasing on a daily basis in order to cope up with the sustainable environment along with the enhancement in the technology. Efficient energy utilization can be beneficial for the ecological as well as economic aspects of the environment that can mitigate the issues related to the environment and smart grids [1]. Thus, there is a need for concentrating electrical systems on the residents as well as the customer's awareness in terms of efficient energy usage.

In this report, the utilization of AG_0 based-Fuzzy Logic Controller or AG_0-FLC to facilitate the smart home energy management in the Smart Grids (SM) is discussed critically. Also, the results of the energy usage efficiency in using home automation based on AG_0-FLC are elaborated in this paper.

1.1. **Role of the fuzzy controller.** In the field of smart grid type of research technique, fuzzy logic has a magnitude role because of controlling load which has a greater effect on the preferences of customers [2]. Management of energy in the environment related to a smart home is the most significant concern in research related to the smart grid and the use of controlling approach [3]. Type of systematic process is generally used for intelligent controlling techniques on the basis of smart grid which is fully based on fuzzy logic including logic controller. In order to complete the research successfully, the acceptance of customers is key vital in this context, due to which, the fuzzy approach mostly allows us to save around 45% which in terms affects overall required capital.

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FIGURE 1. Home automation based agent [1]

The automation system in the home can be developed for minimizing bills of electrical appliances [4].

1.2. **Use of the fuzzy controller system.**

- **Similar to human reasoning** – The FLCs can be regarded as possessing the response that is similar to human responses. They are being programmed in terms of being controlled automatically as the preferences set by the user. The user can also modify the responses as well as the priorities of the usage of the appliances according to their requirements.
- **Based on the linguistics models** – The interface has been created in the GUI creating software of LABVIEW. This interface can be based upon the language as per the choice of the user. The user can customize the language preference according to the needs.
- **Using non-complex and simple mathematics** – The fuzzy controller uses mathematics and the control systems that are noncomplex and simple to understand by the user. The functions of mathematics can also be considered as non-linear as well as integrated.
- **Customizable** – The fuzzy controller can be customizable as well as modified by altering the program according to the needs of the programmer. Thus, it can quite be reasoning and the knowledge of the human can be integrated into the controller by integrating command in the membership functions of the systems.
- **High precision** – The FLCs can be regarded as possessing high precision as the programs that are being set in the fuzzy controller can be set due to the preferences set by the users.
- **Accessible** – The fuzzy logic is also regarded as easily understandable as it is widely utilized in commercial and residential purposes due to its easy accessibility.

1.3. **Advantages of the fuzzy controller.** There are several advantages of the fuzzy controller system in the home automation system of the smart grids [2] (*Refer to Appendix*).

- **Cheaper** – The construction of the fuzzy controller system can be regarded as cheaper as compared to the development of other controller systems in terms of performance.
- **Robust** – The fuzzy controller logics can be considered as more robust than the PID based controller systems due to their capacity of covering greater ranges of conditions of operations.
- **Deductive thinking** – The FLCs are considered to be basically designed by the programmer in order to emulate the deductive thinking ability of the human.

1.4. **Role of FLC in energy management.** The fuzzy controller system can be considered as managing the energy of the home appliances in terms of the performance as well as power consumption. They are being implemented in the residential buildings to increase the convenience in the energy management [5]. The approach that has been made can be quite improved in terms of neural networking as well as Q-learning algorithm can also be added to signify more efficiency to the technique of using FLCs. It can also benefit the environment in reducing the carbon footprints [5]. The technique can also be compared with the conventional system of home management, which results in cost reduction that can bring the balance off the occupant in the comfort as well as residential energy consumption [2]. The proposed AG_0-FLC has helped in the contribution to the power management among the renewable energy generation in terms of energy storage and load [6]. The automation technique used in the FLC can be modified to turn off the appliances when the appliances are not in use. This in turn can be quite beneficial in the implementation of the energy management system of the home appliances.

2. **Home Automation Based on the Fuzzy Controller of AG_0-FLC.** The home automation can comprise components that are distributed with distinctive behaviour and for the sake of ensuring the energy efficiency in the residential buildings, a logical control of the load can be the ideal solution that can be implemented in the load management system [2].

2.1. **Load categorization.** The load can be categorized according to the behaviour of the load usage of various residents. The subcategories of the load are as follows:

- **Permanent load appliances** – This kind of load can be determined according to the energy consumption of various kinds of appliances such as refrigerators, water-heaters along ACs and other appliances [7].
- **Temporary load appliances** – This type of load can be determined by the overall duration of the appliances use and its intended time. They can be subcategorized as: *they must run loads* such as TVs and hair drier and *the shiftable load* such as laptop chargers and dishwashers [2].

2.2. **Multi-agent system modelling.** The Multi-Agent System (MAS) modelling is necessary for the home automation evaluation. This can comprise the entities that can identify the tasks that are to be executed [8]. The agent in Figure 2 can be regarded as the AG_0 that makes the decision related to residential consumption.

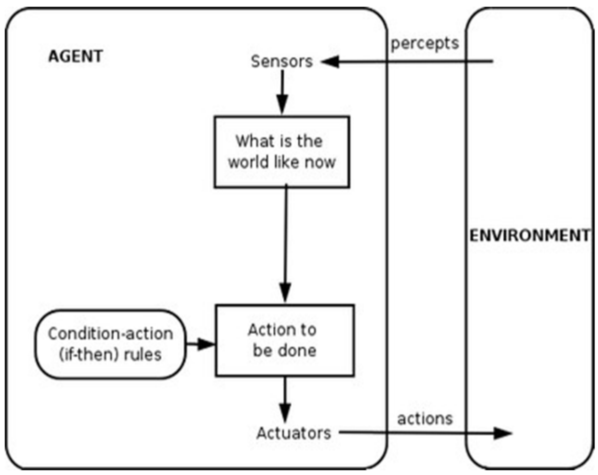


FIGURE 2. Design of an intelligent agent [8]

2.2.1. *AG_0 setting.* The AG_0 setting can be executed according to the following parameters selection and the programming is as follows [8]: 1) New appliances that are added shown in Figure 3; 2) Installation of date and time; 3) Prioritization of the elements in the fuzzy controller has been illustrated in Figure 4; 4) Comfort zone as per the steps in Figure 5; 5) Consumption threshold.

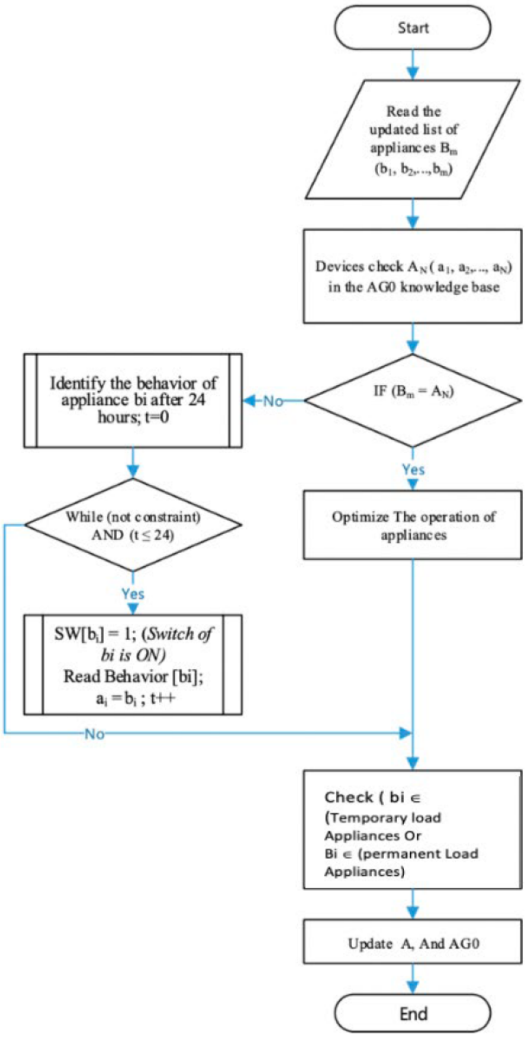


FIGURE 3. Adding of new appliances by AG_0 algorithm [8]

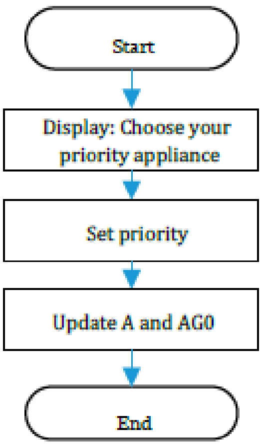


FIGURE 4. Prioritization according to efficient policy

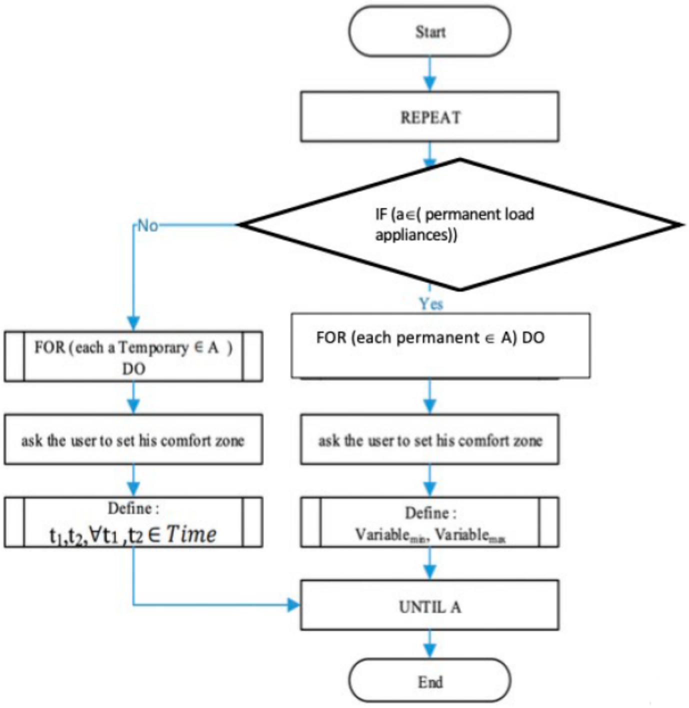


Figure 5. Comfort zone algorithm [12]

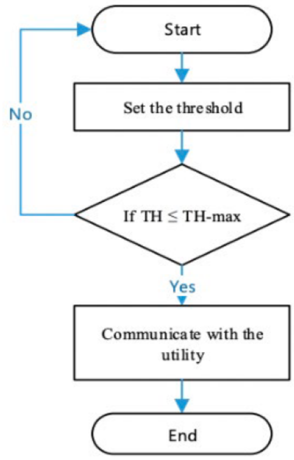


Figure 6. Threshold algorithm

2.2.2. *The coordinator agent tasks.* In the coordinator agent tasks, the given set of appliances can comprise $A = \{a_1, a_2, a_3, \ldots, a_N\}$, where every appliance has their own energy consumption and $a \in A$, energy consumption as Y_a

$$Y = \begin{cases} y \Big| EC_a^{\circ} = \sum_{h=\alpha_a}^{\beta_a} y_a^h, & \forall a \in A, \quad \beta_a - \alpha_a \geq t_a^{req} \\ \delta_a^{\min} \leq y_a \leq \delta_a^{\max}, & \forall a \in A, \quad h \in [\alpha_a, \beta_a], \\ y_a^h = 0, \quad \forall a \in A, & h \in \mathcal{H} \setminus [\alpha_a, \beta_a], \\ \sum_{a \in A} y \leq E^{\max} \end{cases}$$

$$Y_a \triangleq \left[y_a^1 \times y_a^H\right]$$

where $H =$ is 24 hours scheduled range. For each comfort zone α_a, $\beta_a \in \mathcal{H}$, $(\alpha_a < \beta_a)$ can be represented as starting and end time to allow a gap for the scheduled consumption of energy. $(\beta_a - \alpha_a)$ have to be longer as a comparison to the time (t_a^{req}). The formula can be generalized as: $\beta_a - \alpha_a \geq t_a^{req}$. The daily consumption of the energy can be indicated as:

$$EC_a^\circ = y_a h/01.$$

Here $y_a = 0$ for any $h > \beta_a$ and $h < \alpha_a$. Energy consumption of the scheduled vector selection is

$$\delta_a^{\min} \leq y_a \leq \delta_a^{\max}$$

In the case of each residential SM, the overall consumption of energy can be equal or inferior to the predefined hour of threshold energy $E^{\max}$ which is

$$EC^{\circ total} = \sum_{a \in A} y_a \leq E^{\max}, \quad \forall h \in \mathcal{H}$$

$E^{\max}$ and $EC^{\circ total}$ can be utilized as out/input of the FLC. Hence, the possible scheduled collection (Y) for all y_a can be stated as:

$$EC_a^\circ = \sum_{h=\alpha}^{\beta_a} y_{ah}, \leq a \in A, \quad \forall \beta_a - \alpha_a \geq t_a^{req}$$

where, $y \triangleq (y_a; \forall a \in A)$ represents energy consumption of the scheduled vector. The vector y can be valid for $y \in Y$.

2.2.3. *Permanent agent modelling.* PA can be related to the permanent load of each appliance. The comfort zone can depend on the upper as well as lower levels of temperature $\left[T_{ac}^{\min}, T_{ac}^{\max}\right]$. The PA has the tendency to maximize the satisfaction function or SF for each appliance of the permanent load [3].

- **User comfort zone** – The SF of the permanent load can be dependent upon the characteristics of the variables which can be seen in Figure 7. The SF in this case defines the user's desire to operate the appliance in an interval from 0 to 100% where the 0 refers to inadmissible and 100 means superb.

$$SF = T|SF(t) = SF\left(T_{ac}^{\min}\right) = SF\left(T_{ac}^{\max}\right) = 100, \quad \forall T \in \left[T_{ac}^{\min}, T_{ac}^{\max}\right]$$

- **Permanent load's appliances scheduling** – The agent can use the methods of scheduling operations to avoid the demand of peak load that can affect the comfort zone of the user. Therefore, the agent can increase as well as decrease within $[\delta_a^{\min}, \delta_a^{\max}]$ of each appliance [4].

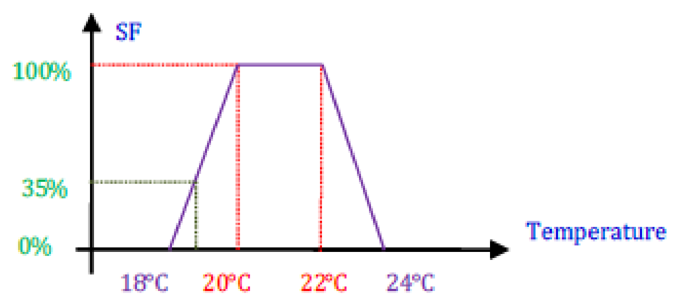


FIGURE 7. AC satisfaction function [3]

2.2.4. *Temporary agent modelling.* The temporary agent can be considered according to the temporary load of the appliances. The *must run load* can be started as the needs of the user and the power consumption is not fixed. Therefore, in the case of high power consumption, the agent can be obliged to utilize FLC. The *shiftable load* can be initiated as per the temporary agent with the comfort zone ranged within $[\alpha_a, \beta_a]$.

- **Comfort zone of the user** – The SF of this kind of load appliances can be dependent upon the shift time of service $[\alpha_a, \beta_a]$ and illustrated in the following equation:

$$SF = \{t|SF(t) = SF(\alpha_a) = SF(\beta_a) = 100, \quad \forall t \in [\alpha_a, \beta_a]\}$$

- **Operation of temporary load's appliances** – The temporary agents can utilize the existing list of priorities that is being prepared by AG_0 and fuzzy logic can be categorized as *low demand, low falling*, and *low rising* [4]. The FLC can be considered as better performing systems as compared to the conventional systems [1]. The FLC use can present the power to manage and facilitate the energy of the home appliances [4]. In this study, the design of the first FLC_1 can shift high power to the *low demand*. The second FLC_2 can shift high power to *low rising* and the third FLC_3 can shift high power to *low falling*.

2.3. **Fuzzy logic controller based home automation.** In order to implement the FLC in SG, the Pc based LABVIEW can be used. The input variables of FLC can be included as FUPDI (Fuzzy Utility Power Demand Indicator) and FThI (Fuzzy Threshold Indicator). The output variables can be included as CMCA (Closed Most Consumed Appliance) and PD (home's Power Demand in W).

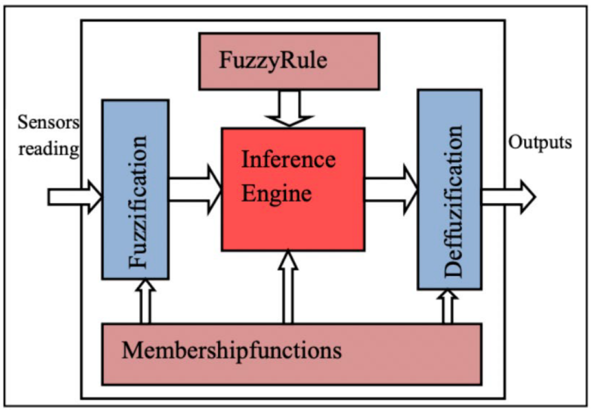


FIGURE 8. Fuzzy logic control system [4]

2.3.1. *Membership functions.* The membership functions are needed to define the linguistic rules in the management of the inputs and the outputs of the systems.

2.3.2. *Fuzzy rules of global FLC.* The FLC rule can be beneficial in the management of the behaviour of the user. When FUPDI = High and FThI is normal, the light is indicated as red.

Developed interface FLC based LABVIEW – The fuzzy interface can be developed by the user by using LABVIEW that utilizes the graphical development of the various modules of the applications and designs.

- **Front panel** – It can represent the GUI of FLC that can enable the user to monitor the parameters of FUPDI and FThI.
- **Block diagram** – This can contain the program codes of the FLC that are being used. The Virtual Instruments (VI) that has been used in the LABVIEW can be designed accurately in real time.

Table 1. Fuzzy rules of global FLC

Rules	IF FUPDI (MW)	AND FThI	THEN PD	AND CMCA
1	Low	Awesome	High	All-opened
2	Low	Normal	High	All-opened
3	Low	Expensive	Medium	Partial-opened
4	Medium	Awesome	High	All-opened
5	Medium	Normal	Medium	P-opened
6	Medium	Expensive	Low	Closed
7	High	Awesome	Medium	P-opened
8	High	Normal	Low	Closed
9	High	Expensive	Low	Closed

2.3.3. *Fuzzy rules of* FLC_1. Shift peak demand to low-demand period.

Table 2. Fuzzy rules of FLC_1

Rules	IF FUPDI (MW)	AND Period	THEN Power demand of appliance
1	Low	–	High
2	L-medium	Low-rising	Average
3	High	–	Low
4	H-medium	Low-falling	Average

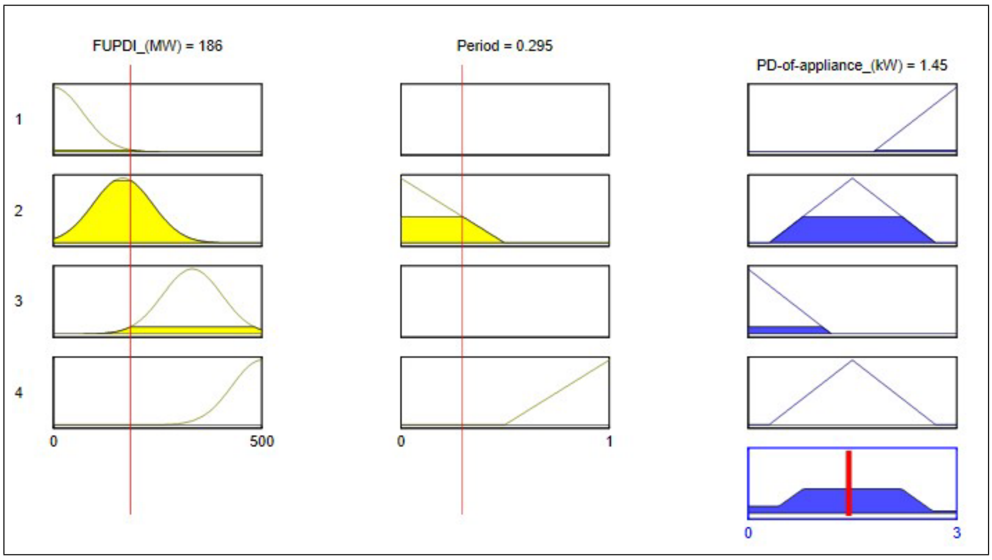


Figure 9. The inferred output of the FLC_1 system [4]

2.3.4. *Fuzzy rules of* FLC_2. Shift peak demand to low-rising period.

Table 3. Fuzzy rules of FLC_2

Rules	IF FUPDI (MW)	AND Period	THEN Power demand of appliance
1	Low	–	Average
2	L-medium	Low-rising	High
3	High	–	Average
4	H-medium	Low-falling	Low

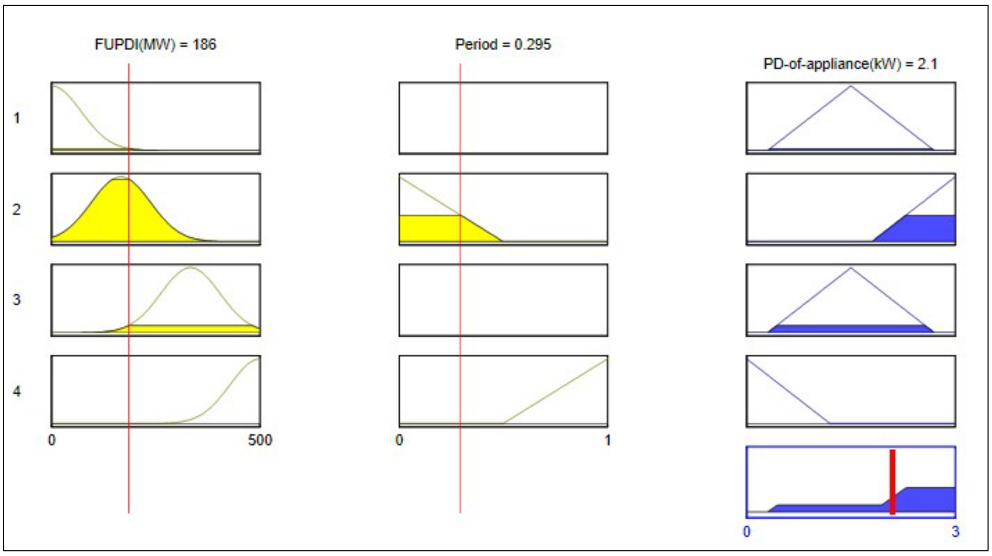


FIGURE 10. The inferred output of the FLC_2 system [4]

2.3.5. *Fuzzy rules of FLC_3.* Shift peak demand to low-falling period.

TABLE 4. Fuzzy rules of FLC_3

Rules	IF FUPDI (MW)	AND Period	THEN Power demand of appliance
1	Low	–	Average
2	L-medium	Low-rising	Low
3	High	–	Average
4	H-medium	Low-falling	High

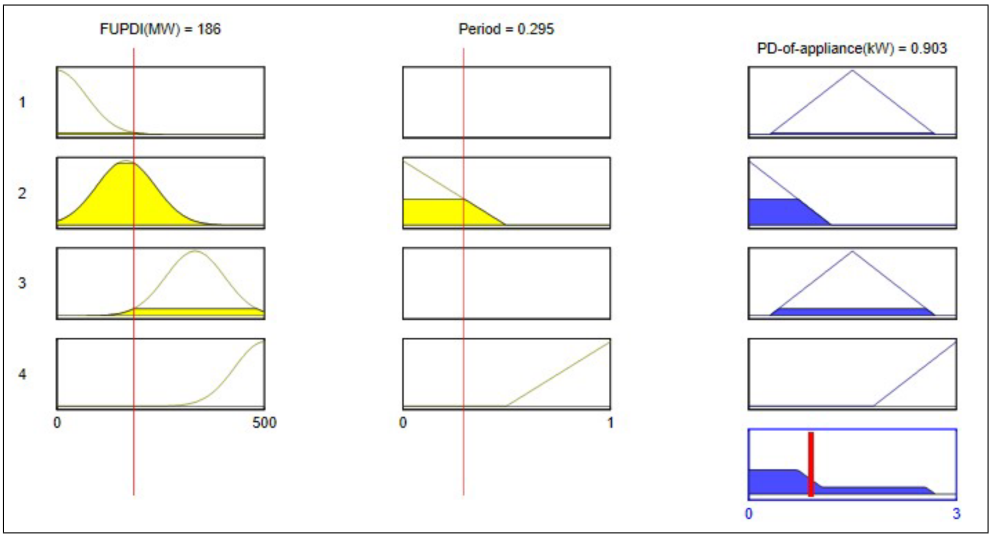


FIGURE 11. The inferred output of the FLC_3 system [4]

3. Application of the Proposed Solution.

3.1. **A cooperative mechanism-based MAS.** The FLC GUI has been designed in the LABVIEW which can be implemented in the controlling home appliances as shown in Figure 12 [4]. Each of the load categories can be related to the scheduling in order for energy reduction through compression of power [1]. The behaviour of the appliances can be analyzed in order to control the appliances.

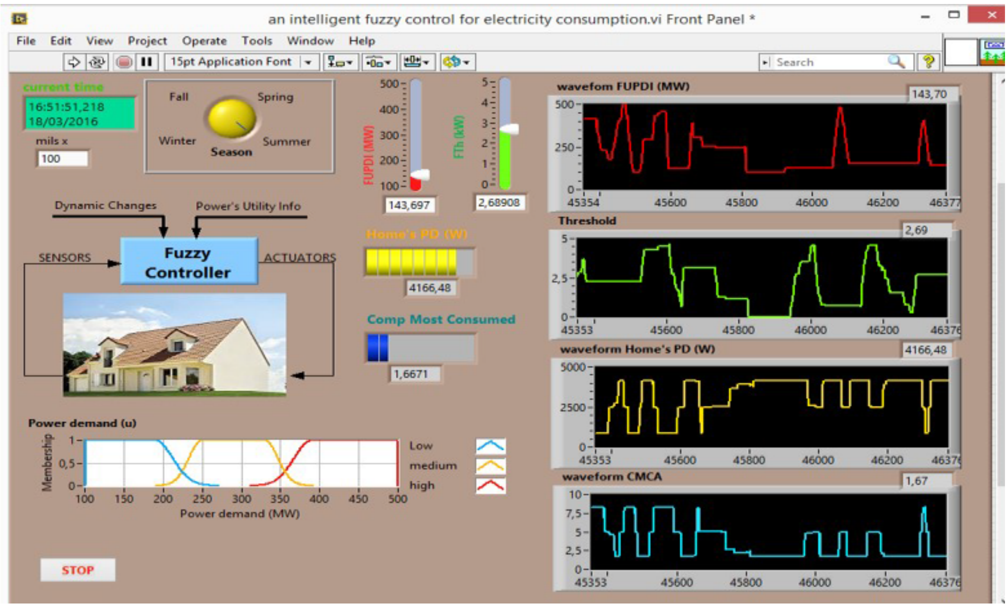


FIGURE 12. GUI for FLC based MAS [4]

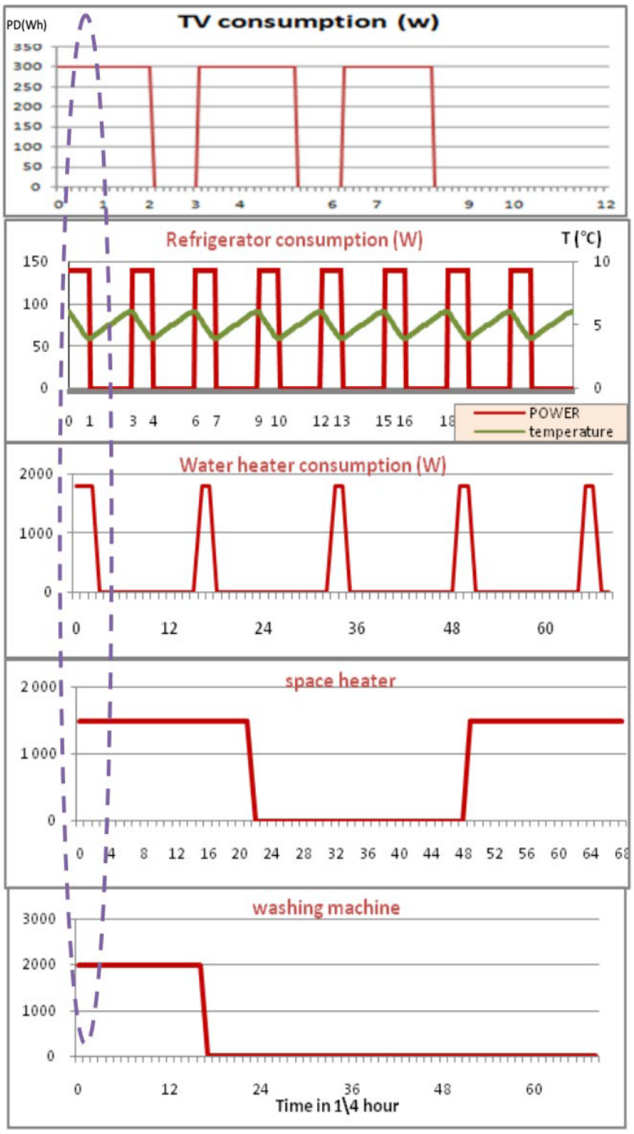


FIGURE 13. Appliances power demand based AG_0-FLC [4]

3.2. **Analysis of the power consumption.** The simulation has been performed per day in order to evaluate the power consumption of the home appliances as the following. The span of a day can be divided quarterly as $t \in Time$ and $Time = \{1, 2, 3, \ldots, etc.\}$. The maximum power output can be 140 W of the refrigerator, 300 W of TV, 1800 W of the water heater as well as 1500 W of a space heater and washing machine of 2000 W. $[E^{\max} = 3000 \text{ W}]$. Therefore, total energy consumption EC^{ototal} is

$$EC^{ototal} = \sum_{a \in A} y_a^{h=1}$$

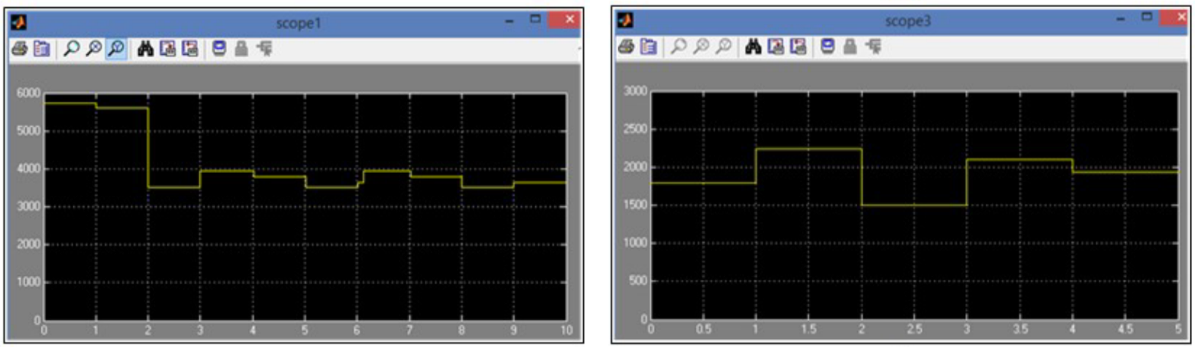
$EC^{ototal} = 140 + 300 + 1800 + 1500 + 2000 = 5740 \text{ W} > E^{\max}$. The quantitative Energy Savings (ES) can be ES (%) $= \{1(\text{EUAfterSchpolicy}/\text{EUBeforeShpolicy})\} \times 100$.

The calculation can be done in two intervals in order to compare the energy consumption of two intervals with and without the controller. The total ES consumed in the first interval $[0, 1]$ is: $EC^{ototal} = 300 + 1500 = 1800$ W.

In this case, the power has been reduced to 69%.

In the second interval $[1, 2]$, $EC^{ototal} = 140 + 300 + 2000 = 2440$ W. In this case, the power reduction was 58%.

3.3. **Discussion and comparative results.** The power consumption and the energy reduction have been shown in Figure 14. This shows that the implementation of the fuzzy controller reduces the power after its scheduling.



(a) (b)

FIGURE 14. The total power consumption (a) before scheduling policy, and (b) after scheduling policy using MATLAB [8]

4. **Conclusion.** Thus, it can be concluded that the FLC can be considered as better-performing systems as compared to the conventional systems. The fuzzy controller that has been constructed by the experiment has certain benefits according to the implementation of the constructed FLC as compared to the conventional methods of controlling the residential load. The result shows that the technique can reduce the peak formation as well as reduce the energy consumption. Management of energy in the environment related to a smart home is the most significant concern in research related to the smart grid and the use of controlling approach. The FLCs can be regarded as possessing the response that is similar to human responses. Construction of the fuzzy controller system can be considered as cheaper as compared to the development of other controlling and logical systems used for renewable energy purpose. The Multi-Agent System (MAS) modelling is necessary for the home automation evaluation. This can comprise the entities that can identify the tasks that are to be executed effectively [5]. The FLC use can present the power to manage and facilitate the energy of the home appliances. However, more commercialized implementation of this technique can be effective in the overall power

consumption. The FLC rule can be beneficial in the management of the behaviour of the user. The further improvement in the smart home automation technology implementation in this report has saved up to 58% of the residential energy in terms of the energy consumption in the utility period of high power demand.

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Appendix. Advantages and Disadvantages of FLC.

Control Method	Advantage	Disadvantage
FL method	(1) Similar to human reasoning. (2) Based on linguistic model. (3) Using simple mathematics for nonlinear, integrated and complex systems. (4) Reasoning and knowledge of human in and in shape of membership rules and functions. (5) Method of nonlinear control and ability to be used efficiently for HVAC systems. (6) High precision. (7) Rapid operation.	(1) For more accuracy, it needs more fuzzy grades which results to increase exponentially the rule. (2) The lower speed and also longer run time of system. (3) Lack of real time response. (4) Be not simply capable to receiving feedback for implementation of learning strategy. (5) Restricted number of usage of input variables. (6) Inability to straightforwardly advance optimal number of fuzzy rules and determine the membership function parameters.

(Source: https://www.researchgate.net/figure/Advantages-and-disadvantages-of-fuzzy-logic-controltechniques_tbl7_323441631)