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The Development of Fuzzy Logic Controller (FLC) in Air Conditioning System Using Several Types of Fuzzy Numbers

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Abstract. This is the age of modern science where different kinds of gadgets are used for the betterment of humanity. A variety of Electronics, Intelligence systems are invented via modern technology where FLC (Fuzzy Logic Controller) is used to develop their intelligence system. Nowadays, FLC is widely used in uncertainty and a robust development system. With the invention of the Air Conditioner, we live a much easier life than we used to live before. In this paper, we will discuss the way of how we can develop the FLC (Fuzzy Logic Controller) of an air conditioner system using a triangular and trapezoidal fuzzy number. Four input parameters are User Temperature (UT), Temperature Difference (Tdf), Dew Point (Td), and Number of Peoples (NP). However, Compressor Speed (CS), Fan Speed (FS), and Fin Direction (FD) are used as outputs. The simulation of this paper is carried out by using MATLAB.

Keywords: Fuzzy Number, Fuzzy Logic Controller, Air Conditioning System, Temperature and humidity control

AMS Mathematics Subject Classification (2010): 94D05, 93C42

1. Introduction

An Iran born American scientist who graduated from the University of Tehran, also received his master's and Ph.D degree from MIT and California respectively was the first person that came with the idea of Fuzzy Logic in 1965. Today, Fuzzy Logic makes a tremendous change in the development of uncertainty in artificial intelligence system. However, it is easy to implement and its impact in modern science is very groundbreaking. Its main objective is to simulate human brain on decision making mechanism in intelligence system while working in a vague, precise or uncertain environment. Although it doesn't need total knowledge about the characteristic of the model, it helps machine to think like human and respond instantly. The contribution of FIS (Fuzzy Inference System) in this manner is not doubtful. Its working principle can be divided into four mechanisms like Fuzzification, Fuzzy Rules Based System, Fuzzy Inference Engine and Defuzzification

[5]. With the introduction of linguistic variable, it is easy to describe fuzzy knowledge-based system where its transition is very smooth between rules-based system. Besides, Fuzzification and Defuzzification system refer to the process of making fuzzy and crisp output. In order to get the target output of an air conditioner by manipulating temperature and humidity to save the energy of compressor and fan while using all the resources, fuzzy logic rules-based system is used for fuzzification, defuzzification for the acquiring the target output [12]. Shodiya in 2017, proposed an air conditioning system which was developed for efficient energy operation and user's indoor thermal comfort [10]. In 2015, Sabhy et al. developed fuzzy logic Control system of an air conditioner where he used several linguistic variables and showed how membership function works in air conditioning system [11]. Another researcher Saepullah modified FIS to save the energy of air conditioner by using Mamdani, Sugeno, and Tsukamoto method in 2015 [1]. Saha et al. proposed a compact controller where the automated scheme of AC is depicted in two steps to decrease energy consumption and provide automated user desired temperature [9]. Back in 2012, Dash et al. proposed an automated intelligent air conditioning system while utilizing all available resources including climatic condition in the efficient manner in order to provide the user comfortable cooling level and also optimized energy consumption [1]. Mahbub et al. [6] and Islam et al. [4] developed intuitionistic fuzzy set indifferent way. Alao, Hemanta [2] defined addition of discrete fuzzy number.

Our aim is to develop fuzzy logic Control System, in order to make it automated by using several fuzzy numbers. This paper provides the idea of improving air conditioner's air quality. Here, we demonstrated a little bit about FIS and in the introductory section while the simulation results and graphical representation which was obtained by using MATLAB are discussed afterwards. Also, this paper describes how automated air conditioning system can be improved which is based on the imprecise input sensors.

2.1. Triangular fuzzy number [3]

A triangular fuzzy number A is defined by a triplet $(a_1,\ a_2,\ a_3)$. The membership function is defined as

$$\mu_A(x) = \begin{cases} \dfrac{x - a_1}{a_2 - a_1}, if\ \ a_1 \le x \le a_2 \\ \dfrac{a_2 - x}{a_3 - a_2}\ , if\ a_2 \le x \le a_3 \\ 0, \qquad otherwise \end{cases}$$

The graphical representation of triangular fuzzy number is present in Fig 1.

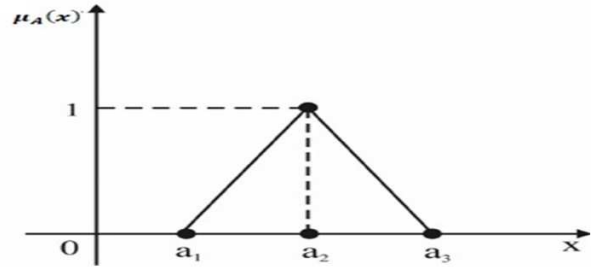

Figure 1: Triangular Fuzzy Number.

2.2. Trapezoidal fuzzy number [3]

A trapezoidal fuzzy number A is a fuzzy number $(a_1,\ a_2,\ a_3,\ a_4)$ and its membership function is defined as

$$\mu_A(x) = \begin{cases} \dfrac{x - a_1}{a_2 - a_1}, & if\ \ a_1 \le x \le a_2 \\ 1, & if\ \ a_2 \le x \le a_3 \\ \dfrac{a_4 - x}{a_4 - a_3}, & if\ a_3 \le x \le a_4 \\ 0, & otherwise \end{cases}$$

The graphical representation of trapezoidal fuzzy number is present in Fig. 2.

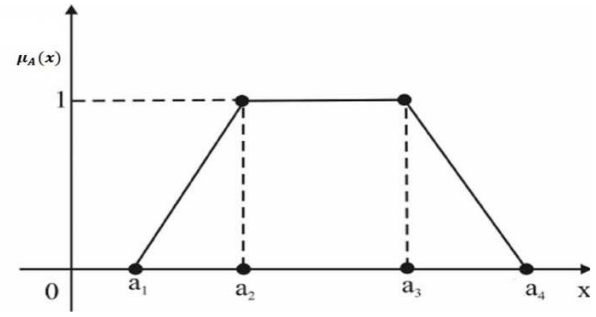

Figure 2: Trapezoidal fuzzy number.

2.3. Linguistic variable [8]

Linguistic variable actually represents this type of variable whose values are word or sentence in an artificial or natural language

3. Working principle of an air conditioner

Usually heat travels from hot air to cold. However, it is totally opposite in air conditioning system. The mechanism of air conditioner is designed to extract heat from a certain area and maintain the user desired temperature on that area. Actually, this process is carried out by a continuous cycle which consists of several steps.

1. One of the most important elements for Air Conditioner is freon gas which flows through compressor and the entire capillary tube. Although it was much cooler before entering the compressor. The compressor compressed it in a small area which causes the hotness of the freon gas;
2. After that hot freon gas passes through a bunch of coils which helps freon gas to decrease its heat and turns it into a liquid freon;
3. When the liquid freon passes through a valve, suddenly its pressure decreases drastically which causes the coolness of the freon gas;
4. Finally, the cold freon gas runs through the capillary tube and absorbs heat from the room where the air conditioner is placed.

4. Air organization system

Due point temperature indicates both Temperature and Relative Humidity (RH) in a certain place. In a certain due point temperature, if RH increases than Temperature will decrease. Again, if Temperature increases than RH will decrease. By controlling due point, material's decay can be decreased. Moreover, it is used to measure humidity. The table 1 shown below shows human's reaction on a standard dew point.

Table 1: A standard dew point human reaction table

Dew point (Td)	Human Reaction
Less than 8°	Very Dry
8°- 14°	Dry
14°-18°	Refreshing
19°-20°	Humid
20°-25°	Comfortable
Above 25°	Painful

5. Fuzzy membership function

Membership function is used to represent a fuzzy set graphically. Several MF (Membership Function) are used in FIS. In this paper, we will use triangular and trapezoidal membership function to develop Fuzzy Logic Controller (FLC). Each input and output including their linguistic variable are discussed below.

5.1. Fuzzy input variables

5.1.1. User temperature (UT)

From the several sensors like thermostat or electronic, user's temperature can be collected which has three linguistic variables named low, medium and high as shown in table 2.

Table 2: User temperature (UT) classification

	Range	Fuzzy Set
User Temperature (UT)	14-26	Low
	22-28	Medium
	26-34	High

5.1.2. Temperature difference (Tdf)

The difference between user's temperature and room's temperature is the temperature difference (Tdf). In this paper, the range of Tdf is taken between -4 to +4. As soon as the difference goes out of the range, the air conditioner switched off since it can't be worked as a heat pump. Four linguistic variables are used here which are neg (negative), zero, pos (positive), hpos (high positive) as shown in table 3.

Table 3: Temperature difference (Tdf) classification

	Range	Fuzzy Set
Temperature Difference (Tdf)	-4 – 0	neg
	-1.5 - +1.5	zero
	0 – +2.5	pos
	+2 - +4	hpos

5.1.3. Dew point (Td)

Dew point temperature is the temperature of captive room where air conditioner is placed. Here, two linguistic variables are taken named Low and High as shown in the table 4.

Table 4: Dew point (Td) classification

	Range	**Fuzzy Set**
Dew Point (Td)	12-20	Low
	17-29	High

5.1.4. Number of people (NP)

The number of people who are staying inside the room are the number of objects. If there is no one inside the room then the air conditioner will remain off. Three linguistic variables are taken here which are Low, Medium and High as shown in the table 5.

Table 5: Number of people (NP) classification

	Range	**Fuzzy Set**
Number of People (NP)	1-4	Low
	3-9	Medium
	7-12	High

5.2. Fuzzy output variables

5.2.1. Compressor speed (CS)

Actually, the compressor speed varies from 0 to 100% depending on the inputs that are taken by the sensors from the room. By controlling the compressor speed, room temperature can be optimized. Three linguistic variables are taken here which are Slow, Medium and Fast as shown in the table 6.

Table 6: Compressor speed (CS) classification

	Range	**Fuzzy Set**
Compressor Speed (CS)	0-55	Slow
	45-75	Medium
	70-100	Fast

5.2.2. Fan speed (FS)

Inside an air conditioner fan is running with a speed that varies from 0 to 100% depending on the inputs. Here, Slow, Medium and Fast are taken as linguistic variables as shown in the table 7.

Table 7: Fan speed (FS) classification

	Range	**Fuzzy Set**
Fan Speed (FS)	0-50	Slow
	45-80	Medium
	70-100	Fast

5.2.3. Fin direction (FD)

The fin direction indicates the direction of the cold air flow that comes from the fin which is a bunch of blades bounded to the air conditioner. Its direction is either towards (Td) the user or away (Aw) from the user.

Table 8: Fin direction (FD) classification

	Range	**Fuzzy Set**
Fin Direction (FD)	0-50	Slow
	45-80	Medium
	70-100	Fast

Here in the Fig. 3 to 16 inputs and outputs membership functions of fuzzy logic shown:

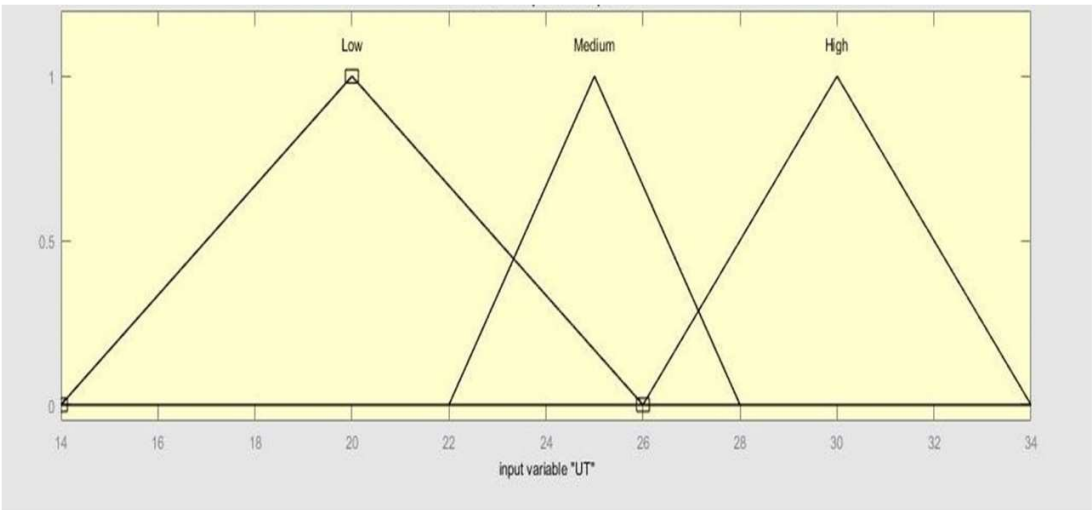

Figure 3: User temperature membership functions

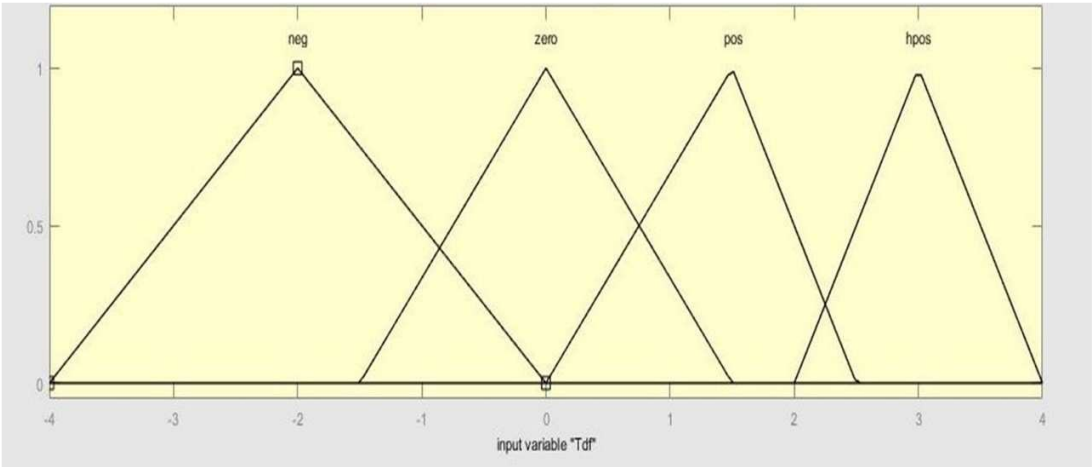

Figure 4: Temperature difference membership functions

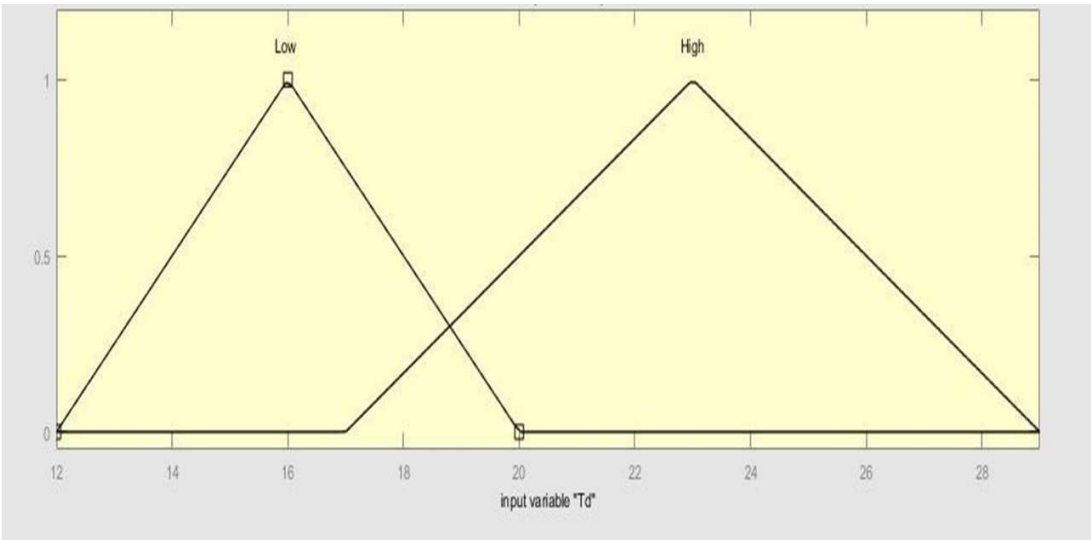

Figure 5: Dew point membership functions

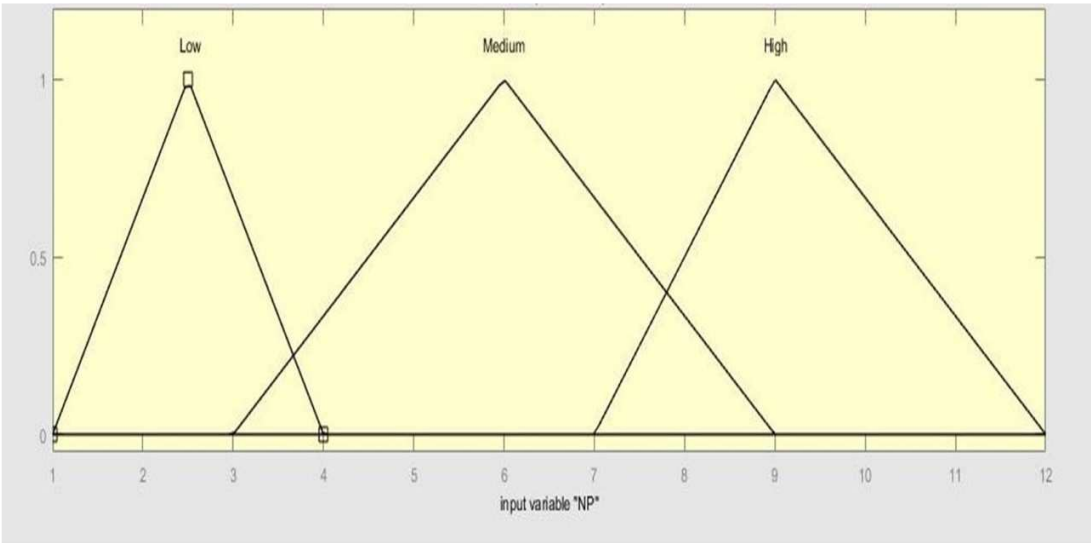

Figure 6: Number of people membership functions

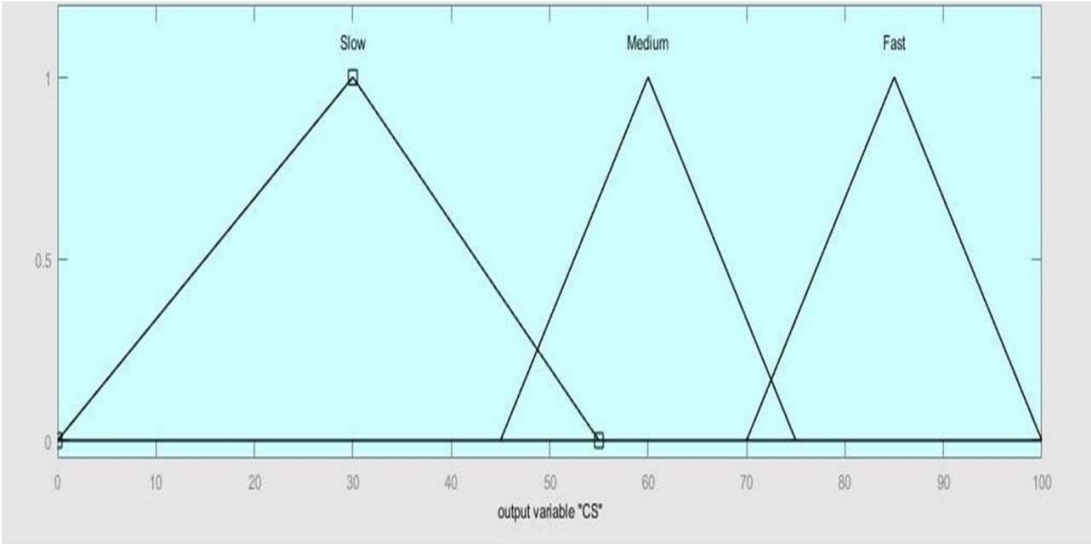

Figure 7: Compressor speed membership functions

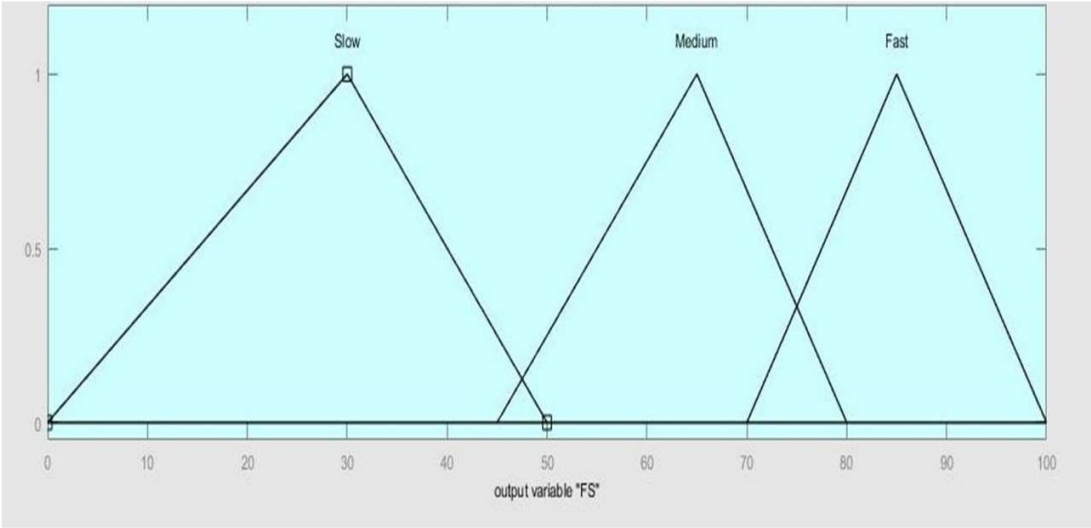

Figure 8: Fan speed membership functions

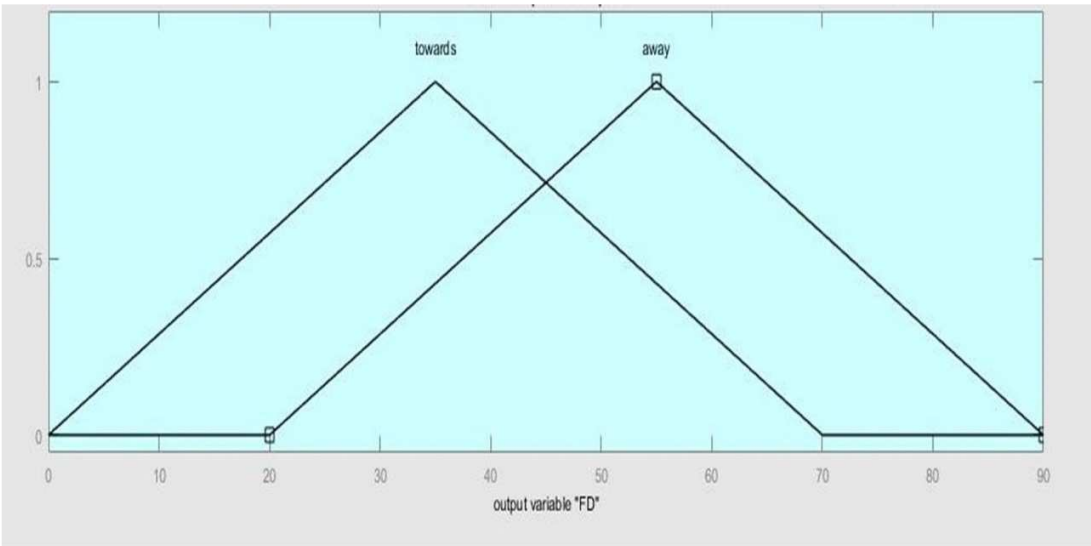

Figure 9: Fin direction membership functions

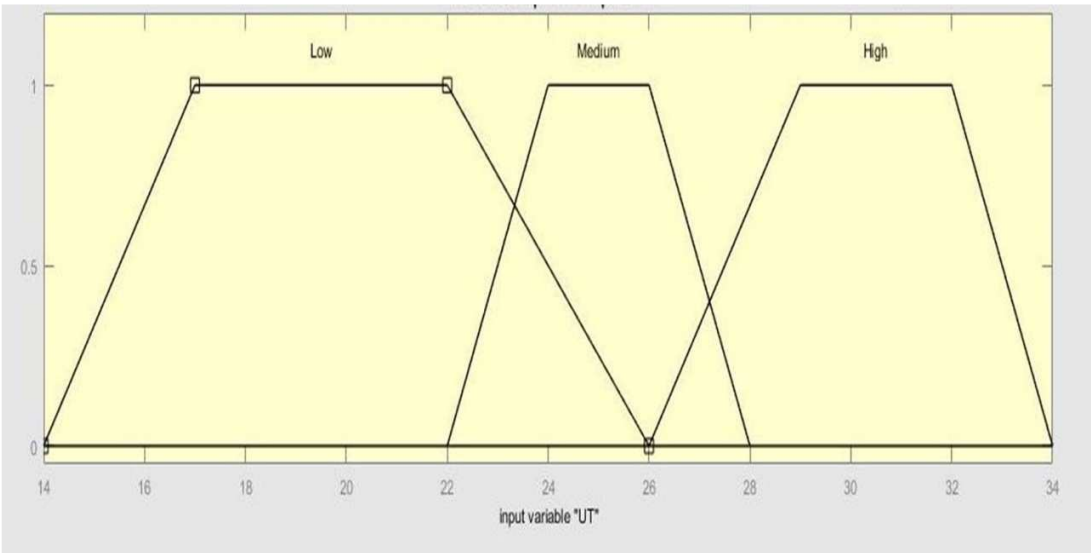

Figure 10: User temperature membership functions

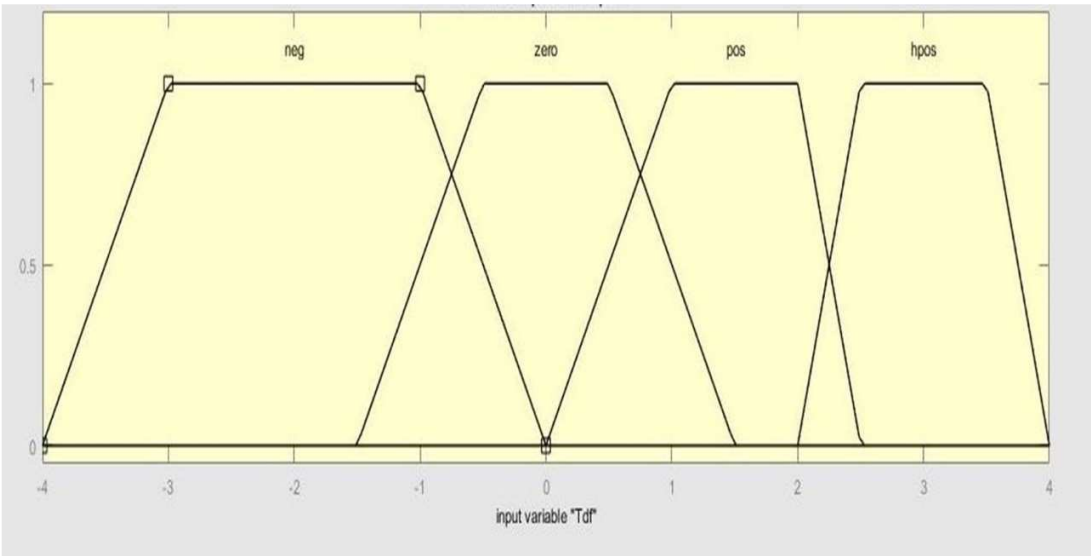

Figure 11: Temperature difference membership functions

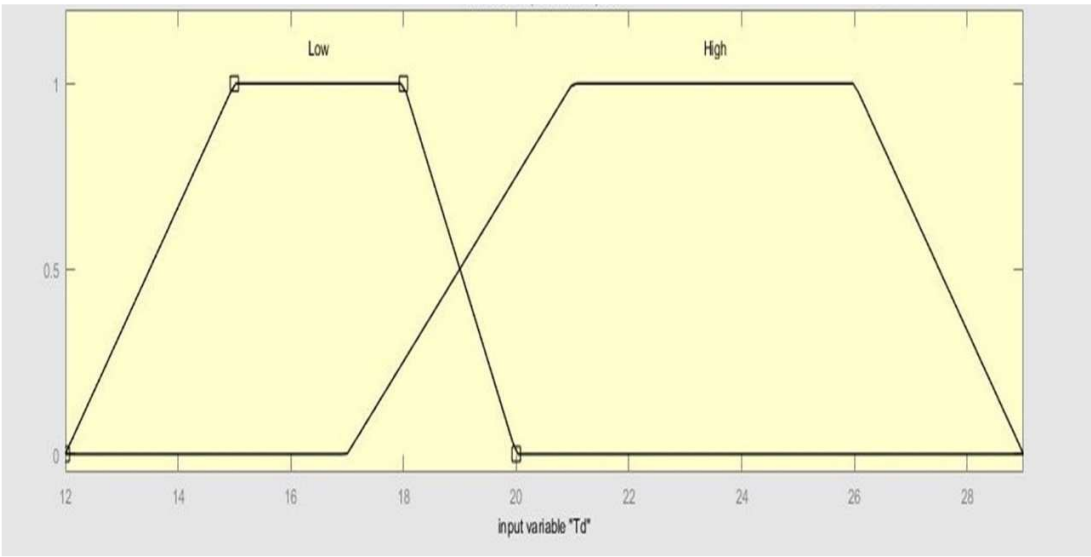

Figure 12: Dew point membership functions

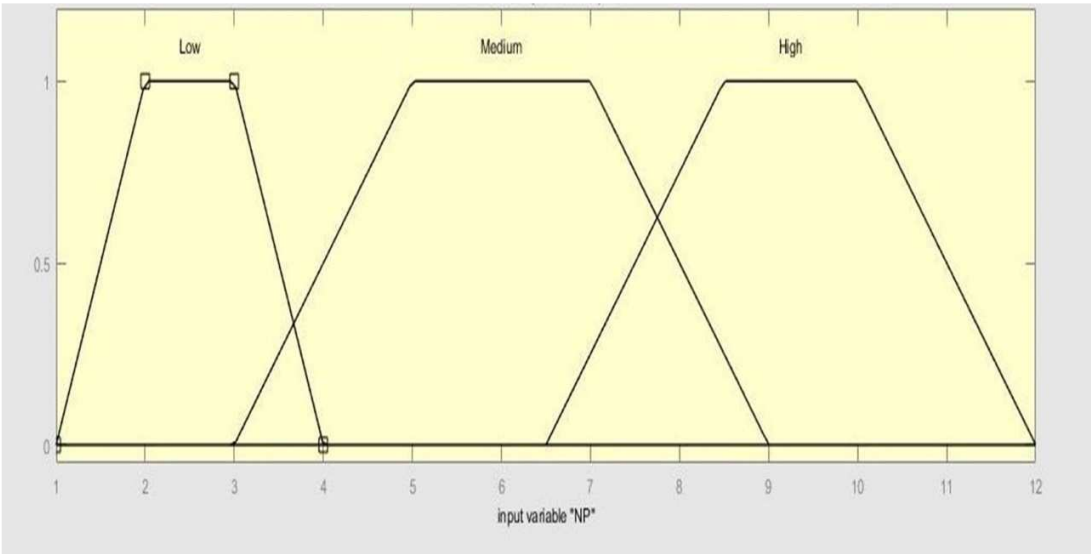

Figure 13: Number of people membership functions

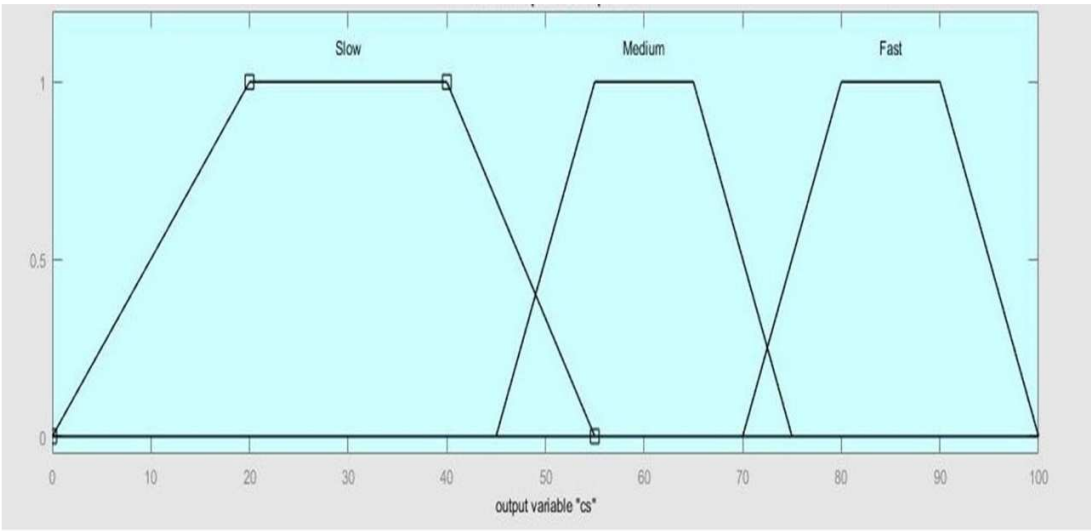

Figure 14: Compressor speed membership functions

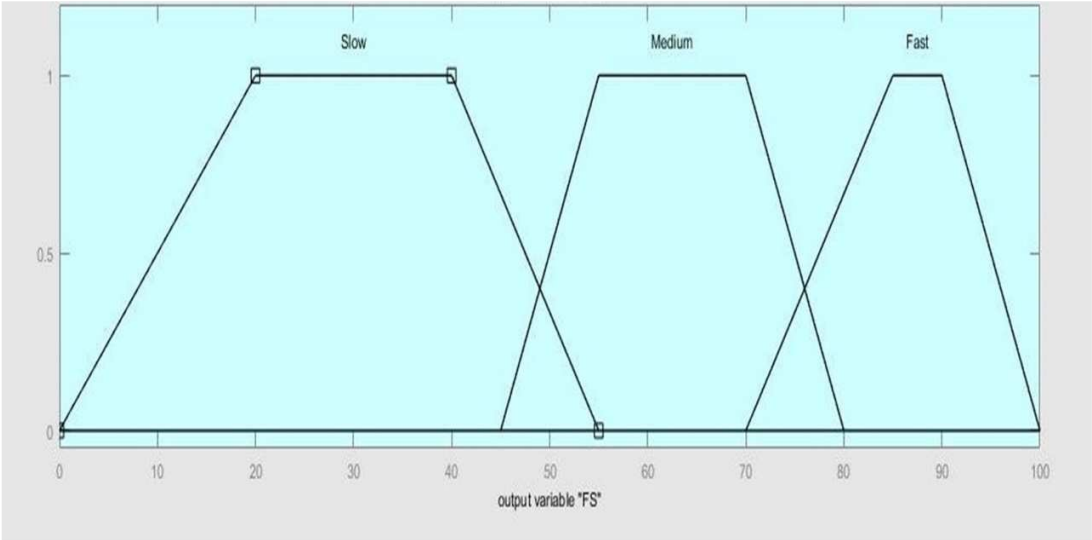

Figure 15: Fan speed membership functions

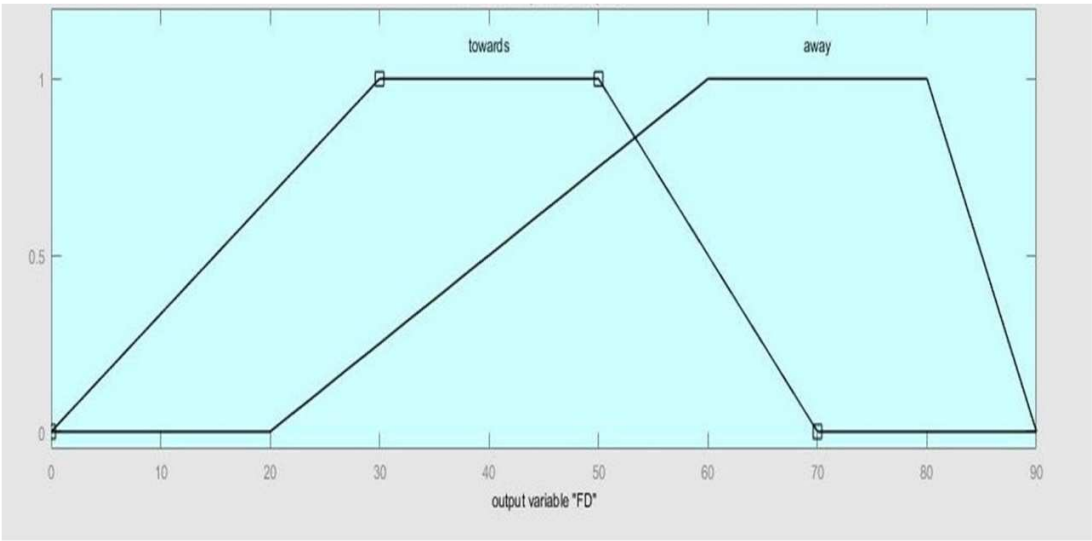

Figure 16: Fin direction membership functions

6. Fuzzy rule-base

Fuzzy Rules based are applied in the FLC by selecting the appropriate sequence in the IF-Then rules which are based on natural language. It is designed to make any automated decision. It is formed by keeping the relationship among Input and output in mind. The input variables (UT, Tdf, Td, NP) make a total of 3*4*2*3=72 as shown in the table 9.

Table 8: Fuzzy rule base

Rule No.	Input Variables				Output Variables		
	UT	**Tdf**	**Td**	**NP**	**CS**	**FS**	**FD**
1	Low	neg	Low	Low	Slow	Slow	away
2	Medium	neg	Low	Low	Slow	Slow	away
3	High	neg	Low	Low	Slow	Slow	away
4	Low	zero	Low	Low	Slow	Slow	away
5	Medium	zero	Low	Low	Slow	Slow	away
6	High	zero	Low	Low	Slow	Slow	away
7	Low	pos	Low	Low	Slow	Slow	away
8	Medium	pos	Low	Low	Slow	Slow	away
9	High	pos	Low	Low	Slow	Slow	away
10	Low	hpos	Low	Low	Slow	Slow	away
11	Medium	hpos	Low	Low	Slow	Slow	away
12	High	hpos	Low	Low	Slow	Slow	away
13	Low	neg	Low	Medium	Slow	Slow	away
14	Medium	neg	Low	Medium	Slow	Slow	away
15	High	neg	Low	Medium	Slow	Slow	away
16	Low	zero	Low	Medium	Slow	Slow	away
17	Medium	zero	Low	Medium	Slow	Slow	away
18	High	zero	Low	Medium	Slow	Medium	towards
19	Low	pos	Low	Medium	Slow	Medium	towards
20	Medium	pos	Low	Medium	Slow	Medium	towards
21	High	pos	Low	Medium	Medium	Medium	towards
22	Low	hpos	Low	Medium	Medium	Medium	towards
23	Medium	hpos	Low	Medium	Medium	Fast	towards
24	High	hpos	Low	Medium	Fast	Medium	towards
25	Low	neg	Low	High	Slow	Slow	towards
26	Medium	neg	Low	High	Slow	Slow	away
27	High	neg	Low	High	Slow	Slow	away
28	Low	zero	Low	High	Slow	Slow	away
29	Medium	zero	Low	High	Slow	Slow	away
30	High	zero	Low	High	Slow	Slow	away
31	Low	pos	Low	High	Medium	Medium	towards
32	Medium	pos	Low	High	Medium	Medium	towards
33	High	pos	Low	High	Medium	Medium	towards
34	Low	hpos	Low	High	Fast	Fast	towards
35	Medium	hpos	Low	High	Fast	Fast	towards
36	High	hpos	Low	High	Fast	Fast	towards
37	Low	neg	High	Low	Slow	Slow	away
38	Medium	neg	High	Low	Slow	Slow	away
39	High	neg	High	Low	Slow	Slow	away

40	Low	zero	High	Low	Slow	Slow	away
41	Medium	zero	High	Low	Slow	Slow	away
42	High	zero	High	Low	Slow	Slow	away
43	Low	pos	High	Low	Medium	Slow	towards
44	Medium	pos	High	Low	Medium	Slow	towards
45	High	pos	High	Low	Slow	Medium	towards
46	Low	hpos	High	Low	Slow	Medium	towards
47	Medium	hpos	High	Low	Medium	Medium	towards
48	High	hpos	High	Low	Medium	Fast	towards
49	Low	neg	High	Medium	Slow	Slow	towards
50	Medium	neg	High	Medium	Slow	Slow	away
51	High	neg	High	Medium	Slow	Slow	away
52	Low	zero	High	Medium	Slow	Slow	away
53	Medium	zero	High	Medium	Slow	Slow	away
54	High	zero	High	Medium	Slow	Slow	away
55	Low	pos	High	Medium	Slow	Medium	towards
56	Medium	pos	High	Medium	Medium	Medium	towards
57	High	pos	High	Medium	Fast	Medium	towards
58	Low	hpos	High	Medium	Medium	Medium	towards
59	Medium	hpos	High	Medium	Medium	Fast	towards
60	High	hpos	High	Medium	Fast	Fast	towards
61	Low	neg	High	High	Slow	Slow	towards
62	Medium	neg	High	High	Slow	Slow	away
63	High	neg	High	High	Slow	Slow	away
64	Low	zero	High	High	Slow	Slow	away
65	Medium	zero	High	High	Medium	Medium	towards
66	High	zero	High	High	Medium	Fast	towards
67	Low	pos	High	High	Fast	Fast	towards
68	Medium	pos	High	High	Fast	Fast	towards
69	High	pos	High	High	Fast	Fast	towards
70	Low	hpos	High	High	Fast	Fast	towards
71	Medium	hpos	High	High	Fast	Fast	towards
72	High	hpos	High	High	Fast	Fast	towards

7. Fuzzy Logic Algorithm

If-Then rules-base format is solved by fuzzy logic algorithm in four steps as follows:

Step-1 Input Variables:

Firstly, a set of MF of linguistic variables are taken as inputs where input variables are basically words or sentences. In order to take any fuzzy or crisp output by fuzzification or defuzzification respectably, fuzzy MF are used.

Step-2 Fuzzification:

Fuzzification is a process which provides fuzzy output. Here, crisp values are fuzzified for fuzzy output.

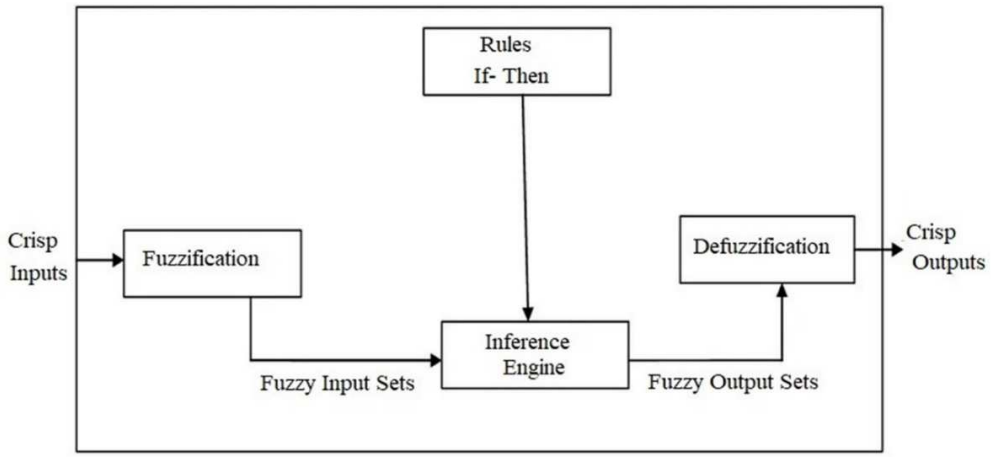

Figure 17: Fuzzy logic system

Step-3 Fuzzy Inference System:
Fuzzy rule-based is applied here. For each antecedent, there is a consequent which is the resulted output for every rule-base. Several operators like or, and, else, not are used in rule-based system to connect multiple linguistic variables so that target output is obtained inside the inference system.

Step-4 Defuzzification:
In the defuzzification process, crisp output is obtained from fuzzy set. Hardware applications are greatly dependent on defuzzification system.

8. FLC implementation in air conditioner using MATLAB

8.1. Fuzzy base class

Mamdani method is used to create system control rules obtained from experienced human operators [7]. In this paper, Mamdani method is used to illustrate and centroid method is used for defuzzification. Here, FIS editor FIS Editor defines the Fuzzy Base Class, the various inputs, i.e. user temperature (UT), Temperature Difference (Tdf), Dew Point (Td), and Number of People (NP) and the various output variables like Compressor Speed (CS), Fan Speed (FS) and, Fin Direction (FD) [13]as shown.

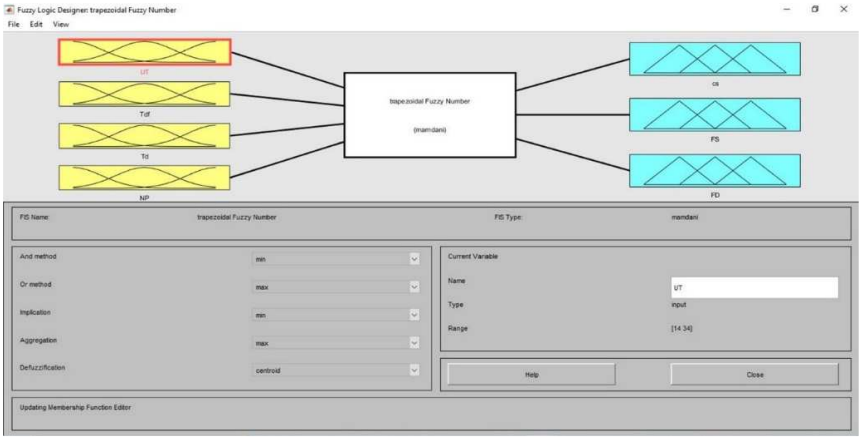

Figure 18: Fuzzy base class

8.2. Fuzzy rule base

Fuzzy rules can be designed manually by a user, or automatically, i.e. the Rule Editor generates rules for all combinations of selected input variable and a user fills consequent fuzzy terms. Inputs and sub-sequentially provide the fuzzy outputs [13] as shown.

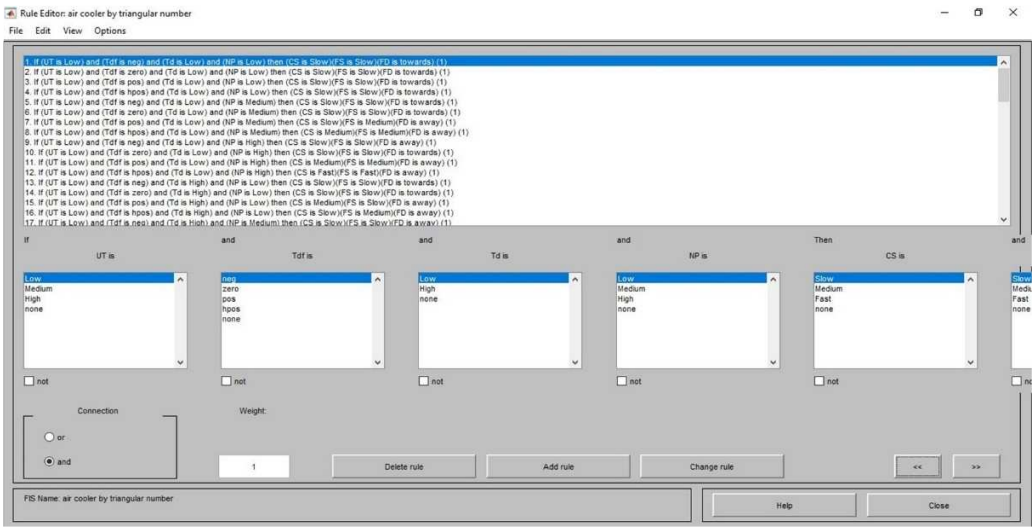

Figure 19: Fuzzy base rules

9. Result and discussion

9.1. Simulated results

The Surface Viewer of the Fuzzy Logic Toolbox in the MATLAB software was used to generate the following Graphs: 3D graphical results of various input variables and corresponding output variables are shown in figure 20 to 25 for triangular and figure 26 to 31 for trapezoidal fuzzy number.

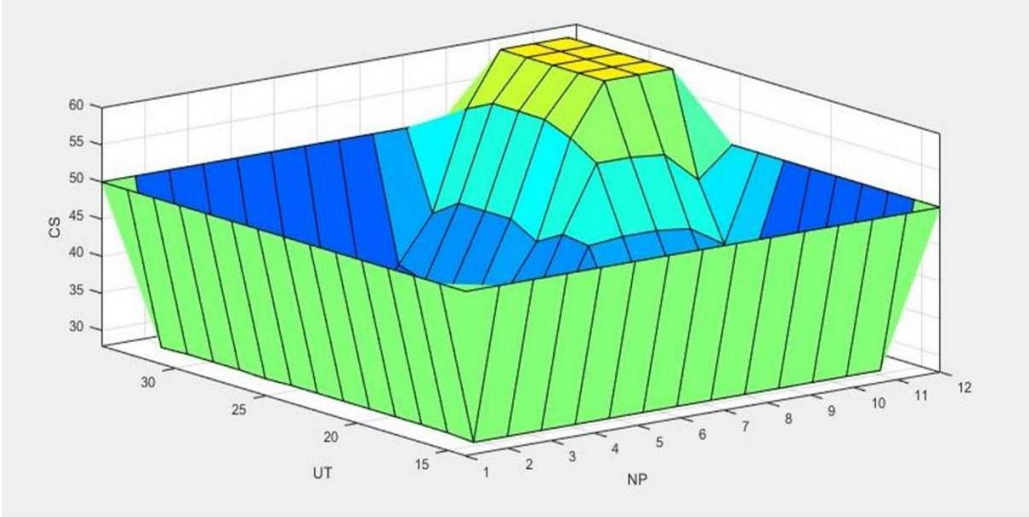

Figure 20: Gradient graph of NP vs UT vs CS

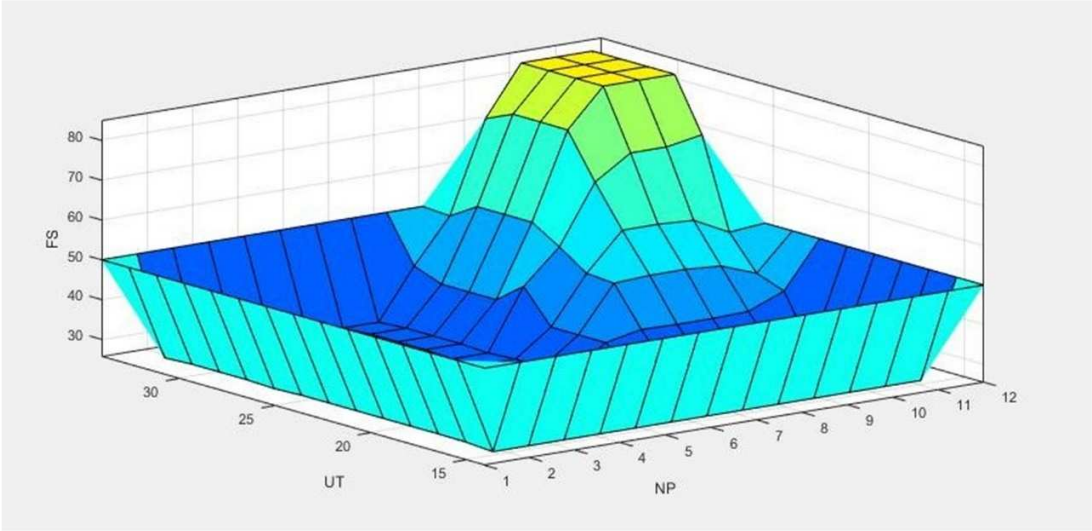

Figure 21: Gradient graph of NP vs UT vs FS

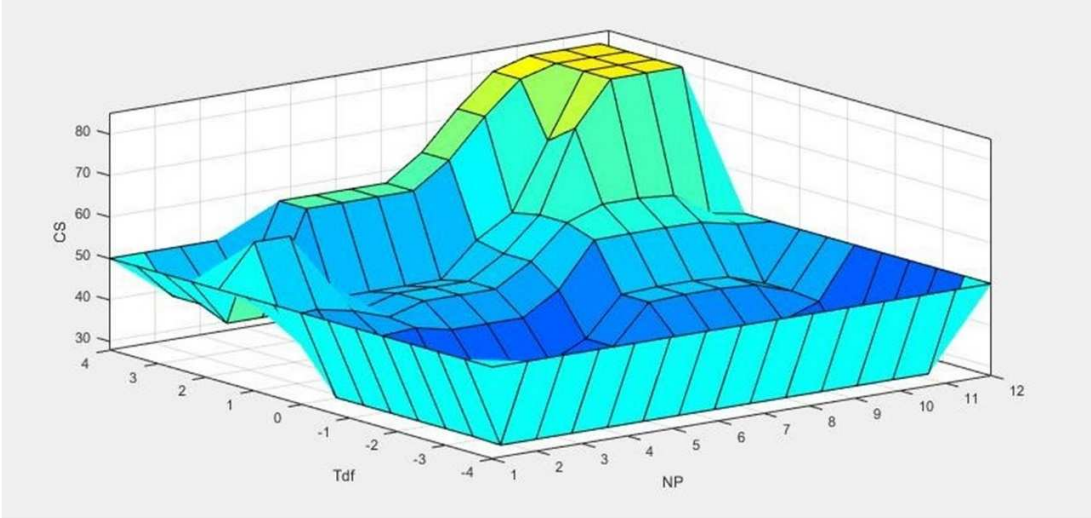

Figure 22: Gradient graph of NP vs Tdf vs CS

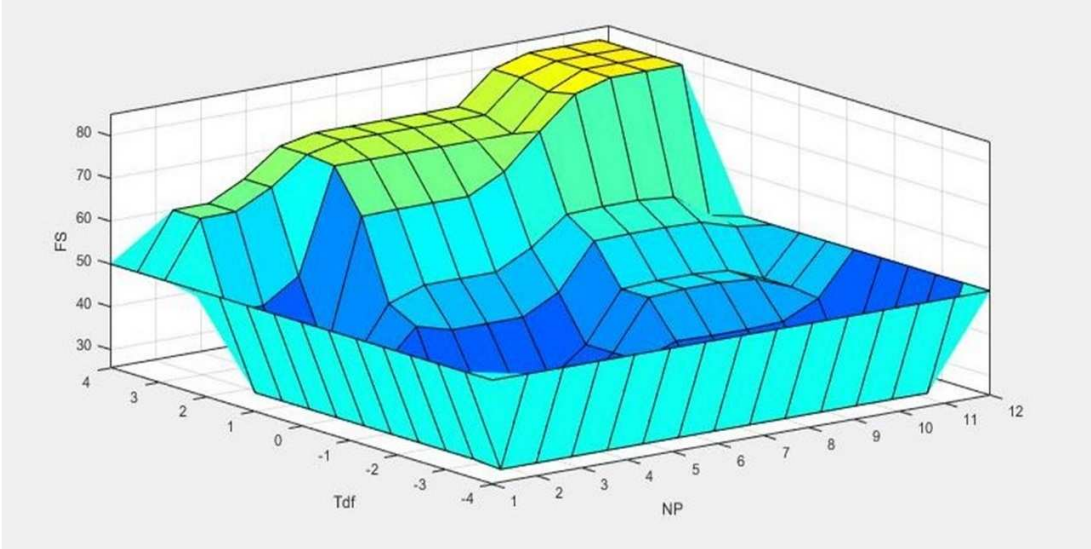

Figure 23: Gradient graph of NP vs Tdf vs FS

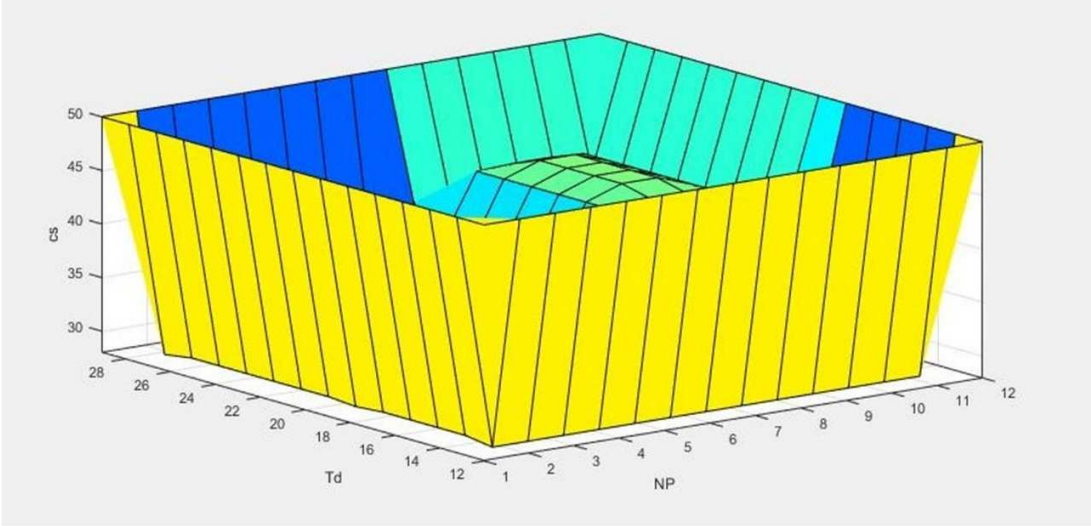

Figure 24: Gradient graph of NP vs Td vs CS

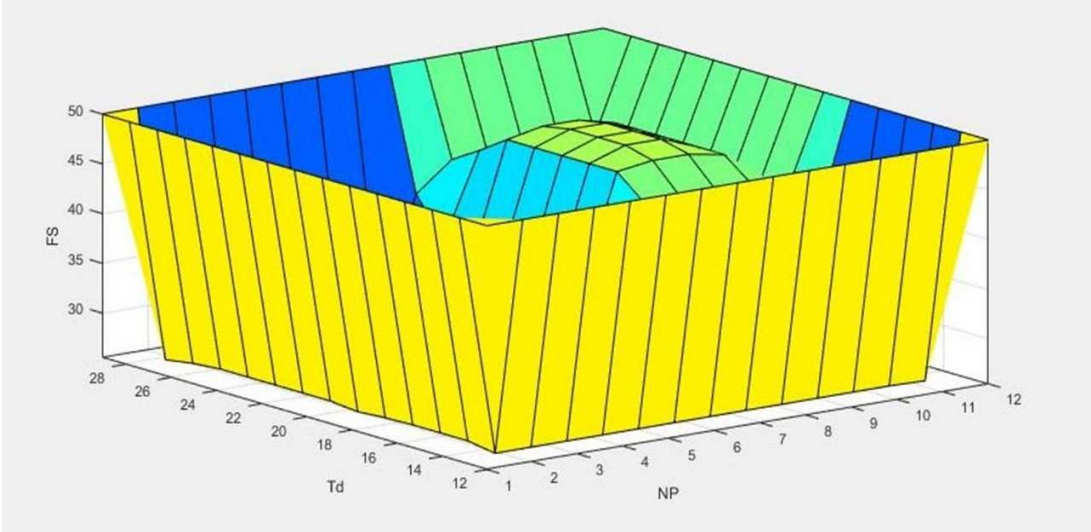

Figure 25: Gradient graph of NP vs Td vs FS

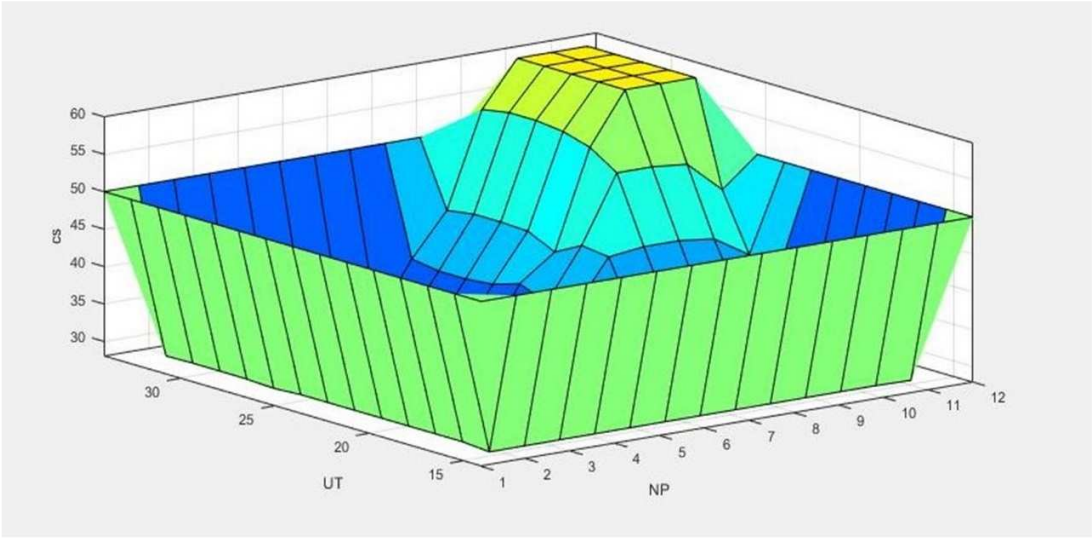

Figure 26: Gradient graph of NP vs UT vs CS

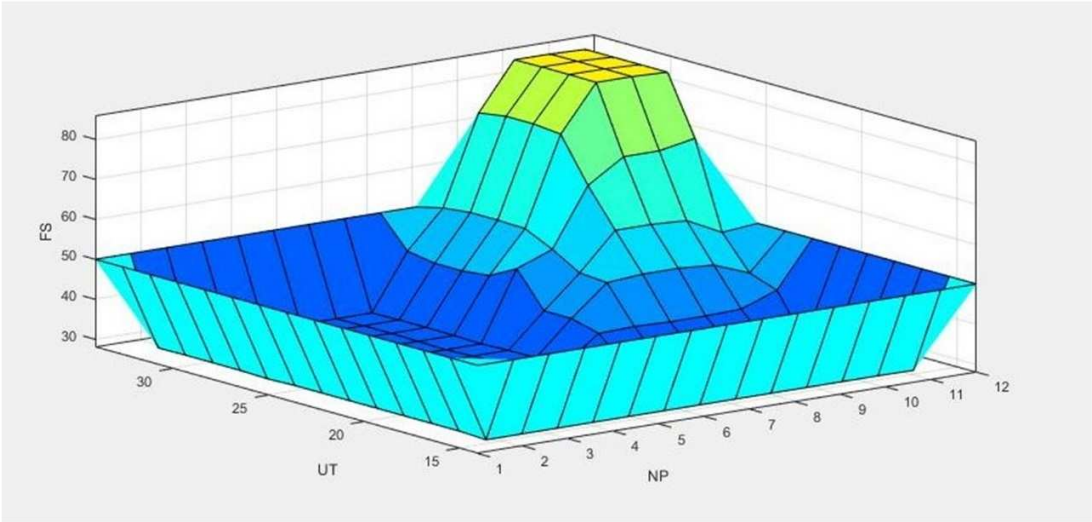

Figure 27: Gradient graph of NP vs UT vs FS

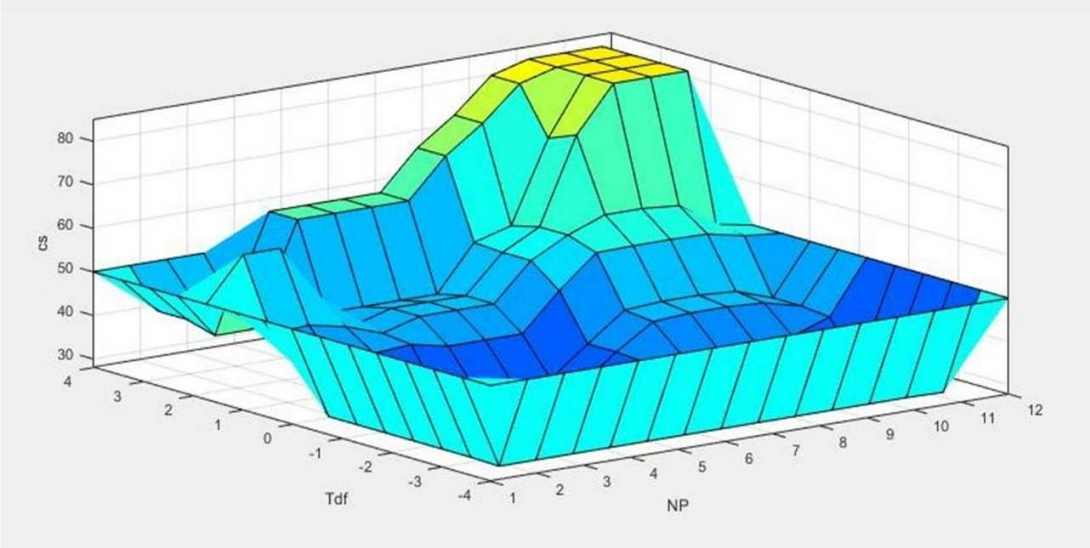

Figure 28: Gradient graph of NP vs Tdf vs CS

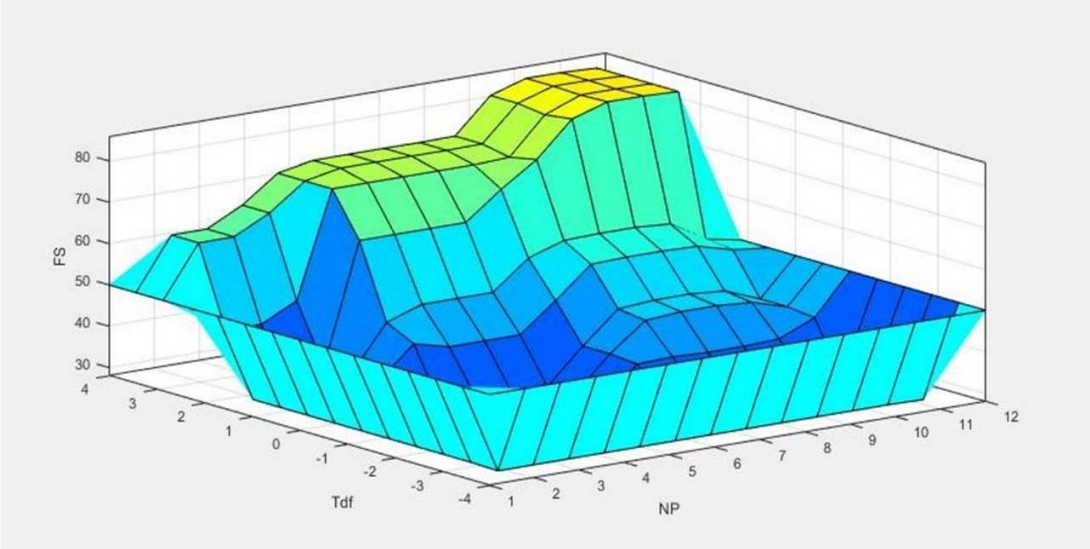

Figure 29: Gradient graph of NP vs Tdf vs FS

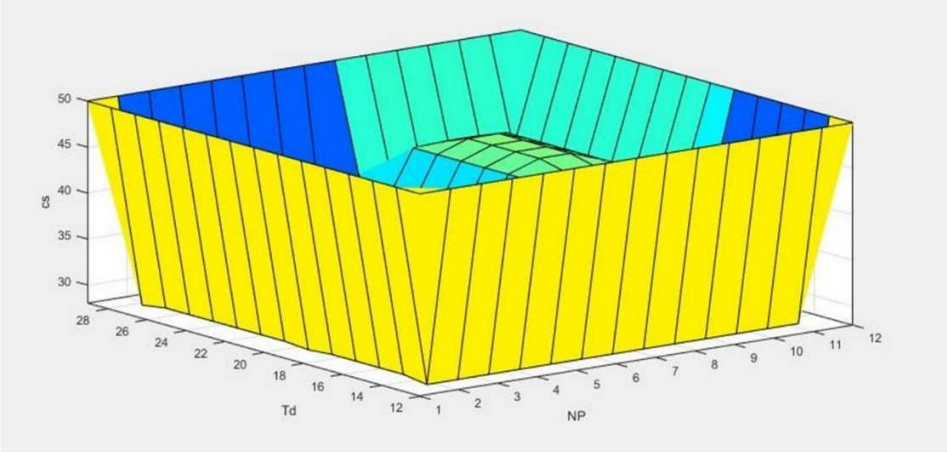

Figure 30: Gradient graph of NP vs Td vs CS

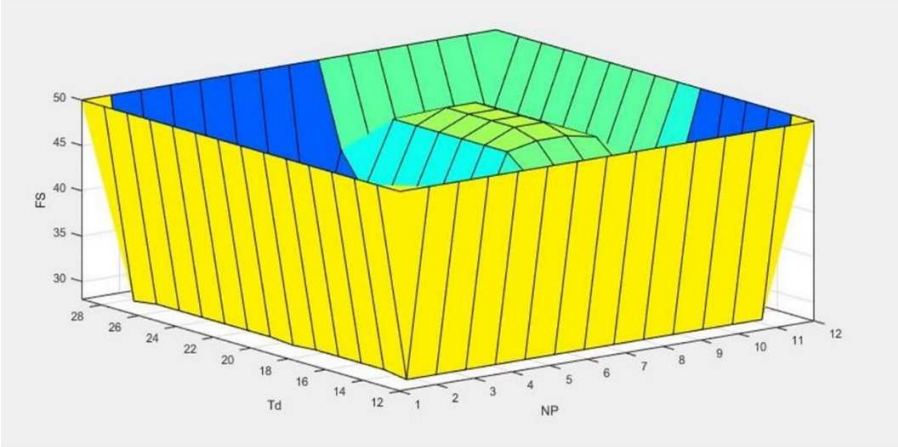

Figure 31: Gradient graph of NP vs Td vs FS

9.2. The rule viewer

In order to apply the FLC designed in this paper, the rule viewer is used. The Rule Viewers as shown in Fig. 12 and 13 gives us the insight about the application of the fuzzy membership function to input values of the simulation. For example, some set of inputs variables were taken.

Triangular Fuzzy Number:

Case-I: UT=22, Tdf=2, Td=24, NP=7 and the corresponding outputs are CS=28.1%, FS=63%, FD=55. Case-II: UT=24, Tdf=1, Td=25, NP=5 and the corresponding outputs are CS=42.5%, FS=45.5%, FD=48.1.

Trapezoidal Fuzzy Number:
Case-I: UT=22, Tdf=2, Td=24, NP=7 and the corresponding outputs are CS=37.3%, FS=66.9%, FD=37. Case-II: UT=24, Tdf=1, Td=25, NP=5 and the corresponding outputs are CS=42.6%, FS=45.8%, FD=44.8.

Figures 32 and 33 represents the Fuzzy Rule Viewer for triangular and trapezoidal fuzzy numbers.

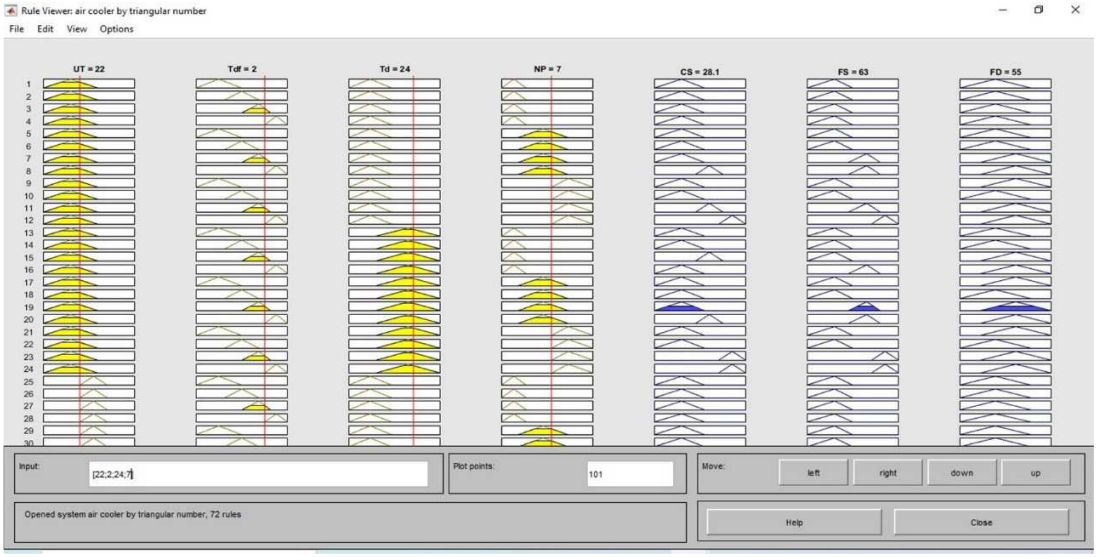

Figure 32: Fuzzy Rule Viewer for Triangular Fuzzy Number.

Figure 33: Fuzzy rule viewer for trapezoidal fuzzy number.

10. Conclusion

In this paper, we can see that, whenever we use a trapezoidal fuzzy number instead of a triangular fuzzy number in the air conditioning system, CS and FS increases a bit. However, FD is not that much accurate when we use trapezoidal fuzzy numbers. Hence, from the above result we can clearly say that it is more appropriate to use trapezoidal fuzzy numbers instead of triangular fuzzy numbers in the development of fuzzy logic controllers in air conditioning systems.

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