Chapter – 1

INTRODUCTION

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1.1 HISTORY OF FUZZY LOGIC :

Fuzzy logic was born in the year 1965. In that year Lofti Zadeh of the university of California, Berkeley, published a paper entitled "Fuzzy Sets" In the Journel of Information and Control[1,3].

Zadeh later proposed the idea of the fuzzy algorithm, which laid the foundation of Fuzzy logic and reasoning. In 1972, Michio Sugeno of the Tokeyo put forth the concept of fuzzy measure and fuzzy integral[1,2].

In 1974 Ebraham Mamdani of the University of London applied fuzzy logic for the first time to the control of a simple Steam engine. The first industrial application of fuzzy logic appeared six years later. In 1980, F. H. Smidth of Denmark applied fuzzy logic to the control of a cement Kiln. in 1980[3]. Fuji Electric of Japan applied fuzzy logic to the control of a water purification process and later Hitachi developed an automatic train control system with fuzzy logic. These were the Forerunners of the fuzzy logic "boom" in Japan in the early 1990's [4].

The international fuzzy system Association (IFSA) was established. In 1984 as the first academic organization for fuzzy logic theorists and practitioners IFSA holds an international symposium every other year. Around the same time, practical applications began to be reported in Japan particularly in the control field. In 1989, the society of fuzzy Theory and Systems (SOFT) was founded and the Laboratory of International fuzzy Engineering (LIFE) was inaugurated in Japan. In the early 1990's fuzzy logic was applied to home electronics products and the non engineering people became aware of fuzzy systems[2].

Fuzzy logic gained importance after Ebrahim Mamdani and Sato demonstrated the practical potential of fuzzy logic. Their pioneering Work led to an exponential growth of fuzzy logic literature and opened avenues for various applications such as industrial process control and consumer products etc. Fuzzy logic uses linguistic modeling of a system as opposed to the mathematical modeling, in the control rules, using the experience of a human operator[2,4,5].

Further advances were made when Togai and Watanabe reported the first fuzzy chip. Yamazaki and Sugeno and Yamakawa developed a microprocessor based on fuzzy controller[5].

Another era started by combining neural networks capabilities with those of fuzzy logic. Kosko presented a new approach for adaptive fuzzy systems using neural networks.

By 1990, fuzzy logic reached the consumer market. Fuzzy logic was used in vaccume cleaners, cameras, microwave ovens and several other consumer products. The fuzzy logic tide today has reached the internet[3,4].

1.2 CRISP SET AND FUZZY SET : [2]

In our conversation we use words e.g. big, small, hot, cold, which do not give exact meaning and hence such words are not uses in conventional set theory e.g. set of good people taller than six feet can be formed easily. Sets, which are exactly defined are called crisp sets, in fuzzy set paralance and they are defined by characteristic function as follows.

If A represents a crisp set on the universe x. Its characteristic function X_A can be defined by a mapping.

$$X_A : X \rightarrow \{ 0, 1 \}$$

as

$$X_A(x) = \begin{cases} 1 & x \in X \\ 0 & x \notin X \end{cases}$$

Fuzzy sets are defines by membership functions.

A Fuzzy set B on the universe x is a set defined by a membership function μ_B representing a mapping.

$$\mu_B : x \rightarrow \{ 0, 1 \}$$

Here the value of $\mu_B(x)$ for the fuzzy set B is called the membership value or the grade of membership of $X \in x$. The membership value represents the degree of x belonging to the fuzzy set B. Thus fuzzy set accepts all the values between 0 and 1. A typical membership function for the temperature is shown in fig. 1.1.

In this example a triangular shape is used to represent a fuzzyset. There are other shapes also to represent the fuzzy set for example, a bell shape, a trapezoidel shape etc.

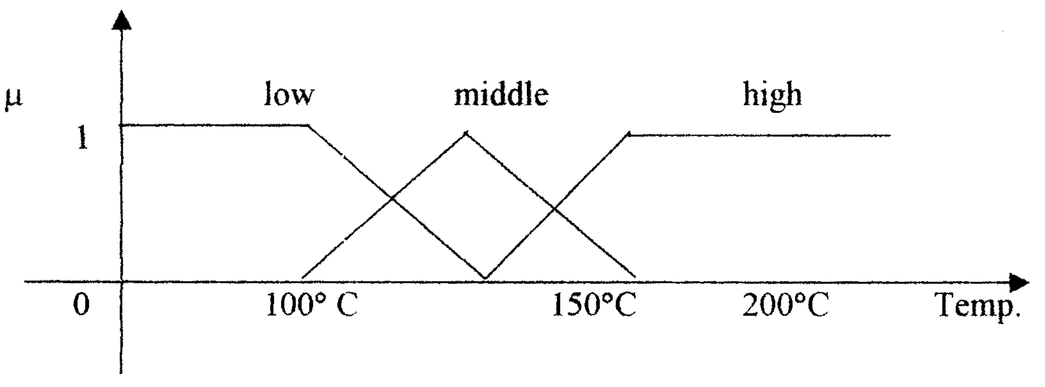

Fig. 1 1 : Fuzzy set of temperature

(2) Triangular fuzzy sets :-

The idea is to represent a set of numbers around zero with peak at $x = 0$.

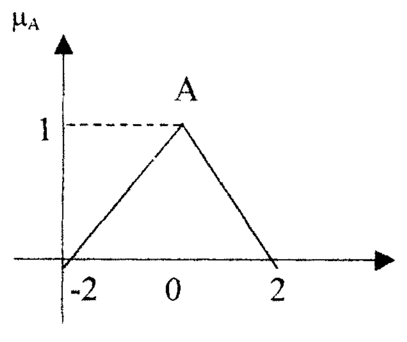

Fig. 1.2 : Infinite triangular fuzzy set

The infinite expression of infinite triangular fuzzy set is

$$A = \int_{-2}^{0} \left(\frac{2 + x}{2} \right) / x + \int_{0}^{+2} \left(\frac{2 - x}{2} \right) / x$$

(2) Trapezoidal fuzzy set :

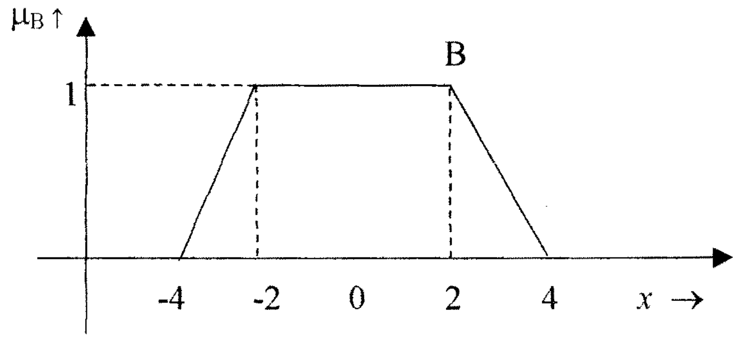

Fig. 1.3 : Trapezoidal fuzzy set

This trapezoidal fuzzy set can be expressed by the infinite expression:

$$B = \int_{-4}^{-2} \left(\frac{4 + x}{2} \right) / x + \int_{-2}^{2} 1 / x + \int_{-2}^{4} \left(\frac{4 - x}{2} \right) / x$$

(3) Exponential fuzzy set

The membership function of this type of fuzzy set is expressed by exponential functions. The infinite expression of this type of fuzzy set can be given as follows :

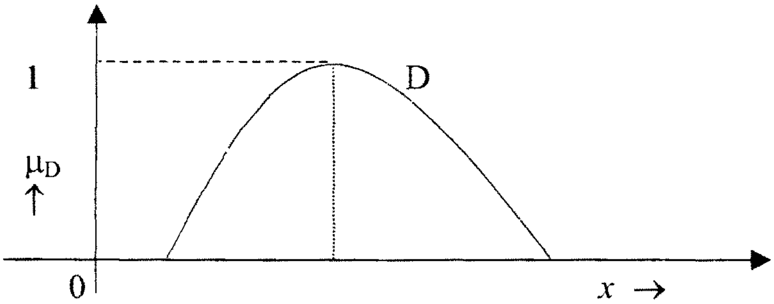

Fig. 1.4 : Exponential fuzzy set.

$$D = \int_x e^{-0.5(x-5)} / x$$

The shape of the membership function determines the degree of capturing the underlying concept or meaning of fuzzy variable. There is no restriction on a particular shape to be used but the triangular shape is used in many engineering applications to gain confidence in the application of fuzzy logic to real time application in addition to

- Computational efficiency
- Effective use of memory
- Simplification of inference process.

1.3 ADVANTAGES & DISADVANTAGES OF FUZZY LOGIC :[4,5,7,9]

Advantages

- Relates input to output in linguistic terms, easily understood
- Allows for rapid prototyping because the system designer does not need to know everything about the system before starting.
- Cheaper because they are easier to design.
- Increased robustness
- Simplify knowledge acquisition and representation.
- A few rules encompass great complexity
- Can achieve less overshoot and oscillation.
- Can achieve steady state in a shorter time interval.

Disadvantages :-

- Hard to develop a model from a fuzzy system
- Require more fine tuning and simulation before operational.
- Have a stigma associated with the word fuzzy engineers and most other people are used to crispness and shy away from fuzzy control and fuzzy decision making.

1.4 APPLICATIONS OF FUZZY LOGIC :[5, 7]

Sr. No.	Consumer Product	Name of the Company
1.	Air conditioner	Hitachi, Matsushita, Mitsubishi, Sharp
2.	Anti-lock brakes	Nissan
3.	Clothes dryer	Sanyo, Matsushita
4.	Copy machine	Canon
5.	Dish washer	Matsushita
6.	Electric fan	Sanyo
7.	Kerosene fan heater	Matsushita, Mitsubishi, Toshiba, Fujitsu, Corona, Toyotomi, Sanyo, Sharp
8.	Microwave	Hitachi, Matsushita, Sanyo, Toshiba, Sony
9.	Refrigerator	Sharp
10.	Rice cooker	Matsushita, Sanyo, Hitachi, Sharp
11.	Still camera	Canon, Minolta
12.	Television	Goldstar, Hitachi, Samsung, Sony
13.	Toaster	Sony
14.	Vacuum cleaner	Hitachi, Matsushita
15.	Video camcorder	Panasonic
16.	Washing machine	Goldstar, Hitachi, Matsushita, Samsung, Sanyo, Sharp

1.5 METHODS OF FUZZIFICATION AND DEFUZZIFICATION :

(I) Fuzzification Methods : [2,5]

Fuzzification process, transforms a set (fuzzy or crisp) to an approximating set that is more fuzzy. The essence of the fuzzification process is point fuzzification. Point fuzzification converts a singleton set $1/\mu$ in U to a fuzzy set u that varies around u. The symbol $\sim$ is used to indicate a fuzzifier. For example 10 represents the fuzzy set of real numbers that are nearly equal to ~ 10. In order to express the dependence of u on $\sim$u, $\sim$u is written as u = K (u). The fuzzy set K (u) is referred to as the kernel of fuzzification.

The decision of how to fuzzify i.e. the description of K(u) depends on the meaning of the sets and criterion used e.g.

$$A = \mu_1/x_1 + \mu_2/x_2 + \ldots + \mu_n/x_n$$

Since every member and its membership grade is not dependent of other members and their membership grades, then it can be assumed that the process of fuzzification is linear and superposition may be applied.

The process of fuzzification of μ_i/x_i gives rise to two special cases; (1) μ_i is kept constant and x_i is fuzzificatied (support fuzzification) and (2) μ_i is fuzzified and x_i is kept constant (grade fuzzification).

1. Support fuzzification (s-fuzzification) support fuzzification of A is denoted by SF(A; K) and denoted as

$$A = SF(A; K) = \mu_1 K(x_1) + \ldots + \mu_n K(x_n)$$

where $\mu_i K(x_i)$ is a fuzzy set that is the product of a scalar constant μ_i and fuzzy set $K(x_i)$.

2. Grade fuzzification (g-fuzzification). Grade fuzzificartion of A is denoted by

GF (A; K) and denoted as.

$$A = GF\ (A;\ K) = K(\mu_i)/x_1 + \ldots + K(\mu_n)/x_n\ ,$$

where $K(\mu_i)$ denoted point fuzzification of μ_i.

(II) <u>Defuzzification Methods</u> : [4, 8]

The output of a fuzzy process needs to be a single crisp quantity as opposed to a fuzzy set. Defuzzification is the conversion of a fuzzy variable to a precise quantity, just as fuzzification is the conversion of a precise quantity to a fuzzy quantity. The output of a fuzzy process is the logical union of two or more fuzzy membership functions defined on the universe of discourse of the output variable.

There are seven different methods available among the many that have been proposed by investigators in recent years popular for defuzzifying fuzzy output functions. These methods are described below in brief.

1. *Height defuzzfication :-* The height method is both a very simple and very quick method. This method takes the peak value of each fuzzy set and weighted value of some of these values as shown in fig. (1.5). This method is given by the algebraic expression.

$$z^* = \frac{\sum_{r=1}^{q} p_m^{(r)} \cdot h^{(r)}}{\sum_{r=1}^{q} h^{(r)}}$$

Where q = number of fuzzy rules fired

$p_m^{(r)}$ = peak value of r^{th} clipped fuzzy set

$h^{(r)}$ = height of r^{th} clipped fuzzy set

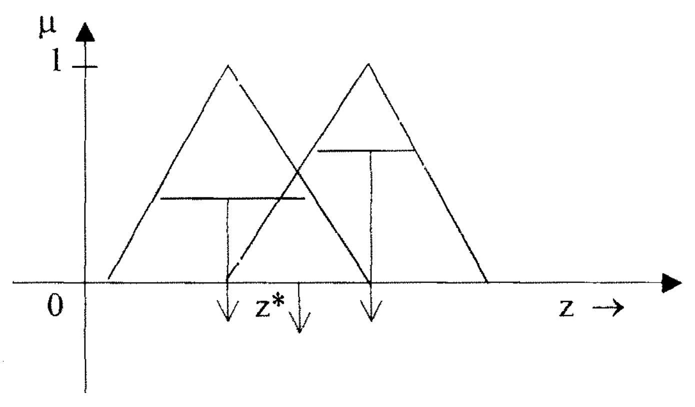

Fig. 1.5 : A graphical representation of the height defuzzyfication method.

2. *Centroid methods* :- This procedure (also called center of gravity) is the most commonly and physically appealing of all the defuzzification methods it is given by the expression

$$z^* = \frac{\int \mu_{\underline{C}}(z)\, z\, dz}{\int \mu_{\underline{C}}(z)\, dz}$$

where $\int$ denotes an algebraic integration. This method is shown in Fig. 1.6

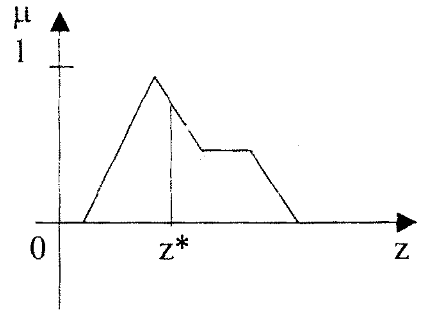

Fig. 1.6 : Centroid defuzzification method

3. *Weighted average method :* This method applies only to symmetrical output membership functions. It is given by the algebraic expression

$$z^* = \frac{\sum \mu_{\underline{C}}(\bar{z}) \cdot \bar{z} \, dz}{\sum \mu_{\underline{C}}(\bar{z}) dz}$$

where Σ denotes an algebraic sum. This method is shown in Fig. 1.7. The weighted average method is formed by weighting each membership function in the output by its respective maximum membership value. As e. g. the two functions shown in Fig. (1.7) will yield the defuzzified value.

$$z^* = \frac{a(0.5) + b(0.9)}{0.5 + 0.9}$$

This method is limited to symmetrical membership functions, and hence values a and b are the means of their respective shapes.

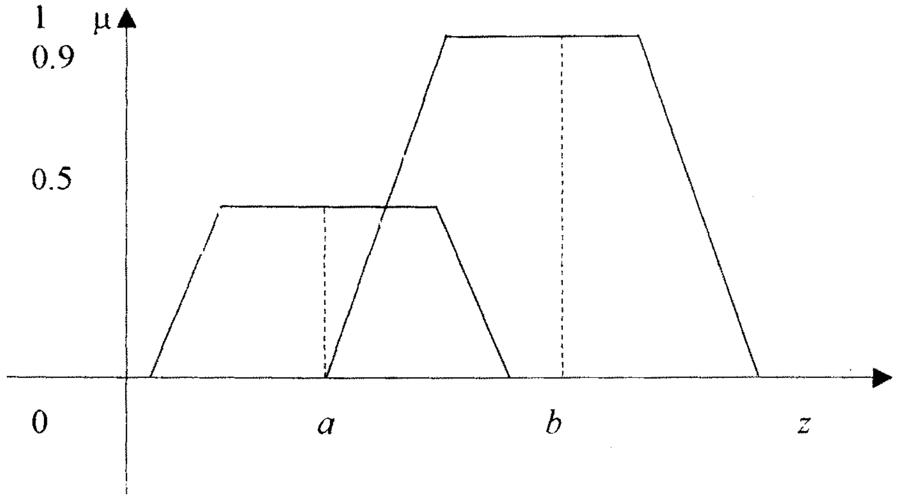

Fig. 1.7 : Weighted average method of fefuzzyfication.

4. *Mean-max membership* :- This method is called middle-of-maxima. The maximum membership can be a plateau rather than a single point. This method is given by the expression.

$$Z^* = \frac{a+b}{2}$$

Where a and b are as defined in Fig. (1.8).

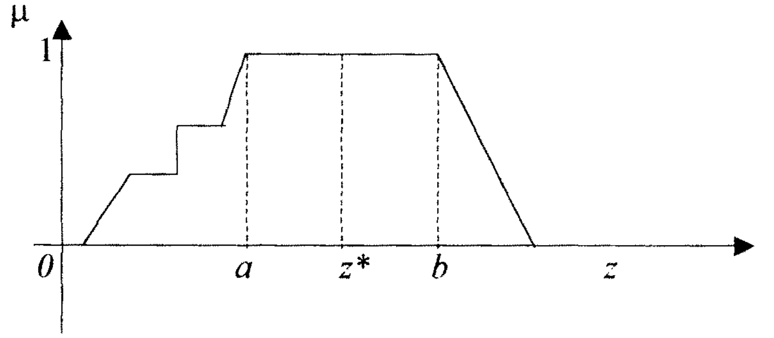

Fig. 1.8 : Min max membership defuzzyfication method.

5. *Center of sums* :- It is a faster defuzzificztion method which involves the algebraic sum of individual output fuzzy sets e. g. C_1 and C_2. This method has drawback that the intersecting areas are added twice the defuzzified values is given by formula.

$$Z^* = \frac{\int_z z \sum_{k=1}^{n} \mu \cdot \underline{c}_k(z) dz}{\int_z \sum_{k=1}^{n} \mu \cdot \underline{c}_k(z) dz}$$

This method is represent by figure (1.9).

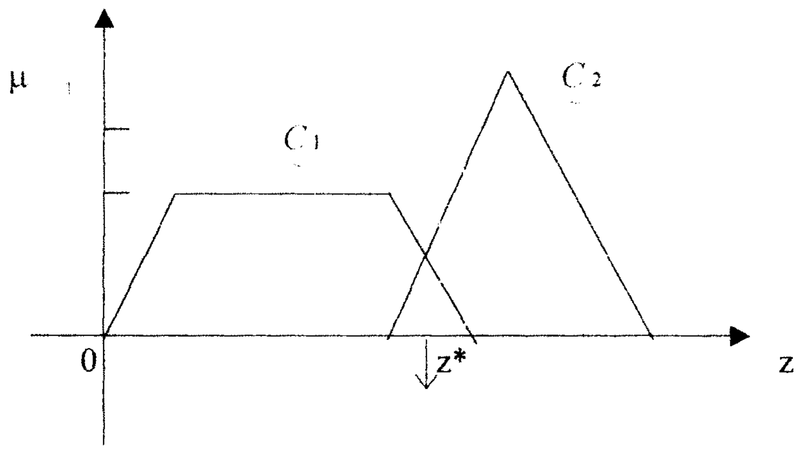

Fig. 1.9 : Center of sum method.

6. *Center of largest area* :- If the output fuzzy set has at least two convex sub- regions, then defuzzyfied value z* calculated using center of largest area method. This is shown graphically in fig.1.10 and given algebraically here :

$$z^* = \frac{\int \mu \, \underline{C}_m(z) z Dz}{\int \mu \, \underline{C}_m(z) Dz}$$

Where $\underline{C}_m$ is the convex sub-region that has the largest area .

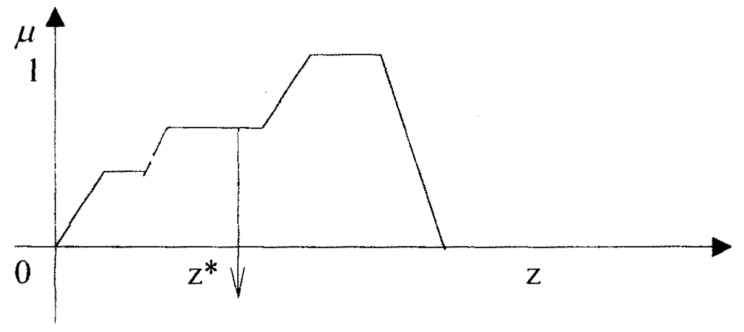

Fig. 1.10 : Centre of largest area method.

7. *First (or last) of maxima* :- This method uses the overall output or union of all individual output fuzzy sets $\underline{C}_k$ to determine the smallest value of the domain with maximized membership degree in $\underline{C}_k$. The equations for z* are as follows.

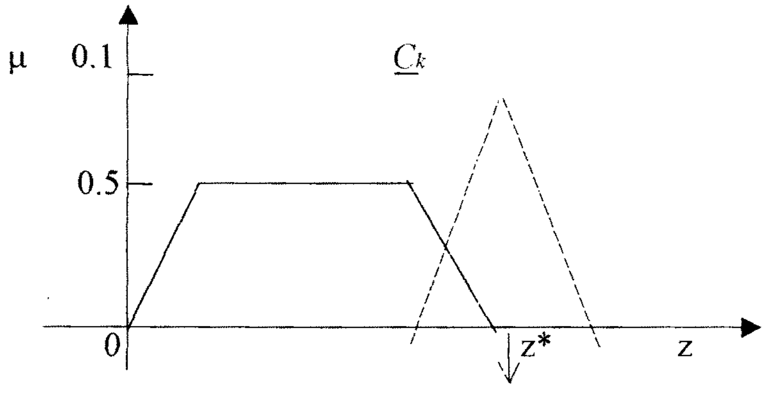

Fig 1.11 : First of maxima method.

First, the largest height in the union [denoted hgt ($\underline{C}_k$)] is determined,

$$\text{hgt}(\underline{C}_k) = \sup_{z \in Z} \mu_{\underline{C}_k}(z)$$

Then the first of the maxima is found,

$$z^* = \inf_{z \in Z} \{ z \in Z \mid \mu_{\underline{C}_k}(z) = \mathrm{hgt}(\underline{C}_k) \}$$

An alternative to this method is called the last of maxima, and it is given by

$$z^* = \sup_{z \in Z} \{ z \in Z \mid \mu_{\underline{C}_k}(z) = \mathrm{hgt}(\underline{C}_k) \}$$

Graphically, this method is shown in Fig. 1.11 where in the case illustrated in the figure. the first max is also the last max and, because it is a distinct max, is also the mean-max.

1.6 LITERATURE SURVEY :

The literature in fuzzy logic controllers (FLC) has been increasing rapidly of-late, making it difficult to present a complete and comprehensive survey. In this chapter a brief review of literature survey of fuzzy logic controllers is presented.

In recent year, designers have successfully applied fuzzy inference to control problems in industrial systems, power systems, home appliances and so on[2,3,5].

The first applications of fuzzy set theory on the control of dynamic processes were reported by Mamdani, et al.[11]. The control problem of regulating the speed and boiler pressure of the steam engine is addressed. Rutherford and Carter reported the first application of FLC on an industrial plant.[12] They developed a controller for a sintering plant and found that the FLC worked somewhat better than PID controller.

A comprehensive survey of the FLC methodology is presented in [3,7,10]. C.Lee has also discussed the fuzzification and defuzzification strategies, the derivation of database and fuzzy reasoning mechanisms. Many references to the fundamental works on this subject are given in [8], while [5] is restricted to a presentation of practical results. The design, implementation and calibration of FLC are also reviewed with specific examples in[2,3].

Since we are interested in the design and development of fuzzy logic temperature controller (FLTC), the survey of literature is confined to the application of FLC to the temperature control problem.

The controlling of the temperature using FLC is reported [4] where authors have achieved improved results over the PI controller. Ramaswamy. P, et. al.[13] have designed an optimized FLC for a wide range nuclear reactor temperature control. To avoid the difficulties in the optimization of FLC, they employed an optimal controller as a reference model to determine automatically the rules for the FLC.

A case study of FLC and its comparison with a PD controller in the problem of temperature control subject to disturbances is presented in[14]. The authors have investigated the control problem of maintaining a desired temperature with a low wattage light bulb in an open environment with fluctuating room temperature. The lack of system modeling and the varying environment render the systematic controller design difficult if not impossible. The authors have concluded that FLC has given satisfactory temperature regulation whereas the PD controller had a significant residual steady-state error.

The design and development of an adaptive FLC applied to home heating system is reported in[15]. The authors have developed home heating FLC system, which guarantees optimal adaptation to the changing customer heating demands, while using one sensor less than the conventional heating systems.

A comparison of the performance of a FLC with a PID controller for a heating process is given in[16]. The authors have demonstrated both by simulation and experiment on the plant, that the fuzzy logic controller can provide better control and do not require a plant model and has better disturbance rejection properties. Fuzzy logic control of the dryer of the washing machine is reported in[17].

From this brief review of literature on FLTC, it is clear that temperature control problem has lot of importance in industrial applications. Many workers have also investigated the advantages of the use of triangular membership function in the fuzzy logic controller.

1.7 ORIENTATION OF WORK :

Many conventional techniques are available for controlling temperature of a process The processes control can be accomplished manually or automatically. Manual control is generally employed for non-critical applications in which changes in manipulate variable cause the process to change slowly and by small amount. Automatic process control is carried out by employing one of the following control modes e.g. ON/OFF control, proportional control, integral control, derivative control, proportional + integral or proportional integral and derivative control. Each of these has its advantages and disadvantages however knowledge of the process & mathematical formulation are to be worked out critically in order to implement these processes successfully. Lot of work has been already done by many workers on temperature control using such techniques.

However there is a lot of scope to implement a temperature controller using fuzzy logic approach employing one of the above controller modes. The advantages of fuzzy logic are the following.

(1) It does not require rigorous mathematical modeling of the process.

(2) This logic is a true extension of linear control models. Hence any thing that was built using conventional design techniques can be built with fuzzy logic and vice-versa

(3) Fuzzy system in time invariant and deterministic. Therefore any verification and stability analysis method can be used with fuzzy logic too.

(4) Fuzzy logic reasoning is close to human logic reasoning.

In this work it is proposed to implement proportional Fuzzy logic controller using a microprocessor or micro controller based system. Software for the same will be developed in assembly language and the proportional control will be implemented by implementing PWM through Fuzzy logic. It is proposed to employ triangular type of membership function for both input and output variables and height defuzzification technique to get the crisp output value.

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