A Review: Fuzzy Logic and Its Application

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***Abstract*— A fuzzy logic approach is given which improve the performance of system and give more accuracy. A fuzzy concept is presented in which the content, value, or boundaries of application can vary according to context or conditions, instead of being fixed once and for all. In this paper all the parts of fuzzy system are presented. Easy steps are presented for creation of a fuzzy interface system. An application of this fuzzy logic in power system stability is also presented.**

***Index Terms*— Fuzzy Set, Fuzzy Inference System, Membership Function.**

I. Introduction

Fuzzy Logic is a problem solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multichannel PC or workstation-based data acquisition and control systems[1]. It can be implemented in hardware, software, or a combination of both. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information[2][4]. Fuzzy Logic approach to control problems that how a person would make decisions within minimum time.

Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. The reason for which is very simple. Fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise soluteons from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design[3].

While other approaches require accurate equations to model real-world behaviours, fuzzy design can accommodate the ambiguities of real-world human language and logic. It provides both an intuitive method for describing systems in human terms and automates the conversion of those system specifications into effective models[5].

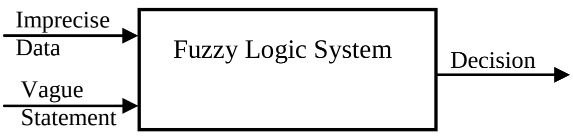

Fig 1: Configuration of fuzzy logic system

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Fig 1 shows the configuration of fuzzy logic, which accepts imprecise data and vague statements such as low, medium, high and provides decisions[4][6].

Advantages fuzzy logic:

- *Fuzzy logic is conceptually easy to understand*
  The mathematical concepts behind fuzzy reasoning are very simple. Fuzzy logic is a more intuitive approach without the far-reaching complexity.
- *Fuzzy logic is flexible*
  With any given system, it is easy to layer on more functionality without starting again from scratch.
- *Fuzzy logic is tolerant of imprecise data*
  Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.
- *Fuzzy logic can model nonlinear functions of arbitrary complexity*
  You can create a fuzzy system to match any set of input-output data. This process is made particularly easy by adaptive techniques like Adaptive Neuro-Fuzzy Inference Systems (ANFIS), which are available in Fuzzy Logic Toolbox software.
- *Fuzzy logic can be built on top of the experience of experts*
  In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you rely on the experience of people who already understand your system.
- *Fuzzy logic can be blended with conventional control techniques*
  Fuzzy systems don't necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.
- *Fuzzy logic is based on natural language*
  The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic. Because fuzzy logic is built on the structures of qualitative description used in everyday language, fuzzy logic is easy to use.

II. Significance of Fuzzy Logic

The various application of fuzzy logic are:

1. Fuzzy Image Processing

Fuzzy image processing is the collection of all approaches that understand, represent and process the images, their segments and features as fuzzy sets. The representation and processing depend on the selected fuzzy technique and on the problem to be solved[3].

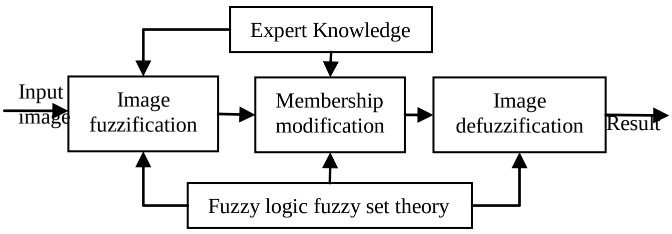

Fig 2: Structure of fuzzy image processing

Fuzzy image processing has three main stages (as shown in fig 2): image fuzzification, modification of membership values and image defuzzification.

The fuzzification and defuzzification steps are due to the fact that we do not possess fuzzy hardware. Therefore, the coding of image data (fuzzification) and decoding of the results (defuzzification) are steps that make possible to process images with fuzzy techniques. The main power of fuzzy image processing is in the middle step (modification of membership values. After the image data are transformed from gray-level plane to the membership plane (fuzzification), appropriate fuzzy techniques modify the membership values. This can be done by fuzzy rule-based approach or by fuzzy integration approach.

2. *Fuzzy Logic-Based Anesthetic Depth Control*

In most surgical operations, to anesthetize patients, manual techniques are used in hospitals. The manual systems work either ON or OFF situations. Because of not having interval values between ON and OFF in manual systems, anesthetic operations could not be safety and comfort. For this reason, Fuzzy logic control is applied to control anesthesia. In this paper, an objective approach of giving anesthetic to patients during surgical operation using Fuzzy logic is proposed[3].

Fuzzy logic theory is a general mathematical approach that allows partial memberships. Several studies have shown fuzzy logic control to be an appropriate method for the control of complex processes.

Fuzzy logic system inputs T and N represent blood pressures (mmHg) and pulse rates (p m−1), which are respectively obtained from patients during anesthesia. Anesthesia Output (AO) represents fuzzy logic system output.

The potential benefits of using fuzzy logic control during anesthesia; increasing patients safety and comfort, directing anesthetists attention to other physiological variables they have to keep under control by abating their tasks, using optimum anesthetic agent, protecting environment by using anesthetic agent and decreasing the cost of surgical operations.

3. *Optimization of a Water Treatment System Using Fuzzy Logic*

This case study is about a fuzzy logic solution in biochemical production at the world's largest oral penicillin production facility in Austria. After extracting the penicillin from the microorganisms that generated it, a waste water treatment system further processes the remaining biomass. Fermentation sludge obtained in the course of this treatment contains microorganisms and remnants of nutrient salts. It is the basic material for a high quality fertilizer and sold as a by-product of the penicillin production. To render the fertilizer, the sludge is concentrated in a decanter and then cleared of the remaining water in a vaporizer. In order to reduce energy costs of the vaporizing process, the separation of water and dry substance in the decanter must be optimized. Before the implementation of the fuzzy logic solution, operators controlled the process manually.

4. Fuzzy Logic Applications in Industrial Automation

In this section, we review eight recent applications of fuzzy logic in industrial automation. All applications used the so-called "fuzzyPLC," an innovative hardware platform that merges fuzzy logic and traditional automation techniques. Following a quick overview on the fuzzyPLC, we discuss the eight applications and focus on how fuzzy logic enabled a superior solution compared to conventional techniques. Whenever possible, we quantify the benefit in cost saving or quality improvement[5].

In recent years, fuzzy logic has proven well its broad potential in industrial automation applications. In this application area, engineers primarily rely on proven concepts. For discrete event control, they mostly use ladder logic, a programing language resembling electrical wiring schemes and running on so-called programmable logic controllers (PLC). For continuous control, either bang-bang type or PID type controllers are mostly employed. While PID type controllers do work fine when the process under control is in a stable condition, they do not cope well in other cases:
– The presence of strong disturbances (nonlinearity)
– Time-varying parameters of the process (nonlinearity)

There are number of application in various fields also, which are as follows:

5. Fuzzy knowledge-based system for the control of a refuse incineration plant refuse incineration.
6. Application of fuzzy control for optimal operation of complex chilling systems.
7. Fuzzy logic enhanced control of an ac induction motor with a DSP.
8. Fuzzy Logic in Automotive Applications
   i. Fuzzy Antilock Brake System
   ii. Antilock-Braking System and Vehicle Speed Estimation Using Fuzzy Logic.
9. Subway trains Cement kilns Washing Machines Fridges Video cameras.
10. Application of Fuzzy Expert System[4]
    i. Applications of Hybrid Fuzzy Expert Systems in Computer Networks Design.
    ii. Fuzzy Expert System for Drying Process Control.
    iii. A Fuzzy Expert System for Product Life Cycle Management.
    iv. A Fuzzy Expert System Design for Diagnosis of Prostate Cancer.
    v. The Validation of a Fuzzy Expert System for Umbilical Cord Acid–Base Analysis.
    vi. A Fuzzy Expert System Architecture Implementing Onboard Planning and Scheduling for Autonomous Small Satellite.

11. Application in Power System

– *Generating unit controls*, which consist of prime mover control and excitation control with automatic voltage control (AVR) and power system stabilization (PSS). The first controls generator speed deviation and energy supply system variable like boiler pressure or water flow. Excitation control aims at maintaining the generator terminal voltage and reactive power output within its machine-dependent limits [6][7].

– *System generation control, w*hich determines active power output such that the overall system generation meets the system load. It further controls the frequency and the tie line flows between different power system areas.

– Finally *transmission control* monitors power and voltage control devices like tap-changing transformers, synchronous condensers and static VAR compensators. In reality all controls affect both components and systems. For example the AVR is known to introduce local mode oscillations as well as inter-area oscillations, which in turn are counteracted by a well-tuned PSS.

III. Structure of Fuzzy Logic

A. *Fuzzy Set*

Fuzzy Set Theory was formalised by Professor Lofti Zadeh at the University of California in 1965. What Zadeh proposed is very much a paradigm shift that first gained acceptance in the Far East and its successful application has ensured its adoption around the world[8-10].

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership.

To understand what a fuzzy set is, first consider the definition of a classical set. A classical set is a container that wholly includes or wholly excludes any given element. For example, the set of days of the week unquestionably includes Monday, Thursday, and Saturday as shown in fig 3. It just as unquestionably excludes butter, liberty, and dorsal fins, and so on.

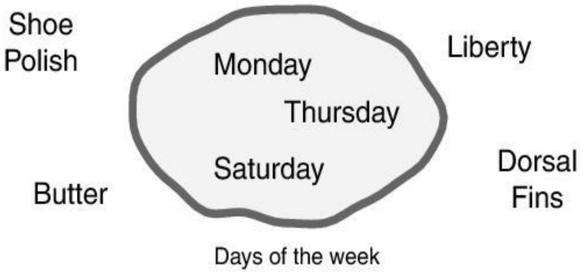

Fig 3: Set representation of classical set

This type of set is called a classical set because it has been around for a long time. It was Aristotle who first formulated the Law of the Excluded Middle, which says X must either be in set A or in set not-A.

Now, consider the set of days comprising a weekend. Fig 4 attempts to classify the weekend days.

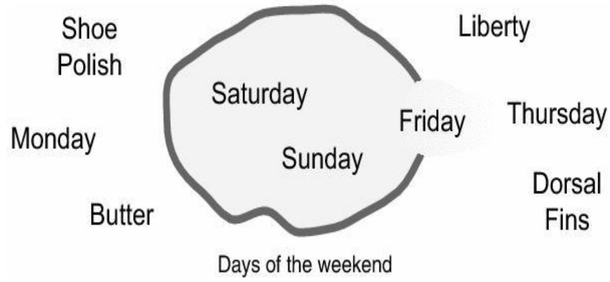

Fig 4: Classify the weekend days

Most would agree that Saturday and Sunday belong, but what about Friday? It feels like a part of the weekend, but somehow it seems like it should be technically excluded. Thus, in the preceding diagram, Friday tries its best to "straddle on the fence." Classical or normal sets would not tolerate this kind of classification. Either something is in or it is out.

B. *Membership Function*

The membership function is a graphical representation of the magnitude of participation of each input [8-10]. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system. There are different memberships functions associated with each input and output response. Some features of membership function are:

<u>Shape</u>: triangular is common, but bell, trapezoidal, haversine and, exponential have been used. More complex functions are possible but require greater computing overhead to implement.

<u>Height</u>: usually normalized to 1.

<u>Width</u>: of the base of function.

<u>Shouldering</u>: locks height at maximum if an outer function. Shouldered functions evaluate as 1.0 past their centre.

<u>Canter Points</u>: centre of the member function shape) Overlap (N&Z, Z&P, typically about 50% of width but can be less.

Here figure 5 illustrates the features of the triangular members.

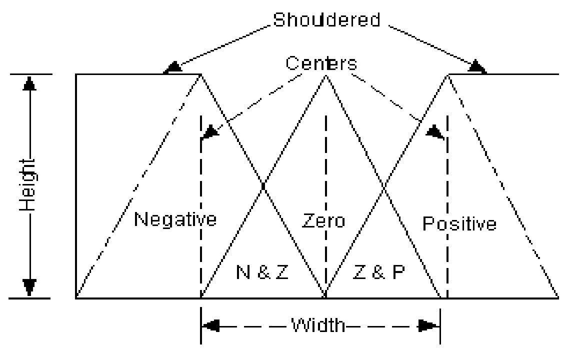

Fig 5: Features of a membership function

C. *Fuzzy Inference System*

Fuzzy inference systems (FISs) are also known as fuzzy rule-based systems. fuzzy model, fuzzy expert system, and fuzzy associative memory. This is a major unit of a fuzzy logic system. The decision-making is an important part in the entire system. The FIS formulates suitable rules and based upon the rules the decision is made[9]. This is mainly based on the concepts of the fuzzy set theory, fuzzy IF–THEN rules, and fuzzy reasoning. FIS uses "IF. . . THEN. . . statements, and the connectors present in the rule statement are "OR" or "AND" to make the necessary decision rules. The basic FIS can take either fuzzy inputs or crisp inputs, but the outputs it produces are almost always fuzzy sets. When the FIS is used as a controller, it is necessary to have a crisp output. Therefore in this case defuzzification method is adopted to best extract a crisp value that best represents a fuzzy set.

D. Fuzzy Interface Methods

There are two types of fuzzy inference method present, Mamdani's fuzzy inference method and Sugeno or Takagi–Sugeno–Kang method of fuzzy inference process[8-10].

i. Mamdani's Fuzzy Inference Method

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed by Mamdani (1975) as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Zadeh's (1973) paper on fuzzy algorithms for complex systems and decision processes.

After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function, and it can be thought of as a prefuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function rather than integrating across the two-dimensional function to find the centroid.

ii. Takagi–Sugeno Fuzzy Method (TS Method)

The Sugeno fuzzy model was proposed by Takagi, Sugeno, and Kang in an effort to formalize a system approach to generating fuzzy rules from an input output data set in 1985. Sugeno fuzzy model is also known as Sugeno–Takagi model. A typical fuzzy rule in a Sugeno fuzzy model has the format

IF x is A and y is B THEN z = f(x, y).

Where AB are fuzzy sets in the antecedent; Z = f(x, y) is a crisp function in the consequent. Usually f(x, y) is a polynomial in the input variables x and y.

Advantages of the Sugeno Method:

- It is computationally efficient.
- It works well with linear techniques (e.g., PID control).
- It works well with optimization and adaptive techniques.
- It has guaranteed continuity of the output surface.
- It is well suited to mathematical analysis.

Advantages of the Mamdani Method:

- It is intuitive.
- It has widespread acceptance.
- It is well suited to human input.

IV. Design of Fuzzy Logic Controller

The principal design parameters of a FLPSS are as follows:

- Choice of process state (input) variables and control (output) variables of FLPSS.
- Selection of Universe of discourse (UOD).
- Determination of the normalization factors of the input signals.
- Fuzzification of crisp input signals.
- Fuzzy partition of the input output spaces,
- Choice of the membership function of a primary fuzzy set.
- Derivation of fuzzy control rules.
- Definition of fuzzy inference engine.
- De-fuzzification strategy.
- Determination of de-normalization factor.

Here the design of fuzzy controller is explained with the example of Power System Stabilizer. The first step in designing a fuzzy controller is to decide which state variables represent of system dynamic performance must be taken as the input signal to the controller. However, choosing the proper linguistic variables formulating the fuzzy control rules are very important factors in the performance of the fuzzy control system. System variables, which are usually used as the fuzzy controller inputs includes states error, state error derivative, state error integral or etc. In power system, based on previous experience. Generator speed deviation ($\Delta\omega$) and acceleration ($\dot{\Delta\omega}$) are chosen to be the input signals of fuzzy PSS. As it was mentioned earlier, if the synchronous generator automatic voltage regulator is utilized in a proper way it is capable of damping electromechanically oscillations of the generator shaft. The input to the excitation system would be the Control variable which is actually the output of fuzzy PSS. In practice, only shaft speed deviation is ready available. Hence, the acceleration signal can be derived from speed signals measured at two sampling instant by the following expression [13]:

$$\Delta\omega(kT_S) = \frac{\Delta\omega(kT_S) - \Delta\omega((k-1)T_S)}{T_S}$$

Where T_S is the sampling time.

Universe of discourse which is basically the range of input variable is selected from -3 to 3 for present investigation. For best result the UOD should be minimum but greater then input of fuzzy controller.

Fuzzification of crisp input signals menace conversion of numerical input signal from SMIB system into fuzzy logic form

After choosing proper variables as input and output of fuzzy controller, it is required to decide the membership function (mfs). These variables transform the numerical values of the input of the fuzzy controller to fuzzy quantities. The number of these membership function specifies the quality of the control which can be achieved using the fuzzy controller. As the number of the membership function increases, the computational time and required memory increase. Therefore, a compromise between the quality of control and computational time is needed to choose the number of linguistic variables. For the power system under study, five membership function for each of the input and output variables are used to describe them, as in the following table 1.

Table 1: Input and output membership function

NB	Negative Big
NS	Negative Small
Z	Zero
PS	Positive Small
PB	Positive Big

The performance of a FLC also depends upon the type of membership functions. The most commonly used membership functions are triangular, trapezoidal, and Gaussian. All the investigations are carried out considering Gaussian membership functions.

A Gaussian membership function is defined as

$$f(X,\sigma,C) = \frac{e^{-(X-C)^2}}{2\sigma^2}$$

Where, c is the canter of Gaussian membership function and σ^2 is the variance. For the present investigations σ = 1.75 is chosen and all the membership functions are symmetrically placed in the universe of discourse (UOD) from -3 to 3. Mamdani Inference engine is used.

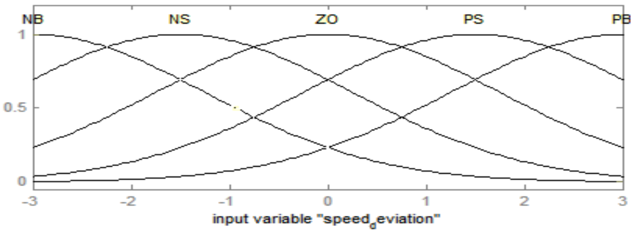

Fig 6: Input 1 speed deviations ($\Delta\omega$) in the form of membership function

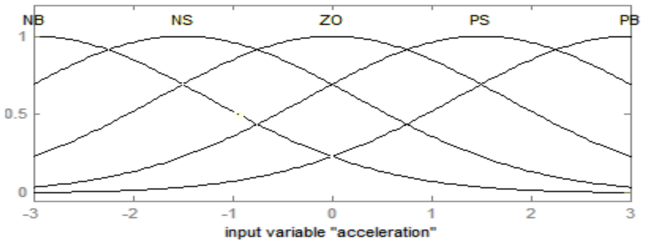

Fig 7: Input 2 acceleration ($\dot{\Delta\omega}$) in the form of membership function

The two inputs; speed deviation and acceleration, result in 25 rules for each machine. As shown in table: 2 that results of 25 rules, where a positive control signal is for the deceleration control and a negative signal is for acceleration control.

Table 2: Rule Base with five membership functions

For example the rule number 1 is: if speed deviation is NB and acceleration is NB then stabilizing signal is NB. According to these rules the stabilizer output is taken.

After it the next step is Defuzzification in which the stabilizer output which is in fuzzy form is to be converted in

$\Delta\omega$	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NS	NS	ZO	NS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PS	PB
PB	ZO	PS	PB	PB	PB

numeric values. There are various methods for Defuzzification: Centroid (centroid of area), bisector (bisector of area), mom (mean value of maximum), som (smallest (absolute) value of maximum), lom (largest (absolute) value of maximum). In this study Centroid method is used.

On the bases of these rules the FLC output in the form of stabilizing signal can seen on surface viewer as shown in the fig: 8.

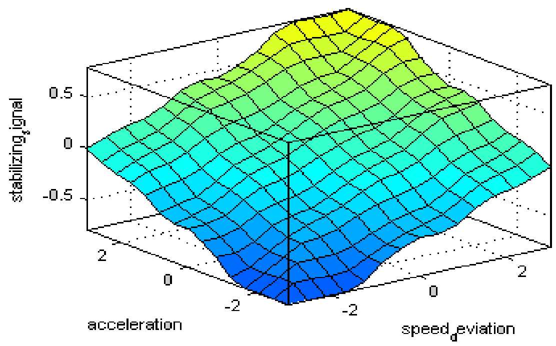

Fig.8: Surface view of stabilizing signal according to both inputs (speed deviation and acceleration)

V. CONCLUSION

A fuzzy logic approach is presented, including all the parts of fuzzy system. As the fuzzy system can work in between zero and one also, it can give more accuracy as compared to classical sets. The step by procedure of formation of fuzzy inference system is presented.

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