IMPLEMENTATION OF FUZZY LOGIC IN POWER ENGINEERING USING VIRTUAL INSTRUMENTATION

Andrei CZIKER[1*], Mircea CHINDRIS[2], Anca MIRON[3]

Curricula for power engineering programs have undergone substantial change in the past years as modern techniques for analysis and design of power systems find their way into these courses.

The paper presents a laboratory controller, implemented as a virtual instrument that mimics a real fuzzy logic controller for a boiler system in a thermal power plant. The instrument is dedicated to laboratory works associated to the course "Application of fuzzy logic in power engineering" at the postgraduate classes at the Technical University of Cluj-Napoca.

The fuzzy controller was developed in LabVIEW software environment that assures a very convenient implementation of desired control blocks and allows students to change al numerical values in order to analyze their influence on the system performances. Student feedback indicates that theoretical developments in lectures on fuzzy control systems were better appreciated after thelaboratory exercises.

Keywords: fuzzy logic, virtual instrumentation, fuzzy controller.

1. Introduction

Main concepts and techniques in the area of intelligent systems were discovered and developed over the past few decades. While some of these methods have significant benefits to offer, engineers are often reluctant to utilize new intelligent techniques for several reasons [1]:

l) there has been a lack of rigorous engineering analysis to verify their performance characteristics;

2) there is not an established track record for the reliability and robustness of such techniques;

3) there has not been comparative analysis to determine their advantages/disadvantages relative to conventional methods;

4) the approaches are not widely understood by practicing engineers.

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[1] Assoc. Prof., Electrical Power Systems Department, Technical University of Cluj-Napoca, Romania

[2] Prof., Electrical Power Systems Department, Technical University of Cluj-Napoca, Romania

[3] Prep., Electrical Power Systems Department, Technical University of Cluj-Napoca, Romania

systems find their way into these courses; it is quite natural, then, that newer courses such as "Application of fuzzy logic in power engineering" were introduced into curricula of post graduate studies at the Technical University of Cluj-Napoca.

On other hand, along with the continuously evolving program of study, there remains a constant in power engineering education: the recognized need for laboratory experience in the curricula. In our case, limited resources have imposed the computer simulator of some fuzzy logic applications, including the fuzzy control.

The paper presents a laboratory controller, implemented as a virtual instrument that mimics a real fuzzy control structure for a boiler system in a thermal power plant. In this way, students may perform experimental exercises that complement the theory presented in lectures.

2. General aspects on LabVIEW

LabVIEW is a graphical programming language that uses icons instead of lines of text to create applications [2]. In contrast to text-based programming languages, where instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines execution. In LabVIEW, a user interface can be built by using a set of tools and objects. The user interface is known as the front panel, and the customer may add codes using graphical representations of functions to control the front panel objects. The block diagram contains this code; in some ways, the block diagram resembles a flowchart.

LabVIEW programs are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments, such as oscilloscopes and multimeters. Every VI uses functions that manipulate input from the user interface or other sources and display that information or move it to other files or other computers. A VI contains the following three components [3]:

- *Front panel* - Serves as the user interface.
- *Block diagram* - Contains the graphical source code that defines the functionality of the VI.
- *Icon and connector pane* - Identifies the VI so that the customer can use the VI in another VI. A VI within another VI is called a subVI; practically, a subVI corresponds to a subroutine in text-based programming languages.

The front panel is the user interface of the VI, and it can be built with controls and indicators, which are the interactive input and output terminals of the VI, respectively. Controls are knobs, pushbuttons, dials, and other input devices; they simulate instrument input devices and supply data to the block diagram of the

VI. Indicators are graphs, LEDs, and other displays, and simulate instrument output devices and display data the block diagram acquires or generates.

3. Fuzzy Control

3.1. Conventional control versus fuzzy control

Conventional control theory techniques are based on mathematical models of the open-loop process, called *system*, to be controlled. They use a so-called white-box approach to acquire the knowledge about the system (or process) to be controlled [4]; the philosophy of this approach lies in that if the characteristics of all the elements in the box (representing the process being considered) are known, then the complete relation between the process output and input can be obtained. Major drawbacks of the white-box approach are: 1) a good mathematical model depends on our knowledge about each of the elements in the system and unfortunately our knowledge about the elements is limited and incomplete most of time; and 2) even if we can develop an accurate mathematical model, our ability to solve the mathematical problem is limited.

The human operator, on the other hand, acquires the knowledge about the process using the so-called black-box approach. By observing enough input-output samples, the human operator is able to establish the relation between the input and output of the process using the brain neural computing and fuzzy reasoning and performs a very effective control. The main idea of fuzzy logic control is to use the control ability of human being which includes experience and intuition of human experts [5].

Since the introduction of fuzzy set theory by Zadeh and the first invention of a fuzzy controller by Mamadani [6], fuzzy control has gained a wide acceptance, due to the closeness of inference logic to human thinking, and has found applications in many power plants and power systems. It provides an effective means of converting the expert-type control knowledge into an automatic control strategy. The two reasons most often sighted for pursuing fuzzy control are the desire to incorporate linguistic control rules and the need to design a controller without developing a precise system model.

The main advantages of the fuzzy control systems are as follows [6, 7]:

- It is not necessary to build a detailed mathematical model;
- The fuzzy controllers have a high strength and a high adjustment;
- They can operate with a high input number;
- They can be adapted easily into non-linear systems;
- The human knowledge can be easily applied;
- The process development time is relatively lower.

3.2. Fuzzy Controllers

In this case, general control rules that are relevant to a particular system based on experience are introduced and analysis or modeling considerations come later. This rule implements a control concept for anticipating the desired position and reducing the control level before the set point is reached in order to avoid overshoot. A full control design requires developing a set of control rules based on available inputs and designing a method of combining all rule conclusions. Within power systems, fuzzy logic controllers have been proposed primarily for stabilization control.

In a fuzzy logic controller (FLC), the dynamic behavior of a controlled system is described by a set of fuzzy associative memory (FAM) rules that correlate a fuzzy input set to a fuzzy output set of the FLC; based on expert knowledge, these rules establish linguistically how the control output should vary with the control input. The expert knowledge is usually of the form **IF** (a set of conditions, antecedent components, are satisfied) **THEN** (a set of consequences can be inferred); practically, given a set of control inputs, the controller applies appropriate rules to generate a set of control outputs. Since the antecedents and the consequents of these IF-THEN rules are associated with fuzzy concepts (linguistic terms), they are often called *fuzzy conditional statements*.

Basically, fuzzy control rules provide a convenient way for expressing control policy and domain knowledge. Furthermore, several linguistic variables might be involved in the antecedents and the conclusions of these rules. The FAM rules can be derived based on one's sense of realism, experience, and expert knowledge about the process. Fuzzy set and fuzzy logic theories are applied to quantify the control inputs, FAM rules and control outputs. This type of control strategy is very simple and generic, and effective control actions can be generated very quickly. This type of controller was suggested originally by *Mamdani and Assilian* in 1975 and is called the *Mamdani type* FLC. A fuzzy logic system has three blocks as shown in Figure 1. Crisp input information from the sensor is converted into fuzzy values for each input fuzzy set with the *fuzzification* block. The decision-making-logic determines how the fuzzy logic operations are performed, and together with the knowledge base determine the outputs of each fuzzy IF-THEN rule; these two components are combined into the *inference* block. All outputs are combined and converted to crispy values with the *defuzzification* block.

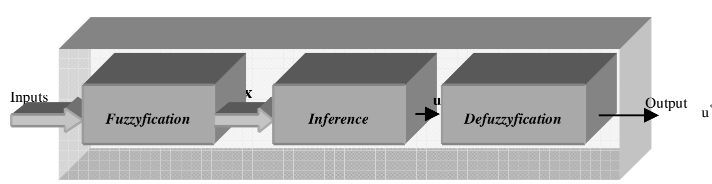

Fig. 1. Block diagram of a fuzzy controller

4. Application

4.1. Boiler system

In this chapter, a fuzzy controller for a boiler system, implemented as a virtual instrument, is presented. The boiler system in a thermal power plant consists mainly of a steam-water system and combustion system, which produce a high-pressure superheated steam to drive a generator in order to produce power. The superheated steam temperature control and the separator water level control of a steam water system are very important to guarantee operation safety and to improve economic benefits of the power plant [7].

The suitable generation of the superheated steam is regarded as a controllable process with multiple distributed parameters, large time-delay and unmeasurable disturbances. The precise mathematical models of main steam flow can not be built easily due to several unfavorable features such as non-linearity, interference, dead time, and external disturbance, etc. Traditional control approaches usually cannot achieve satisfactory results for this kind of processes, and designing a conventional controller is difficult and time consuming.

However, using a fuzzy controller, we can deal with this problem simply by taking factors (such as *pressure*), which have influence on the output, into account when designing the controller; to create a fuzzy controller for the above system, what we need to do is to write rules that contain not only *temperature* but also *pressure* in their antecedents. As shows the structure of the proposed FLC, presented in Figure 2, inputs to the controller are measured steam temperature and the measured variation of steam pressure (pressure is used because it has a large influence on temperature to be controlled). Output signal of the controller adjust the electro pneumatic valve for the admission of fuel in the boiler.

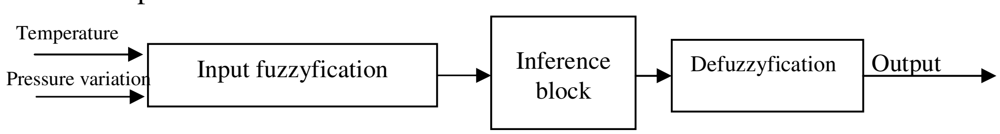

Fig. 2. Block diagram of the fuzzy controller for a boiler system

4.2. Design Methodology

One begins from the assumption that the control rules for a system can be expressed adequately by a human expert. The design phase then concerns the refinement of these control rules and the subsequent inference process. Here, it is assumed the control rules are general and given.

In general, FLC design consists of the following actions:

1. Identify the inputs and their ranges and name them;
2. Identify the outputs and their ranges and name them;

3. Create the degree of fuzzy membership function for each input and output (fuzzyfication);
4. Construct the rule base that the system will operate under;
5. Decide how the action will be executed by assigning strengths to the rules and how the rules will be combined;
6. Defuzzify the output.

1. This is the first step in a fuzzy analysis. For our case [8], there are two inputs, named “Temperatura” and “Variatia presiunii”; according to the process data, their ranges are 50 – 350 ^{0}C for temperature and 0 – 600 mbar/s for the pressure variation.

2. There is only one output, explicitly “Curent comanda”, i.e. the current supplied to the electro-pneumatic converter controlling the fuel valve; it is a dc ranging between 4 and 20 mA.

3. The domains where inputs and output may evaluate were divided in three sub-domains, as follows:

- for “Temperatura”: temp_scazuta, temp_medie, temp_ridicata;
- for “Variatia presiunii”: pres_neglijabila, pres_lenta, pres_rapida;
- for “Curent comanda”: marime_iesire_mic (m_i_m), marime_iesire_mediu (m_i_md), marime_iesire_mare (m_i_M).

The membership function is a graphic representation of the degree of membership of each variable to a specific sub-set. Figure 3 presents the membership functions for all variables: trapezoidal fuzzy numbers for the two inputs, and singleton for the output; for the latter, the following single numeric values were assigned to each sub-domain of the output: m_i_m = 5, m_i_md = 10, m_i_M = 16.

4. In this step, the evolution of the system is described through a set of FAM rules. The proposed controller is a *table based* one, i.e. the relations between all input combinations and their corresponding outputs are arranged in a table. The array implementation improves execution speed, as the run- time inference is reduced to a table look-up which is a lot faster, at least when the correct entry can be found without too much searching. Two inputs and one output results in a two dimensional table as showed in Figure 4.

5. The inference process consists in combining the rules in order to obtain a global fuzzy set representing the result of all fired rules. For this application, the following inference methods have been implemented, and can be selected by the user: MIN-MAX, MAX-PROD and SUM-PROD.

6. Defuzzyfication assigns a crisp value to the control variable. Taking into account the characteristics of the studied process, the centre of gravity method for singletons (COGS) was implemented. In this case, the output value is:

$$u = \frac{\sum_i \left(\mu(s_i)\cdot s_i\right)}{\sum_i \mu(s_i)} \tag{1}$$

where s_i is the position of singleton i in the universe, and $\mu(s_i)$ is equal to the firing strength α_i of rule i. This method has a relatively good computational complexity, and u is differentiable with respect to the singletons s_i, as shows Figure 5.

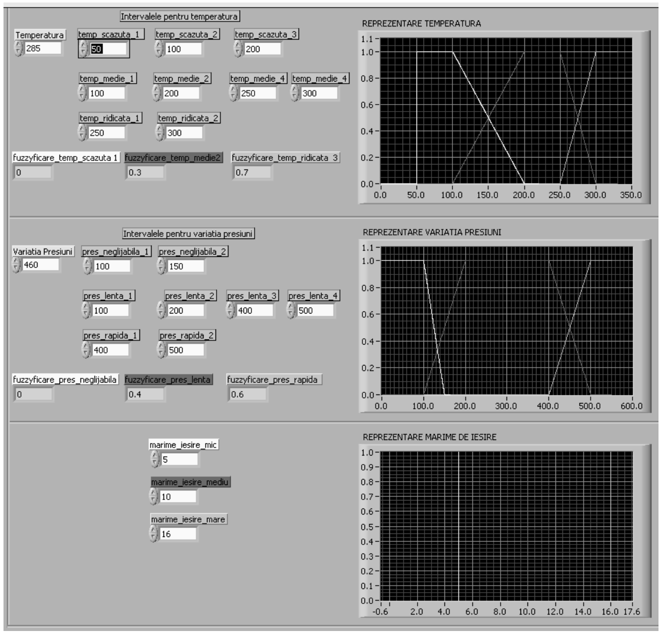

Fig. 3. Fuzzyfication of inputs and output

marimea de iesire		viteza de variatie a presiuni		
		rapida	lenta	neglijabila
temp	ridicata	high	high	medium
	mediu	high	medium	low
	scazuta	medium	low	low

Fig 4. Rules table

Fig. 5. The crisp value of the control signal

Other defuzzyfication rules as centre of gravity (COG), center of maxima (C-o-M), mean of maxima (MoM), etc. can be also selected if the output variable represents a fuzzy number.

5. Conclusions

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