FUZZY BASED EXPERT SYSTEM FOR RENEWABLE ENERGY MANAGEMENT

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ABSTRACT

The aim of this work is determine the most appropriated period for connecting a particular generation source fuelled by biogas on a distribution network. The main electrical characteristics of the network are evaluated. The proposed simulations provided data for analyzing the quantitative parameters – voltage levels, power losses and load current. A group of decision makers was selected for establishing scores applied to the qualitative parameter evaluation – availability of ancillary services support – according to each period in analysis. The fuzzy-based expert system is then applied for selecting and ranking the most appropriated period for connecting the distributed generation source. The definition of the ranking is the outcome according to the final priorities – quantitative and qualitative analysis. .

INTRODUCTION

The aim of this work is determine the most appropriated period for connection of a particular generation source fuelled by biogas produced from livestock manure. Anaerobic digesters are used to decompose the manure in a controlled way. It is important to emphasize that Brazilian energy legislation establishes incentives to reduce the use of fossil fuels in isolated regions without affecting their economic development. This incentive policy is offered for generation plants using alternative sources of energy, mainly biomass. The Biogás® software was used to estimate the amount of methane generated in the livestock. The PSL®DMS software was used to simulate the main electrical characteristics of the network in analysis. These simulations provided data for evaluating the quantitative parameters – voltage levels, power losses and load current. The demand curve is also considered for evaluation of the feeder. A group of decision makers – researchers from The Federal University of Santa Maria – was selected for establishing scores applied to the qualitative parameter evaluation – availability of ancillary services support – according to each period in analysis. After definition of the quantitative and qualitative parameters the fuzzy-based expert system was then applied for selecting and ranking the most appropriated period for connecting the distributed generation source (DG) on the distribution network [1]. The paper is organized as follows: Section 2 introduces the fuzzy concepts and further methodological aspects. Section 3 outlines the application of the fuzzy-based expert system for selecting and ranking the most appropriated period for distributed generation connection – according to the particular study case. Concluding remarks are discussed in Section 4.

FUZZY EXPERT SYSTEM

Initial Concepts

Fuzzy rule-based expert systems can improve the interpretability of results and increase the interaction of Decision Makers (DM) on the decision process [2], [3]. For the inference fuzzy process there are two well-established classes of fuzzy controllers: Mamdani and Takagi-Sugeno. The most fundamental difference between Mamdani and Sugeno is the way the crisp output is generated from the fuzzy inputs [4]. While Mamdani uses the technique of defuzzification of a fuzzy output, Sugeno uses weighted average to compute the crisp output. Therefore in Sugeno the defuzzification process is bypassed. The expressive power and interpretability of the Mamdani output are lost when using Sugeno, since the consequents of the rules are not fuzzy [5].

The most common fuzzy system is the Mamdani system, which is used in this paper. The choice of Mamdani controller it is mainly related to the following aspects [6]:

- it is suitable for engineering systems because its inputs and outputs are real-valued variables;
- it provides a natural framework for incorporating fuzzy rules from human experts;
- there is much freedom for the choices of fuzzifier, fuzzy inference engine, and defuzzifier;
- it provides an effective framework to integrate numerical and linguistic information.

Mamdani controller performs three major steps: fuzzification of the input variables; inference (rule evaluation and implication plus aggregation); and defuzzification – as illustrated in Figure 1

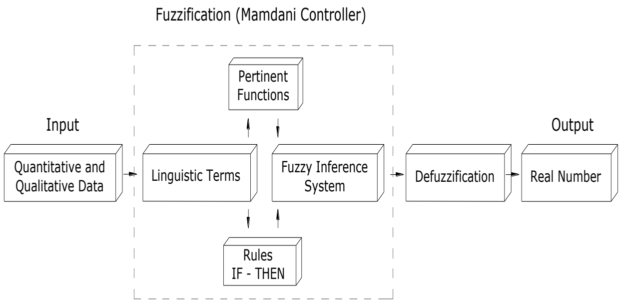

Fig. 1. Basic steps on the Mamdani controller.

A basic Mamdani fuzzy system accepts numbers as input and then translates the input numbers into linguistic terms, such as low, medium, high (fuzzification). Rules map the input linguistic terms – which are represented in membership functions – into similar linguistic terms describing the output linguistic terms (inference). Finally, the output linguistic terms are translated into an output number (defuzzification).

Fuzzification

The membership functions are represented in fuzzy sets with a certain shape. It is popular to use trapezoidal or triangular fuzzy sets due to their computational efficiency [7],[8]. In this paper, inputs and the output are arranged in five linguistic terms – very low (VL), low (L), medium (M), high (H) and very high (VH) – represented by five membership functions applied in each fuzzy variable, as shown in Figure 2.

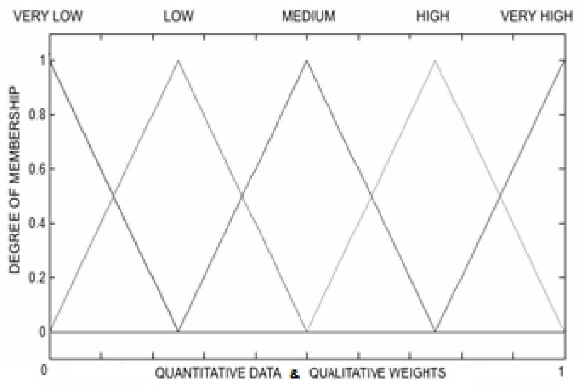

Fig. 2. Fuzzy variable defined for each criterion (MATLAB® Software).

The number of membership functions used in the fuzzy set is determined to maintain a good accuracy for the analysis [9]. The multi-rules-based used in this work consists of a collection of if-then propositions. The number of fuzzy rules grows exponentially with the number of input criteria and with the number of membership functions used to represent each criterion. The improvement of rules has attracted much attention for a long time in the fuzzy community. In the literature, different aspects and various techniques have been studied, such as hierarchical fuzzy and genetic algorithms [10], artificial neural networks [11], among others. These techniques try to reduce the number of rules, while keeping a good accuracy. In fact, certain states can be neglected in most applications either because they are impossible or because a control action would not be helpful. It is therefore sufficient to write rules that cover only parts of the state space.
In the proposed methodology, the development of the rules for the fuzzy-based expert system is established according to important definitions, which follow the criteria rank. These definitions are presented below:

• Definition of the Logical Operations – only the Logical Operation "and" is used. The application of only one logical operation is optional; it is possible to use the "or" logical operation instead or together with "and" in the same rule. In this case, the logical operation "and" was applied according to DM preferences.

• Basis Definition – following a standard rule, for example (analyzing criteria A,B,C and D) :
IF A = L and B = L and C = L and D = L THEN OUTPUT = L.
IF A = M and B = M and C = M and D = M THEN OUTPUT = M.
IF A = H and B = H and C = H and D = H THEN OUTPUT = H.

• Definition of Construction Level – increasing the value of the pertinent function after three equal outputs (S), e.g.
IF A= VL and B= VL and C = VL and D = VL, THEN OUTPUT = VL.
IF A= VL and B= VL and C = VL and D = L, THEN OUTPUT = VL.
IF A= VL and B= VL and C = VL and D = M, THEN OUTPUT = VL (last VL).
IF A= VL and B= VL and C = VL and D = H, THEN OUTPUT = L (first L).

• Definition of Start/End point – establishing the initial point (start) of the Construction level. This definition is applied to attribute some relevance to the most important criterion (criterion A in this case), following the criteria rank, e. g.
IF A = VL, THEN OUTPUT = VL. Thus, the start point is:
IF A = L and B= VL and C = VL and D = VL, THEN OUTPUT = VL.
IF A = VH, THEN OUTPUT = VH. Thus, the end

point is:
IF A = H and B= VH and C = VH and D = VH, THEN OUTPUT = VH.

It is necessary to observe that application of this last definition is optional. In this case, it was applied according to DM preferences.

Table I presents the complete set of rules developed by using the criteria rank and the proposed definitions. To understand the table construction, it is necessary to analyze each one of the outputs separately.

For example, considering the first cell in bold, inside the first line of the Table I:

IF A=L and B=L and C= VL and D=VL THEN OUTPUT = VL; or considering, for the same output cell, the analysis of A=M by just skipping the first column for criterion B:
IF A=M and B=VL and C= VL and D=VL THEN OUTPUT = VL.

TABLE I COMPLETE SET OF RULES FOLLOWING THE LINGUISTIC TERMS - VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H) AND VERY HIGH (VH).

		A = L					*A = M*	*A = H*
		B=VL	*B=L*	*B=M*	*B=H*	*B=VH*	*B=VH*	*B=VH*
C= VL	*D=VL*	VL	**VL**	VL	L	L	L	M
	D=L	VL	VL	L	L	L	M	M
	D=M	VL	L	L	L	M	M	M
	D=H	L	L	L	M	M	M	**H**
	D=VH	L	L	M	M	M	H	H
C = L	*D=VL*	VL	VL	L	L	L	M	M
	D=L	VL	L *(BASIS)*	L	L	M	M	M
	D=M	L	L	L	M	M	M	H
	D=H	L	L	M	M	M	H	H
	D=VH	L	M	M	M	H	H	H
C = M	*D=VL*	VL	L	L	L	M	M	M
	D=L	L	L	L	M	M	M	H
	D=M	L	L	M	M	M	H	H
	D=H	L	M	M	M	H	H	H
	D=VH	M	M	M	H	H	H	VH
C = H	*D=VL*	L	L	L	M	M	M	H
	D=L	L	L	M	M	M	H	H
	D=M	L	M	M	M	H	H	H
	D=H	M	M	M	H	H	H *(BASIS)*	VH
	D=VH	M	M	H	H	H	VH	VH
C= VH	*D=VL*	L	L	M	M	M	H	H
	D=L	L	M	M	M	H	H	H
	D=M	M	M	M	H	H	H	VH
	D=H	M	M	H	H	H	VH	VH
	D=VH	M	H	H	H	VH	VH	VH

Inference

The Maximum of minimum method – maximum aggregation of the minimum implication – is here used as the inference process. It is the most commonly used inference process found in the literature [4], [5], [12].
The Medium Square Error can be calculated for three different inference methods. The Max-Min method achieves the highest performance, as described in [13].

Defuzzification

Regarding the defuzzification process, there are several possible choices to be made and many different methods have been proposed [14]. This study applied the so-called Center of Area (COA) or Center of Gravity (COG) method [15]. This method chooses the control action that corresponds to the center of the area with membership greater than zero. The area is weighted with the value of the membership function. The choice for COG is justified in [16], who suggested some requirements that should be satisfied by an ideal defuzzification method. In conclusion, the COG application satisfies the three major requirements analyzed by [16] – continuity, disambiguity and plausibility. It is necessary to observe that the defuzzification methods Center of sums and Height also satisfy these requirements. It could be therefore possible to apply any of these three methods in the proposed study

FUZZY EXPERT SYSTEM FOR RANKING THE MOST APPROPRIATED PERIOD TO CONNECT THE DG SOURCE

Papers The fuzzy-based expert system is tested using the MATLAB® Software under multi-rules-based decision and multi-sets considerations. A brief description of fuzzy modeling used in this practical analysis is presented below:

- Mamdani Controller;
- Rule evaluation – logical operator used in the development of rules to obtain a single number: AND Operator;
- Implication – evaluation of each rule generating a single output: Method of Minimum (MIN);
- Aggregation – unification of the output of all rules: Method of Maximum (MAX).
- Defuzzification – the output linguistic value is translated into an output number: Center of Gravity (COG).

In addition, the arrangement modelled for DG selection is described with four inputs – A, B, C, D (parameters in analysis) and only one output (final score). The main fuzzy variable used to characterize each criterion was described in Figure 2. The multi-rules-based used in this work consists of a collection of if-then propositions taking as basis the previous criteria rank. The rank defined by the DMs is:

- 1st losses, 2nd voltage levels, 3rd ancillary services, 4th load current.

In this case, it is possible to observe that the losses criterion is the most important and the load current criterion is the less important, according to DM preferences. The values presented in Table II represent the rated data obtained from PSL®DMS software and the scores stipulated by the DMs.
The qualitative criterion Ancillary Services is expressed through scores stipulated by the DM in the intervals from 0 to 1.0, with 1.0 being the highest score. The DMs evaluated the demand curve of the distribution network, as well as the needs of the distribution company according to ancillary services support. DMs ought to discuss about disagreements in order to eliminate some incorrect scores.

TABLE II RATED DATA OBTAINED FROM PSL®DMS SOFTWARE AND THE SCORES STIPULATED BY DMS

Hour	I (A)	VL (kV)	L (MW)	AS
1	28,50	22,96	87,97	0,25
2	25,00	22,97	81,39	0,25
3	22,30	22,98	76,44	0,25
4	21,50	22,99	74,43	0,25
5	21,90	22,98	76,34	0,25
6	22,10	22,98	75,59	0,25
7	27,00	22,97	81,22	0,25
8	32,10	22,95	109,80	0,50
9	96,30	24,45	692,88	0,75
10	114,20	24,30	834,61	1,00
11	124,60	24,25	910,23	1,00
12	115,20	23,32	824,05	0,75
13	51,30	23,84	271,49	0,75
14	112,60	24,34	804,85	1,00
15	118,00	24,30	855,71	1,00
16	116,00	24,34	842,10	1,00
17	103,80	23,95	740,13	1,00
18	124,50	24,28	884,93	1,00
19	114,70	23,99	754,91	1,00
20	100,90	22,94	587,65	1,00
21	50,40	22,88	130,56	0,50
22	45,00	22,90	113,53	0,25
23	38,80	22,92	107,79	0,25
24	34,22	22,94	98,82	0,25

Where: VL (Voltage Levels variation; I (current); L (Losses); AS (Ancillary Services).

The final classifications (CL) determined by using the proposed fuzzy-based expert system is presented in Table III.

TABLE III. FINAL CLASSIFICATIONS – APPROPRIATE PERIOD FOR DG CONNECTION

Hour	CL	Hour	CL
11	1st	17	7th
-	-	18	5th
-	-	19	6th
14	4th	-	-
15	2nd	-	-
16	3rd	-	-

By observing the data presented in Table III, the most appropriate period for distributed generation connection is between 11h A.M and 7h P.M excluding the period between 12h and 1h P.M

CONCLUSION

This paper presents a study addressing the problem of management a distributed generation source based on biogas produced from livestock manure by using anaerobic digesters to decompose the manure in a controlled way. A methodology incorporating fuzzy multi-rules and fuzzy multi-sets is developed. The fuzzy-based methodology improved the interpretability of results and provided more insight into the classifier structure and decision making process. As regards distributed generation management, an appropriate period for DG connection was presented. As suggestion, the excluded period can be used as preventive maintenance for ensuring power supply. The outcome of the proposed methodology – the most appropriate period for connecting a distributed generation source – was satisfied according to evaluation of the feeder characteristics and major concerns of the Distribution Energy Company.

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