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THREE-PHASE FUZZY MODEL OF A DYNAMIC PRODUCTION SYSTEM

TRIFAZNI MEHKI MODEL DINAMIČNEGA PROIZVODNEGA SISTEMA

Janez Usenik[ℜ], Meta Vidiček[1]

Keywords: dynamic production system, control, fuzzy model, fuzzy reasoning.

Abstract

In this article, a three-phase fuzzy model of controlling a dynamic production system is presented. A power supply system can be an example of such a system. Fuzzy system control follows a stochastic mathematical closed-loop model of the control of stocks (additional capacities) in a production system. The fuzzy model is demonstrated with a numerical example.

Povzetek

V članku je predstavljen trifazni mehki model v procesu upravljanja dinamičnega proizvodnega sistema. Takšen sistem je lahko tudi energetski sistem. Mehko upravljanje sistema izhaja iz slučajnostnega matematičnega zaprtozančnega modela upravljanja zalog v proizvodnem sistemu. Mehki pristop vpeljemo z uporabo trifaznega sistema mehkega sklepanja in pomeni približek zaprtozančnemu sistemu upravljanja. Mehki algoritem je ilustriran z numeričnim primerom.

1 INTRODUCTION

Every production system is a complex dynamic system. If a theoretical mathematical dynamic model of it is to be created, a great many variables and their interrelationships have to be taken into

ℜ Corresponding author: Prof. Janez Usenik, Ph.D., University of Maribor, Faculty of Energy Technology, Tel.: +386 40 647 689, Fax: +386 7 620 2222, Mailing address: Hočevarjev trg 1, SI 8270 Krško, Slovenia, e-mail address: janez.usenik@um.si

[1] Landscape Governance College Grm Novo mesto, Sevno 13, 8000 Novo mesto

consideration. However, with methods of logical and methodological decomposition, every may be divided into a finite set of simpler subsystems, which are then studied and analysed separately, [1]. A model of optimal control is determined with a system, its input/output variables, and the optimality criterion function. The system represents a regulation circle, which generally consists of a regulator, a control process, a feedback loop, and input and output information. In this article, dynamic production systems will be studied. The optimality criterion is the optimal and synchronized balancing of planned and actual output functions, [2].

Let us consider a production model in a linear stationary dynamic system in which the input variables indicate the demand for products manufactured by a company. These variables can be deterministic, stochastic or fuzzy.

The fuzzy approach to the control of dynamic systems is approximately 50 years old. Thierry et al., [3] described the development of the fuzzy system control. From 1965 to 1985, the heuristic approach was pioneered, and earlier industrial applications were made. From 1985 to 2005, the model base approach was developed, including fuzzy modelling, model base fuzzy control design and adaptive fuzzy control. Since 2005, there have been new improvements in TS (Tagaki-Sugeno) system analysis, such as non-quadratic Lyapunov functions, delay, fuzzy-polynomial techniques, shape-dependent laws, asymptotic exactness, and adaptive control.

In this article, a new fuzzy approach to the control of dynamic systems is presented. It is based on the fuzzy inference rules in the if-then form. In Usenik, [4], the two-phase system was defined, and in this article a new and innovative expansion is developed.

2 DEFINING THE PROBLEM

Demand for a product should be met, if possible, by the current production. The difference between the current production and demand is the input function for the control process; the output function is the current stock/additional capacities, [4]. When the difference is positive, the surplus will be stocked, and when it is negative, the demand will also be covered by stock. In the case of a power supplier, stock in the usual sense does not exist (such as cars or computers, etc.); energy cannot be produced in advance for a known customer. The demand for energy services is neither uniform in time nor known in advance. It varies, has its ups (maxima) and downs (minima), and can only be met by installing and activating additional proper technological capacities, [5]. Because of this, the function of stock in the energy supply process is held by all the additional technological potential/capacities large enough to meet periods of extra demand.

The output function measures the amount of unsatisfied customers or unsatisfied demand in general. When this difference is positive, i.e. when the power supply capacity exceeds the demand, a surplus of energy will be made.

For this model, the regulation circuit is given in Figure 1, [4]. The task is to determine the optimum production and stock/capacities so that the total cost will be as low as possible, [1].

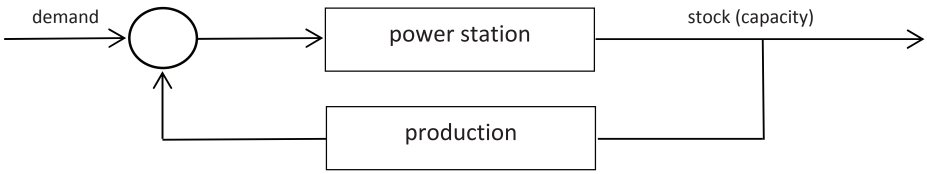

Figure1: *Regulation circuit of the production system*

3 FUZZY MODEL

Construction of a fuzzy system takes several steps, [6], [7]: selection of decision variables and their fuzzification, establishing the goal and the construction of the algorithm (base of rules of fuzzy reasoning), inference and defuzzification of the results of fuzzy inferences. A graphic presentation of a fuzzy system is given in Figure 2, [8].

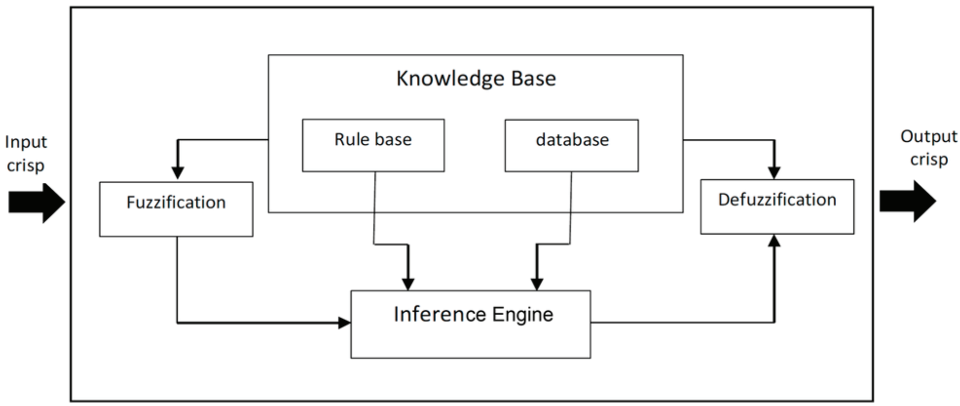

Figure 2*: Architecture of a fuzzy expert system*

In, [4], a fuzzy two-phase system, given in Figure 3, was designed.

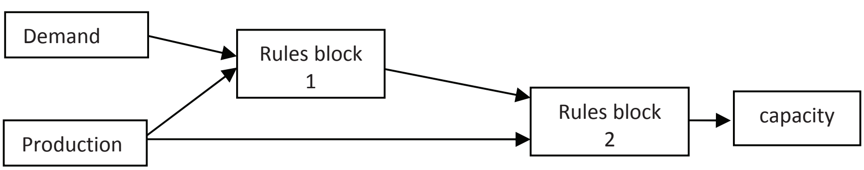

Figure 3*: The fuzzy two-phased system*

Now, this fuzzy model will be expanded, and a three-phase fuzzy model will be created.

Following the dynamic system, there are two subsystems in the first phase: system DEMAND and system PRODUCTION.

Let us assume that the demand (Figure 4) depends on:

- the market area,
- the density of the area,
- the price,
- the season,
- the uncertainty

and the production (Figure 5) on:

- the costs of production,
- the policy,
- the season,
- the weather, and
- the uncertainty.

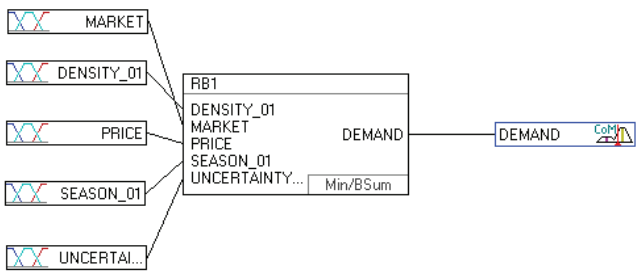

Figure 4*: The fuzzy subsystem "demand"*

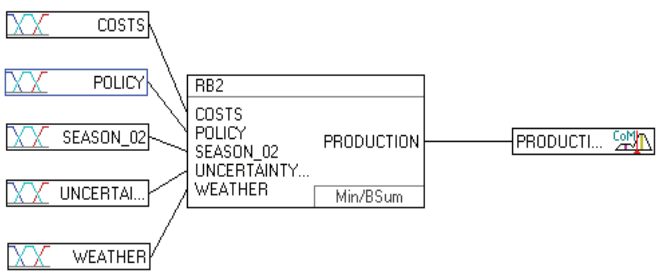

Figure 5*: The fuzzy subsystem "production"*

In the second phase, the output "SUPPLY" depends on the fuzzy input variables "demand" and "production"; in the third phase, with the output "CAPACITY" we have the fuzzy input variables "supply" and "production" (Figure 6).

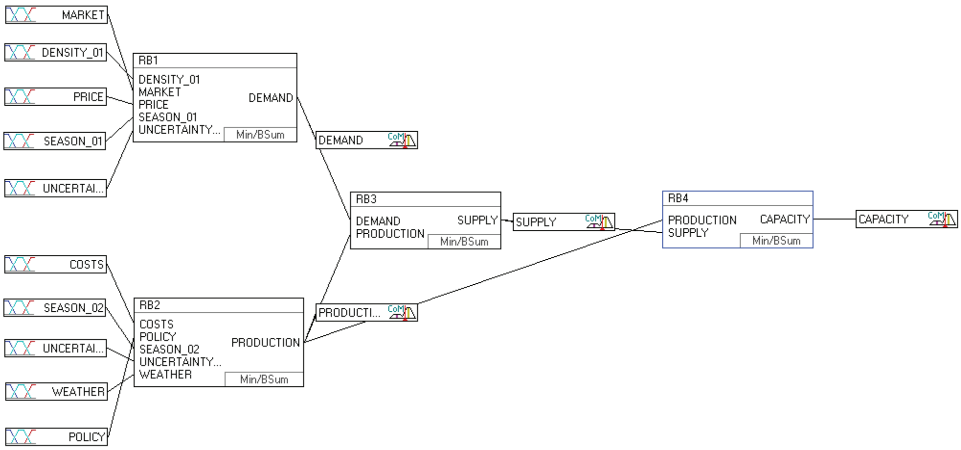

***Figure 6**: The fuzzy three- phase system*

We assume that all expressions in our model are fuzzy variables.

3.1 Fuzzification

In the fuzzification procedures, fuzzy sets for all fuzzy variables (input and output) must be defined, as well as their membership functions. Every fuzzy variable is presented by more terms/fuzzy sets. In our system, there are fourteen fuzzy variables: the market area, the density of the area (density_01), the price, the season_01, the uncertainty_01, the demand, the costs of production, the policy, the season_02, the weather, the uncertainty_02 and production in the first phase and capacity_01 in the second phase and, finally, in the third phase the capacity as output of the system.
Fuzzy sets are given by terms below.

In the first rules block (subsystem_01):

- the input fuzzy variable MARKET AREA is represented by the fuzzy sets: SMALL, BIG,
- the input fuzzy variable DENSITY OF THE AREA (DEeNSITY_01) is represented by the fuzzy sets: WEAK, MEDIUM, STRONG,
- the input fuzzy variable PRICE is represented by the fuzzy sets: LOW, MEDIUM, HIGH,
- the input fuzzy variable SEASON_01 is represented by the fuzzy sets: LOW, HIGH,
- the input fuzzy variable UNCERTAINTY_01 is represented by the fuzzy sets: SMALL, MEDIUM, BIG, VERY_BIG,
- the output fuzzy variable DEMAND is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH.

In the second rule block (subsystem_02):

- the input fuzzy variable COSTS is represented by the fuzzy sets: LOW, NORMAL, HIGH,
- the input fuzzy variable SEASON_02 is represented by the fuzzy sets: LOW, HIGH,
- the input fuzzy variable UNCERTAINTY_02 is represented by the fuzzy sets: SMALL, MEDIUM, BIG, VERY_BIG,
- the input fuzzy variable WEATHER is represented by the fuzzy sets: GOOD, BAD,
- the input fuzzy variable POLICY is represented by the fuzzy sets: BAD, MEDIUM, GOOD,
- the output fuzzy variable PRODUCTION is represented by the fuzzy sets: LOW, MEDIUM, HIGH.

In the third rule block (second phase):

- the input fuzzy variable DEMAND is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH,
- the input fuzzy variable PRODUCTION is represented by the fuzzy sets: LOW, MEDIUM, HIGH,
- the output fuzzy variable SUPPLY is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH.

In the fourth rule block (third phase):

- the input fuzzy variable SUPPLY is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, VERY_HIGH,
- the input fuzzy variable PRODUCTION is represented by the fuzzy sets: LOW, MEDIUM, HIGH,
- the output fuzzy variable CAPACITY is represented by the fuzzy sets: VERY_LOW, LOW, MEDIUM, HIGH, EXTREMELY_HIGH.

For every fuzzy set, membership functions must be created (Figures 7-18). On the x-axis, the measures would be given in units, such as the number of customers, EUR, EUR/kWh, MWh, and so on, depending on the data. On the y-axis, membership in the interval [0, 1] is measured for every possible fuzzy variable and for every fuzzy set.

Due to the uniqueness of this model, we suppose that all units for all fuzzy variables are given in relative measure, i.e. percentages from 0 to 100. Of course, the expert knows what, for example, 30% for "weather" or 80 % of the "price" etc. means.

The fuzzy variables SUPPLY and CAPACITY are outputs of the fuzzy system.

SUPPLY means a quantity of the goods, which is delivered to the customers on the basis of the demand directly from the factory by the current production.

The fuzzy variable CAPACITY means extra capacities that should be added in the process of the production if it is not sufficient for current demand.

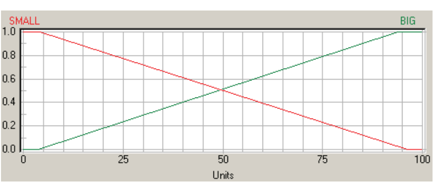

***Figure 7**: MBF of "MARKET"*

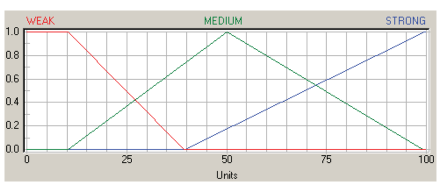

***Figure 8**: MBF of "DENSITY_01"*

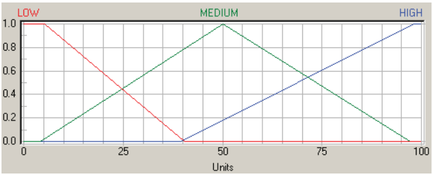

Figure 9: *MBF of "PRICE"*

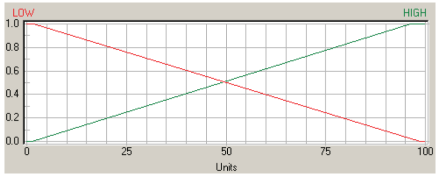

Figure 10: *MBF of "SEASON"*

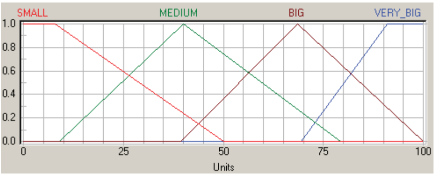

Figure 11: *MBF of "UNCERTAINTY"*

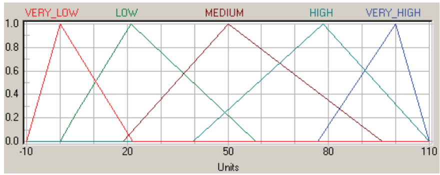

Figure 12: *MBF of "DEMAND"*

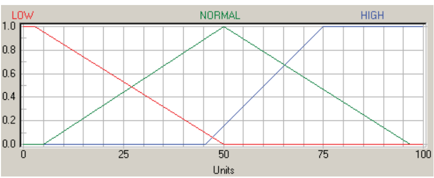

Figure 13: *MBF of "COSTS"*

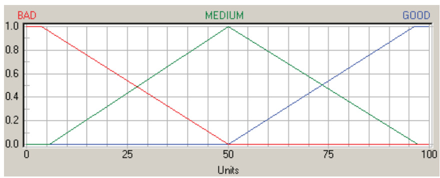

Figure 14: *MBF of "POLICY"*

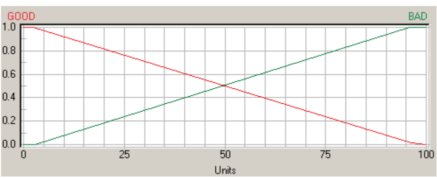

Figure 15: *MBF of "WEATHER"*

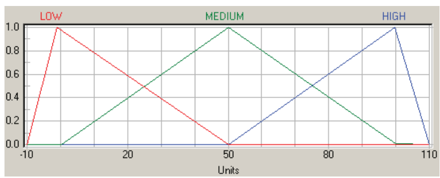

Figure 16: *MBF of "PRODUCTION"*

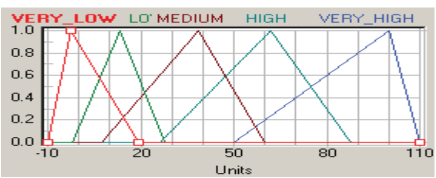

Figure 17: *MBF of "SUPPLY"*

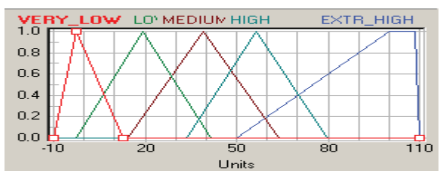

Figure 18: *MBF of "CAPACITY"*

3.2 Fuzzy inference

Fuzzy inference is a process in which a certain conclusion is derived from a set of fuzzy statements. In addition to linguistic variables, there are basic widgets of a fuzzy logic system as well as sets of rules that define the behaviour of a system. A single fuzzy rule (implication) assumes the form: *if x is A, then y is B,* where *A* and *B* are linguistic values defined by fuzzy sets on the universes of discourse *X* and *Y,* respectively. Variables *x* and *y* are defined by the sets *X* and *Y*. With fuzzy inference, we must put all values and facts in a definite order and connect them to the procedure of inference execution, so that it will be feasible to do so with a computer. This order is given as a list or system of rules (rule block), [9], [10].

We applied FuzzyTech software, [11]. In the first phase (Rule block 1, Rule block 2), 144 rules in each block are automatically created. Some of them are represented in Tables 1 and 2. In block 3 and the block 4, FuzzyTech software creats 15 rules (Tables 3 and 4).

***Table 1**: Some rules of the Rule Block "RB1"*

IF					THEN	
DENSITY_01	MARKET	PRICE	SEASON_01	UNCERTAIN	DoS	DEMAND
WEAK	BIG	HIGH	LOW	BIG	1.00	HIGH
WEAK	BIG	HIGH	LOW	MEDIUM	0.01	HIGH
WEAK	BIG	HIGH	LOW	VERY_BIG	1.00	HIGH
WEAK	BIG	HIGH	HIGH	SMALL	0.00	MEDIUM
WEAK	BIG	HIGH	HIGH	BIG	0.00	LOW
WEAK	BIG	HIGH	HIGH	MEDIUM	1.00	LOW
WEAK	BIG	HIGH	HIGH	VERY_BIG	0.00	LOW
MEDIUM	SMALL	LOW	LOW	SMALL	0.91	LOW
MEDIUM	SMALL	LOW	LOW	BIG	1.00	LOW

***Table 2**: Some rules of the Rule Block "RB2"*

IF					THEN	
COSTS	POLICY	SEASON_02	UNCERTAIN	WEATHER	DoS	PRODUCTIC
NORMAL	GOOD	HIGH	VERY_BIG	BAD	1.00	MEDIUM
HIGH	BAD	LOW	SMALL	GOOD	1.00	LOW
HIGH	BAD	LOW	SMALL	BAD	1.00	MEDIUM
HIGH	BAD	LOW	BIG	GOOD	1.00	LOW
HIGH	BAD	LOW	BIG	BAD	1.00	MEDIUM
HIGH	BAD	LOW	MEDIUM	GOOD	1.00	LOW
HIGH	BAD	LOW	MEDIUM	BAD	1.00	LOW

Table3: *Rules of the Rule Block "RB3"*

IF		THEN	
DEMAND	PRODUCTION	DoS	SUPPLY
VERY_LOW	LOW	1.00	VERY_LOW
VERY_LOW	MEDIUM	1.00	LOW
VERY_LOW	HIGH	1.00	MEDIUM
HIGH	LOW	1.00	VERY_LOW
HIGH	MEDIUM	1.00	LOW
HIGH	HIGH	1.00	HIGH
LOW	LOW	1.00	LOW
LOW	MEDIUM	1.00	MEDIUM
LOW	HIGH	1.00	HIGH
MEDIUM	LOW	1.00	LOW
MEDIUM	MEDIUM	1.00	HIGH
MEDIUM	HIGH	1.00	VERY_HIGH
VERY_HIGH	LOW	1.00	MEDIUM
VERY_HIGH	MEDIUM	1.00	HIGH
VERY_HIGH	HIGH	1.00	VERY_HIGH

Table 4: *Rules of the Rule Block 'RB4'*

IF		THEN	
PRODUCTION	SUPPLY	DoS	CAPACITY
LOW	VERY_LOW	1.00	EXTR_HIGH
MEDIUM	VERY_LOW	1.00	MEDIUM
HIGH	VERY_LOW	1.00	LOW
LOW	LOW	1.00	EXTR_HIGH
MEDIUM	LOW	1.00	MEDIUM
HIGH	LOW	1.00	HIGH
LOW	MEDIUM	1.00	MEDIUM
MEDIUM	MEDIUM	1.00	LOW
HIGH	MEDIUM	1.00	HIGH
LOW	HIGH	1.00	MEDIUM
MEDIUM	HIGH	1.00	HIGH
HIGH	HIGH	1.00	VERY_LOW
LOW	VERY_HIGH	1.00	LOW
MEDIUM	VERY_HIGH	1.00	HIGH
HIGH	VERY_HIGH	1.00	VERY_LOW

3.3 Defuzzification

Defuzzification is the conversion of a given fuzzy quantity to a precise, crisp quantity. There are many procedures for defuzzification, which give different results. In our example, the fuzzy model is created with FuzzyTech 5.55i software, and we use the Centre of Maximum (CoM) defuzzification method.

3.4 Optimisation

When the system structure is set, and membership functions and rules in all the rule blocks are defined, the model must also be tested and checked.

During optimization, the entire definition area of input data are verified. For optimisation, there are various methods. One of the most efficient methods is using neural nets during the neuro-fuzzy training to obtain good and regular results.

4 NUMERICAL EXAMPLE

Starting with the fuzzy model using FuzzyTech software, we can simulate all possible situations interactively.

Subsystems 1 and 2 are independent, and numerical examples can be made separately. Because subsystems are one-phased, neurofuzzy training can be used for each of them.

Some results are given in Tables 5 and 6.

Table 5: *Some numerical results of the subsystem 1*

DENSITY_01	MARKET	PRICE	SEASON_01	UNCERT_01	**DEMAND**
10	10	10	10	10	**38**
50	70	30	50	40	**62**
80	20	50	80	80	**46**
30	50	90	30	30	**45**
60	80	80	40	50	**59**
100	100	80	60	90	**44**
30	80	20	80	20	**61**
40	40	40	40	40	**65**
60	60	50	50	20	**67**
100	100	2	100	2	**100**

Table 6: *Some numerical results of the subsystem 2*

COSTS	POLICY	SEASON_02	UNCERT_02	WEATHER	**PRODUCTION**
10	10	10	10	10	**46**
50	50	50	50	100	**67**
100	1	1	100	1	**0**
50	60	80	20	50	**57**
70	60	100	20	50	**60**
80	80	30	60	60	**50**

80	30	30	60	60	**34**
30	80	80	10	50	**70**
30	80	90	50	100	**82**
30	80	90	60	80	**71**

With the interactive simulation, made possible by using FuzzyTech software, every situation can be simulated. The quality of the results depends on the expert who prepares a data file for the neuro-training procedure.

After optimizing both of the subsystems in phase 1, the entire fuzzy system can be run in all three phases. Some numerical results are presented in Table 7.

Table 7: *Some numerical results in three-phased fuzzy system*

DENSITY_01	10	20	30	50	60	80	80	80	100	100	5
MARKET	10	40	40	20	80	80	50	50	50	100	5
PRICE	10	40	80	80	90	20	20	40	70	5	100
SEASON_01	10	10	20	20	50	50	80	80	60	100	5
UNCERTAINTY_01	10	40	40	80	80	50	50	20	20	5	100
DEMAND	38	41	37	40	45	61	61	53	57	100	2
COSTS	10	60	60	80	80	20	20	50	50	5	100
POLICY	10	50	50	20	20	80	80	40	40	100	5
SEASON_02	10	80	80	50	50	40	40	90	90	100	5
UNCERTAINTY_02	10	30	30	50	80	80	20	50	60	5	100
WEATHER	10	10	80	80	40	40	70	80	90	100	5
PRODUCTION	50	40	56	43	32	50	65	57	50	100	0
SUPPLY	**41**	**33**	**42**	**40**	**34**	**45**	**50**	**47**	**42**	**100**	**0**
(weighted)	**51**	**41**	**49**	**48**	**41**	**52**	**57**	**54**	**49**	**100**	**0**
CAPACITY	**40**	**47**	**43**	**43**	**49**	**42**	**37**	**40**	**43**	**0**	**100**
(weighted)	**49**	**59**	**51**	**52**	**59**	**48**	**43**	**46**	**51**	**0**	**100**

The data in the rows SUPPLY and CAPACITY are the basic information about the behaviour of our fuzzy system.

For the extreme situations given in (data) columns 10 and 11, it can be observed that if demand is very big (maxima 100 units), and current production is zero then (of course) the supply from current production is zero and we have to activate stocks (extra capacities) in all 100 units; if demand is very small (near 0 units), and production is zero, then all demand is satisfied from stocks.

Other results yield similar information. For example, in the first (data) column we have with respect to the conditions for demand and for current production, weighted supply from current production 51 units. In the case of the "negative" supply, we can activate stocks (i.e. additional capacities) in the other 49 units of goods.

5 CONCLUSION

The fuzzy mathematical model of system control can be used in an energy technology system and in its subsystems. During the control process, a great deal of information must be processed, which can only be done if a transparent and properly developed information system is available. The solution depends on many numerical parameters. All data and numerical analysis can only be processed into information for control if high quality and sophisticated software and powerful hardware are available.

The fuzzy approach in creating the mathematical model with which we are describing the system can be successful if we have a good robust base of expert knowledge for neural training. Experts can use fuzzy models for real numerical predictions.

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