Fuzzy Models for Intellectual Industrial Regulators in Control Systems of Thermal Power Stations

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ABSTRACT: This paper examines ideas proposed in a previous article [1] by the authors and the results of applying the theory of fuzzy sets and fuzzy logic to the analysis and diagnosis of the state of functioning power installations, which are represented as open MECHANISMS. Procedures are created and united into fuzzy production models for recognition of "generalized images of the state" of the elements (or nodes) of a power installation. Fuzzy models are applied for the first time in designing an intellectual fuzzy regulator for rarefaction in a turbine condenser.

KEYWORDS: Fuzzy Models, Intellectual Regulators, Control Vacuuming Turbine, Thermal Power Stations.

1. INTRODUCTION

Automatic control of thermal power processes takes place in conditions of uncertainty or partial uncertainty of the initial information due to the absence of authentic statistics about the behaviour of power installations of a thermal power plant (TPP) - boiler units, turbines and auxiliary equipment. Designers of control systems of such facilities take into account some non-formalizable or difficult to formalize factors in the identification of power installations of TPPs. However, the behaviour of these systems is so complex that the use of known determinate and statistical models for their control, analysis and diagnosis does not provide the desired characteristics. In this case, adequate mathematical models of the operation of power installations can be based on the theory of fuzzy sets allowing the design of an intellectual control system.

The foundation for designing intellectual fuzzy regulators is the construction of "knowledge" by applying the methods of representation and search of knowledge and is based on principles of artificial intelligence.

2. PROBLEM FORMULATION

Let X be a set of elements of the MECHANISM [1], for which each value **x** represents an inducing element X, i.e. X = {x}. Then the fuzzy set A in X is a set of ordered pairs {(x, m_A(x))}, where m_A(x) is called [2,3] the membership function of A, and m_A(x) is defined as

$$m_A: X \rightarrow [0,1] \quad (1)$$

Here m_A specifies the degree of membership of A to the fuzzy set X. We shall assign fuzzy set A to fuzzy sets of the first kind, which are the most widespread at this time.

The mathematical apparatus [3,5,6] used in developing fuzzy models for control systems of TPP generating units was examined in [7]. Membership functions are formed from rules, verbally submitted by engineers of TPP power installations, with the help of composite rules of fuzzy conclusions of the type:

" IF...,THEN...,ELSE... " (2)

During design, concrete membership functions are created from production rules of verbal representation of the state of the object. These membership functions are recorded in the COMPUTER as the KNOWLEDGE BASE about the state of the given TPP installation. For these purposes, the following formalization of expert reasoning is used by authors.

Let knowledge of the expert A→B reflect the fuzzy cause relationship between the antecedent and the conclusion in the form of the fuzzy relationship R = A→ A′.

Let's take R as a fuzzy set of the direct product X×Y (of the entire space between the antecedents X and the entire space of the conclusions Y). Then the procedure for obtaining the fuzzy result of the conclusion B′ using data of observation A′ and knowledge A→B will look like

$$B' = A' \bullet R = A' \bullet (A \to B). \qquad (3)$$

Here the symbol • is called a composite rule (or rule of convolution) of fuzzy conclusion, and the arrow → in the rule A→B is called “fuzzy implication” [5]. Fuzzy implication is the operation of taking the minimum $X_1 \to X_2 = X_1 \wedge X_2$. The fuzzy conclusion from the rules (2,3) and fig. 2 is the result of using the maximum composition as the composite rule of fuzzy conclusion, and the operation of taking the minimum as fuzzy implication:

$$\begin{aligned} m_{B'} &= \bigcup_{x\in X}(m_{A'}(X) \wedge m_R(X,Y)) = \bigcup_{x\in X}(m_{A'}(X) \wedge (m_A(x) \wedge m_B(Y))) = \\ &= (\bigcup_{x\in X}(m_{A'}(X) \wedge m_A(X))) \wedge m_B(Y) = \bigcup_{x\in X} m_{A'\cap A}(X) \wedge m_B(Y) = \\ &= a \wedge m_X(Y) = m_{aY\cap B}(Y) \\ CG &= \int_Y Y \cdot m_{B'}(Y)dY \Big/ \int_Y m_{B'}(Y)dY \end{aligned} \qquad (4)$$

Here $A \cap A'$ is the result of the approximate juxtaposition of the rule A and the observation data A'; ***a*** - measure of the juxtaposition $A \cap A'$; ***aY*** - a way of reducing B for the choice of the cut-off in proportion to the juxtaposition **a**, that is, the membership function $m_{aY}(Y) = a$ for $\forall Y \in Y$; CG - centre of gravity of the composition maximum - minimum.

3. SOLUTION METHODS AND RESULTS

The structure of an intellectual control system with a fuzzy regulator is presented in fig. 1.

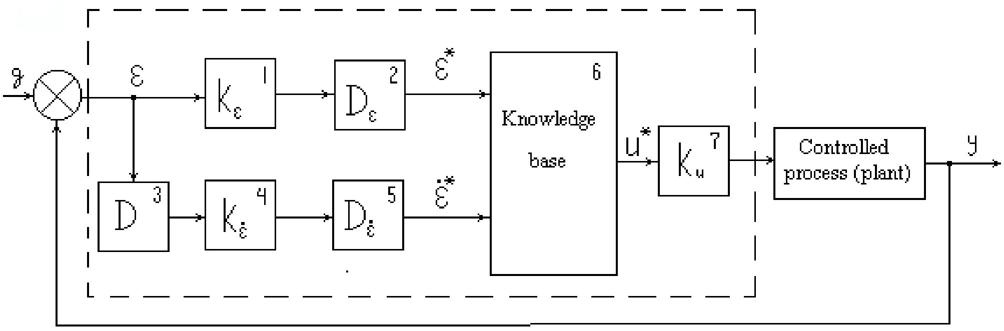

Figure 1: Structure of an intellectual control system with a fuzzy regulator

Here the output variable of the object of regulation of the production process **y** is compared to its given value **g** and the mismatch error ***e*** enters simultaneously the scale element *1* with the coefficient k_e and the differentiator 3, the output of which is multiplied by k_e in the scale element *4*. The elements *2,5* are intended for transformation of the current values of the error and the derivative of the error (rate of change of the error) into their linguistic values. The fuzzy values e^*, $\dot{e}^*$ enter the knowledge base 6, representing the main element of the fuzzy regulator. The knowledge base is constructed on the basis of the production model of knowledge and has the following construction: "IF...,THEN...,ELSE..." [2,3]. Each production represents a set of pairs "SITUATION - ACTION", and allows the assignment of an action of the regulator to the current situation as a value of the regulating influence on the object.

The found linguistic control value, after multiplication by the scaled coefficient $\boldsymbol{k_U}$ in element 7 and transformation into its distinct value ***U*** (defuzzification), enters the executive element of the control object.

In the synthesis of fuzzy regulators of such complex objects as TPP power installations, the main thing is to design for them a KNOWLEDGE BASE. In the KNOWLEDGE BASE (KB) the experience and the knowledge of the operator can be remembered in various ways [2,3,4].

Examples of forming fuzzy conclusions (« IF the is temperature head is high, increase the amount of cooling water») are presented in fig. 2.

1. The operator-expert controls the industrial process of rarefaction of the condenser, which is being "observed" by a regulator. The regulator "memorizes" all the actions of the expert and their location in the KB;
2. The operator formalizes his actions at each observable situation as the production “IF..., THEN...,ELSE...", the set of which makes up the KB of the regulator;
3. The designer sets the purpose of the fuzzy regulator - ensuring the desirable transient characteristic of a control system and gives some information about the industrial process and object of control.

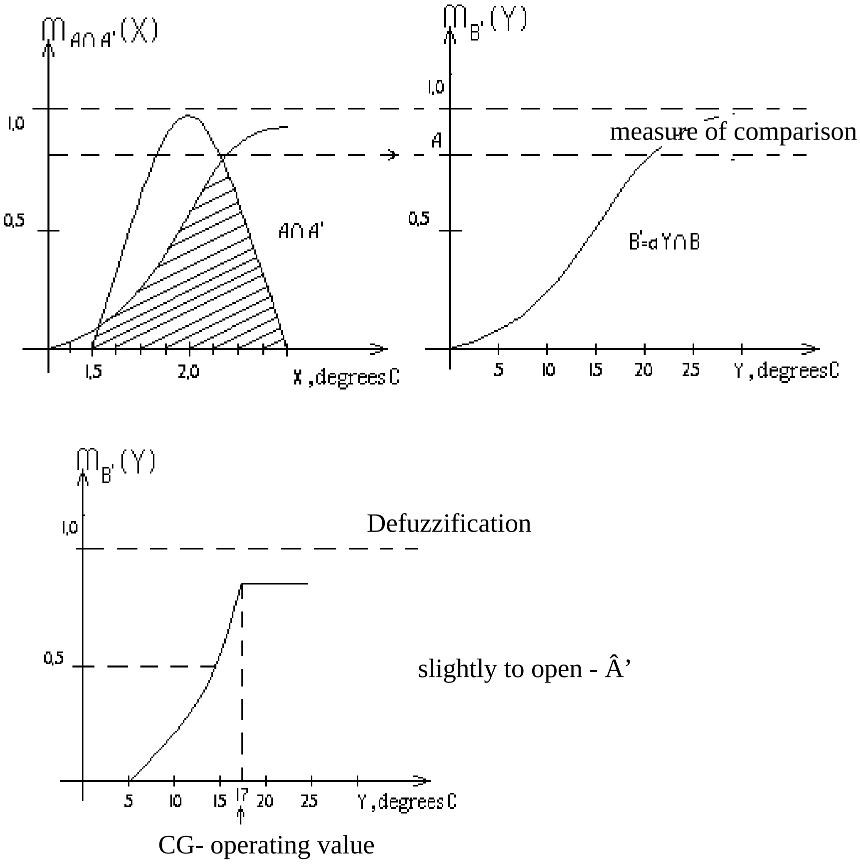

Figure 2: An example of a fuzzy conclusion from rules

Here, defuzzification - transformation of a fuzzy set to a distinct representation (on the basis of the membership function, for ***B***, values of the operation to be carried out are extracted for each point in ***Y***).

In the long term the regulator itself, without the expert, through trial and error, can collect knowledge and, thus, organize itself.

Here, a qualified TPP engineer acts as the operator.

In the theory of artificial intelligence, as it is known from [3÷6], the representation of knowledge in continuous control systems can be carried out through logical, relational, frame or production languages.

The authors of the paper have taken into account the special features of a thermal power installation, the complexity of its regulation, the close connection with social infrastructures, and the direct ecological dependence between the installation and the environment. Therefore, for formalization of the available information about power installation operation, production models with fuzzy regulators are used. The operational and structural model for diagnostics, which is examined in this paper, is shown in fig. 3.

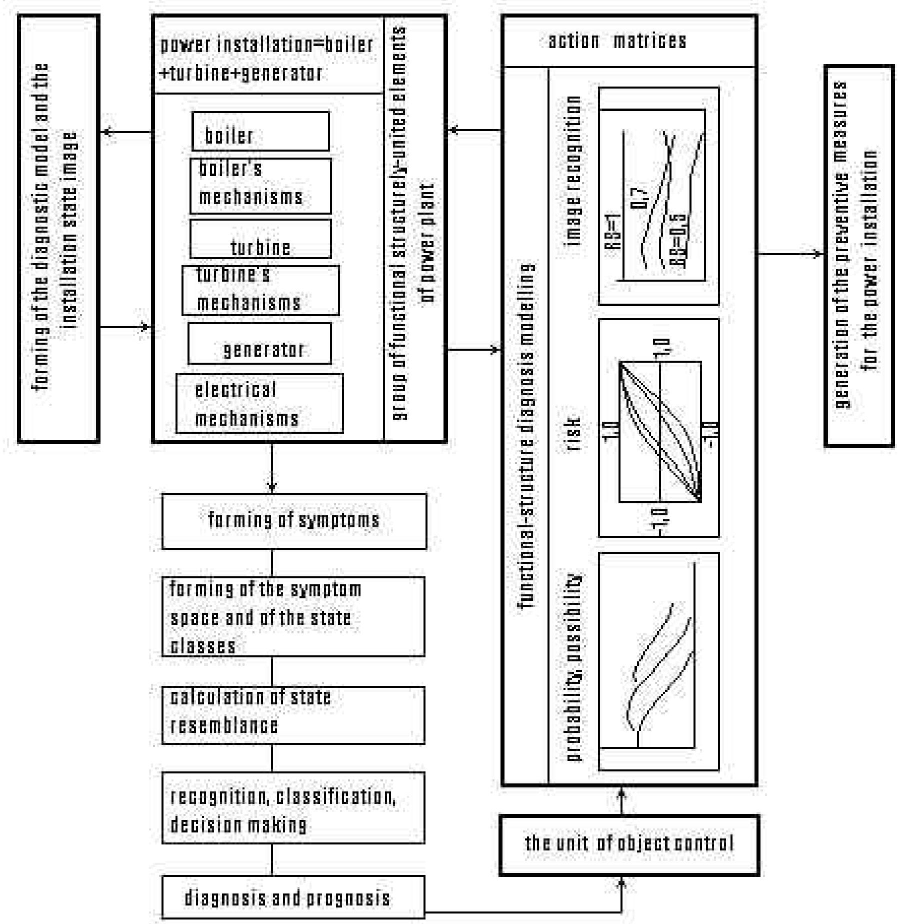

Figure 3: Functional-structure model of diagnostic of the power plant TPS.

By experiment, knowledge of expert technicians was determined and presented as nomographs $[dt = f(Dt, k, F, W) = \frac{Dt}{e^{kF/W} - 1}]$ about what operations are necessary to execute in the condensers of the turbine at considerably high, in comparison with normative, temperature head, rarefaction and heating of water for cooling. The following number of preventive measures, characteristic for TPP condensers is proposed:

- To check the quantity of cooling water entering the condensers and to adjust its processing mode for the purpose of removing biological impurities, acidifying and softening the water;
- To clean the condenser tubes in the customary way for the TPP;
- To find and remove places of air suction in the vacuum part of the turbine;
- To check and adjust the operation of the air suction and closing devices;
- To check the operation of measuring devices;
- To check the operation of condensate and circulating pumps;
- To check the general state of the vacuum system turbine by determining the rate of change of rarefaction in the vacuum system while closing the latch on the feed of the working steam to the nozzle of the ejectors;
- To determine the salt and oxygen content of the turbine condensate.

This knowledge represents the production rule, " IF...,THEN..., " as follows:

1) "IF the temperature head is high, and the circulating system and pumps allow in the water expenditure, THEN increase the flow rate of cooling water";
2) "IF the temperature head is high, and the circulating system and pumps do not allow in the water expenditure, THEN clean the condenser";
3) "IF the temperature head is normal, THEN do nothing". (5)

Each similar production is a fragment of knowledge - a nucleus in the synthesis of knowledge and takes the form: "CONDITION - ACTION ". The left part of the production (5) is the conjunction of elementary perception conditions, and the right part as a set of elementary actions. For the regulator (fig. 1) any rule in the KB looks like:

$$\text{IF } (e \text{ is } e_1^*) \text{ and } (\dot{e} \text{ is } \dot{e}_1^*) \text{ THEN } (u \text{ is } u_1^*), \qquad (6)$$

where e , $\dot{e}$, u - variables,

e_1^*, $\dot{e}_1^*$, u_1^* - linguistic values of the examined variables.

Tab. 1 shows the linguistic rules which are included in the KB of the fuzzy regulator for rarefaction control in the turbine condenser (fig. 4). The following designations are used: NORM - normal (normative); VNORM - very normal (better than normative); ALNORM - almost normal (worse than normal, but permissible);MLNORM- more or less normal (little more than the lower permissible limit); ABNORM- not normal (below the lower permissible limit).

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	$\dot{e}$				
ε	ABNORM	VNORM	ALNORM	MLNORM	NORM
ABNORM	NORM	NORM	NORM	NORM	NORM
MLNORM	VNORM	VNORM	VNORM	VNORM	VNORM
NORM	ABNORM	ABNORM	ABNORM	ABNORM	ABNORM
ALNORM	MLNORM	MLNORM	MLNORM	MLNORM	MLNORM
VNORM	ALNORM	ALNORM	ALNORM	ALNORM	ALNORM

Table 1: Linguistic rules for a fuzzy regulator Rarefaction in the turbine condenser.

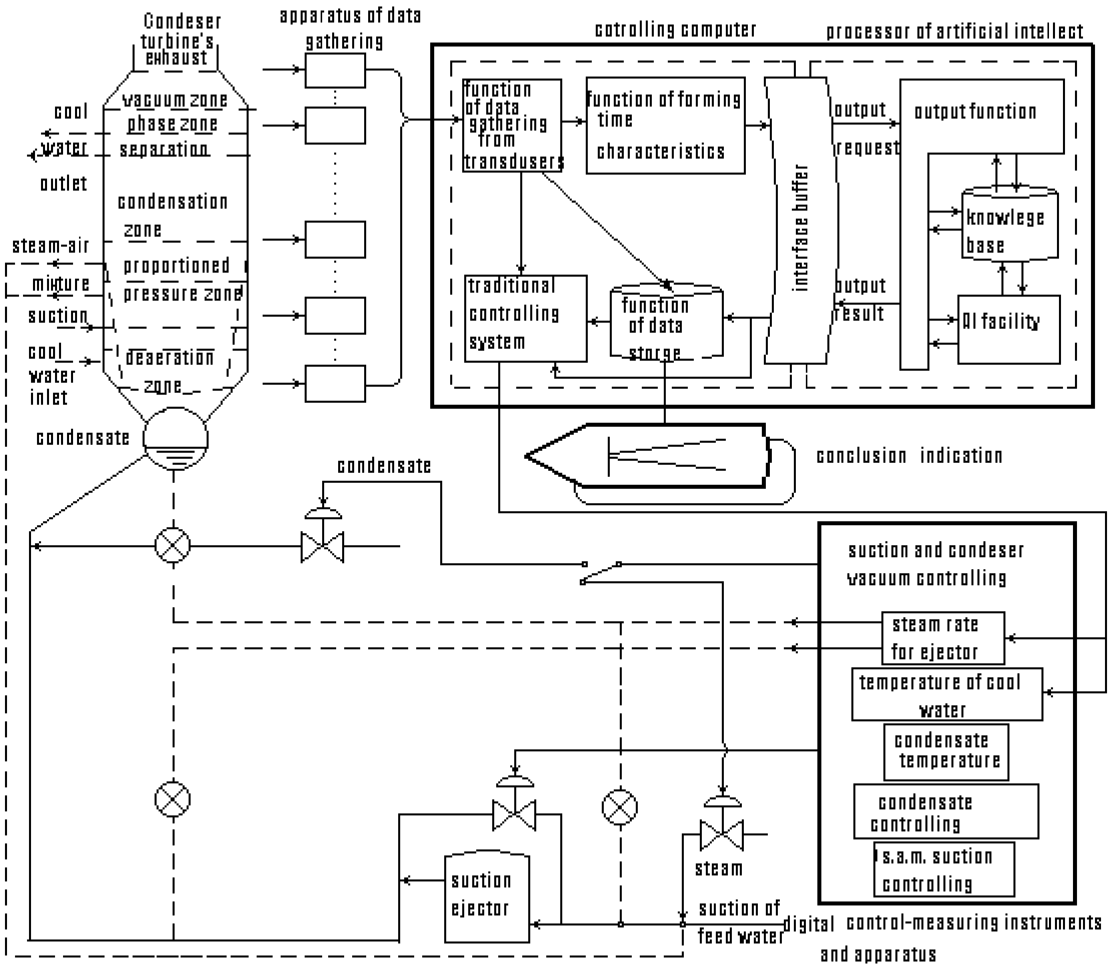

Figure 4: Structure of an expert control system for the turbine condenser with a fuzzy regulator in the knowledge base.

The scale coefficients k_e , $k_{\dot{e}}$, k_u , are parameters of universal sets *E*, *E¢*, and *U*, on which, the fuzzy sets e , $\dot{e}$, u are determined depending on the conditions of the specific controlled object. For example, if universal set **E**, for values of temperature head in Celsius, is the set {5,8,10,12,18,20} and it is required, that the mismatch error in the system be in the range (-1, + 1) degrees Celsius, then k_e is taken as equal to 12.0 degrees C, so that the fuzzy regulator can use the whole universal set, which determines the fuzzy conclusion «NORMAL TEMPERATURE HEAD IN THE CONDENSER » (fig. 2,5).

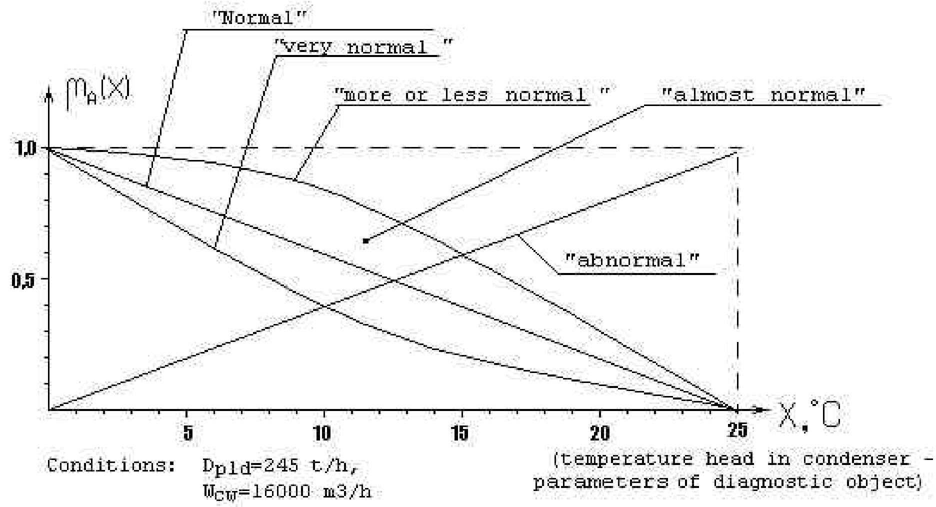

Figure 5: An example of transforming a fuzzy conclusion - "normal temperature head in the condenser" - into evaluations of the membership function $m_A(x)$.

In the knowledge base of the regulator being developed, knowledge accumulates (as fuzzy rules) for use in the control of rarefaction in the turbine condenser. The fuzzy judgments described in the antecedents and conclusions of each rule, are made of a number of members. The authors have developed a knowledge base of the following type [1]:

$$\text{IF } A_{i1}=0, A_{i2}=0, ..., A_{im}=0, \text{ THEN } B_{i1}=\Delta, B_{i2}=\Delta, ..., B_{im}=\Delta \Big\}_{i=1}^{I} , \qquad (7)$$

where ***I*** - number of rules; ***m*** - number of members in the antecedent; ***n*** - number of members in the conclusion.

4. CONCLUSION

The number of fuzzy rules has turned out to be small for developing a fuzzy expert system for functional diagnosis with a fuzzy regulator built into the control loop of the power installation. This is due to the fact that each fuzzy rule takes the place of many conditions in the exact world. This, naturally, makes obtaining knowledge from an expert easier, simplifies the debugging of the expert system and allows the synthesis of a system with a good cost / productivity ratio.

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