Michał PAJĄK
Radom University of Technology, Faculty of Mechanical Engineering,
Department of Thermal Technology, Radom
Janusz KALOTKA
Radom University of Technology, Faculty of Mechanical Engineering,
Department of Thermal Technology, Radom

FUZZY MODELLING AS A WAY OF ESTIMATING THE EXPLOITATION PARAMETERS

Keywords

Fuzzy model, genetic algorithm, fuzzy statistic and data analysis, large-scale system, linguistic modelling.

Abstract

To carry out the exploitation process in the proper way, it is necessary to know the values of the exploitation parameters for each moment of the process. It is especially important for large industrial objects. A lot of exploitation parameters are measured on-line, but some of them should be calculated. There are situations when the input information for the calculations are included in the measured data, but its form is entangled. In this paper a fuzzy modelling is proposed as a solution of the described problem. As an example, a fuzzy model of the temperature difference in a condenser of 13K215 steam turbine is considered.

Introduction

The supervision of the exploitation process is based on the analysis of the exploitation parameters. There are measuring instruments installed on a supervised device, which collect the operating parameters of the machine. Despite that, not all exploitation parameters are measured on-line. There is a group of exploitation parameters which are calculated. The measured values are the basis for these calculations. To execute the calculations, it is necessary to know a formula which expresses the calculated values as a function of the measured data. Sometimes it is hard to formulate this dependence. It happens when the needed information is included in the measured data but its form is entangled. Such a situation can occur in case of a complex industrial process. Additionally, even if it is possible to execute the calculations, it could take too long to do it on-line. The described problem is a typical implementation of the fuzzy logic theory [1]. To check the usefulness of such approach in case of a real industrial object a study has been carried out. As a place for the fuzzy logic theory implementation, a power plant exploitation system was selected. It is on a large scale, a real industrial system where about 1000 pieces of information are collected in real time in one unit [2]. The research is focused on the estimation of the exploitation process of a steam turbine condenser. To check the correctness of the fuzzy model, the temperature difference in the condenser was estimated. This parameter is not a measured value but could be calculated on the basis of the measured data. Thanks to it, a comparison of the fuzzy model output value and the calculated temperature difference can define the accuracy of the fuzzy model.

1. Description of the exploitation process

The power unit’s condenser is a place where an isobaric condensation occurs [2]. If we assume a zero value of energy loss and the lack of the working medium inflows to the condenser, it will be possible to write the energy balance for a surface condenser in the following form (1):

$$\dot{M}_{ps}(i_{ps} - i_{ws}) = \dot{M}_w c_w (T_{w2} - T_{w1}) \tag{1}$$

where:
- M_{ps} – mass flux of condensed steam,
- i_{ps} – enthalpy of condenser incoming steam,
- i_{ws} – enthalpy of condenser outgoing drips,
- M_w – mass flux of cooling water,
- c_w – specific heat of water,
- T_{w2} – temperature of condenser outgoing cooling water,
- T_{w1} – temperature of condenser incoming cooling water.

The pressure of an isobaric process depends on the cooling conditions in the condenser. For a condenser we can write down the following temperature equation (2):

$$T_{ps} = T_{w1} + \Delta T_w + \delta T \tag{2}$$

where: T_{ps} – temperature of condenser incoming steam
ΔT_w – temperature rise of cooling water
δT – difference between the saturation temperature in condenser and the outgoing cooling water.

The mean value of the temperature rise of the cooling water is about 8 to 12 K [3] and is described by the formula (3):

$$\Delta T_w = T_{w2} - T_{w1} \tag{3}$$

So, we can type the following formula (4):

$$T_{ps} = T_{w2} + \delta T \tag{4}$$

The temperature difference in a condenser can be described as a function of five variables but it is very difficult to formalise it [4]

$$\delta T = f(d_s, T_{w2}, v_w, \beta_z, \beta_p) \tag{5}$$

where: d_s – unitary steam load of condenser
v_w – velocity of water flow in condenser pipes
β_z – heat exchange surface fouling factor
β_p – factor of air existence in condenser

The mean value of the temperature difference in a condenser is about 2 to 4 K [5].

The unitary steam load of a condenser could be calculated according to the following formula (6):

$$d_s = \frac{\dot{M}_{ps}}{F_{ws}} \tag{6}$$

where: M_{ps} – mass flux of condensed steam
F_{ws} – heat exchange surface of condenser

According to the law of the partial pressures for a condenser steam and water mixture we can write the following equations down (7):

$$p_{sg} = p_{pg} + p_{ag}$$
$$p_{sd} = p_{pd} + p_{ad} \qquad (7)$$

where: p_{sg} – pressure of condenser upper part steam and water mixture,
p_{sd} – pressure of condenser lower part steam and water mixture,
p_{pg} – partial pressure of condenser upper part steam,
p_{pd} – partial pressure of condenser lower part steam,
p_{ag} – partial pressure of condenser upper part air,
p_{ad} – partial pressure of condenser lower part air.

Assuming the zero value of a pressure loss, we obtain the following relationship (8):

$$p_{pd} = p_{pg} - (p_{ad} - p_{ag}) \qquad (8)$$

On a real industrial object p_{ad} pressure is higher than p_{ag} so that p_{pd} is lower than p_{pg}.

Because (9):

$$T_{ps} = T_{sat}(p_{pg}) \qquad T_{ws} = T_{sat}(p_{pd}) \qquad (9)$$

where: T_{sat} – saturation temperature,
T_{ws} – temperature of condenser drips

so:

$$T_{ws} = T_{ps} - \Delta T_s \qquad (10)$$

where: ΔT_s – overcooling of condensate.

The real value of condensate overcooling depends on the amount of air and on the level of the condensate in the condenser and equals about 1 to 2 K.

2. Initial processing of exploitation parameters of the real industrial object

The real object data is collected by Computerized System of Power Plant Activity Monitoring and Supervising ERO-TKE. In the analysis, the data covering fifteen months of a power plant operation is considered [6]. The data set includes over six hundred thousand data vectors. Each data vector consists of *34* exploitation parameters which describe the operation point of a power unit for a defined moment in time. The list of the collected data is presented at the end of the paper (Table 2).

The state of the power unit is generated as a result of the measured data analysis or recorded as a result of the power unit operator action [7]. It is possible to distinguish between 14 different power unit's operation points (Table 2). The algorithm of the power unit state generation is presented at the end of the paper (Fig. 1).

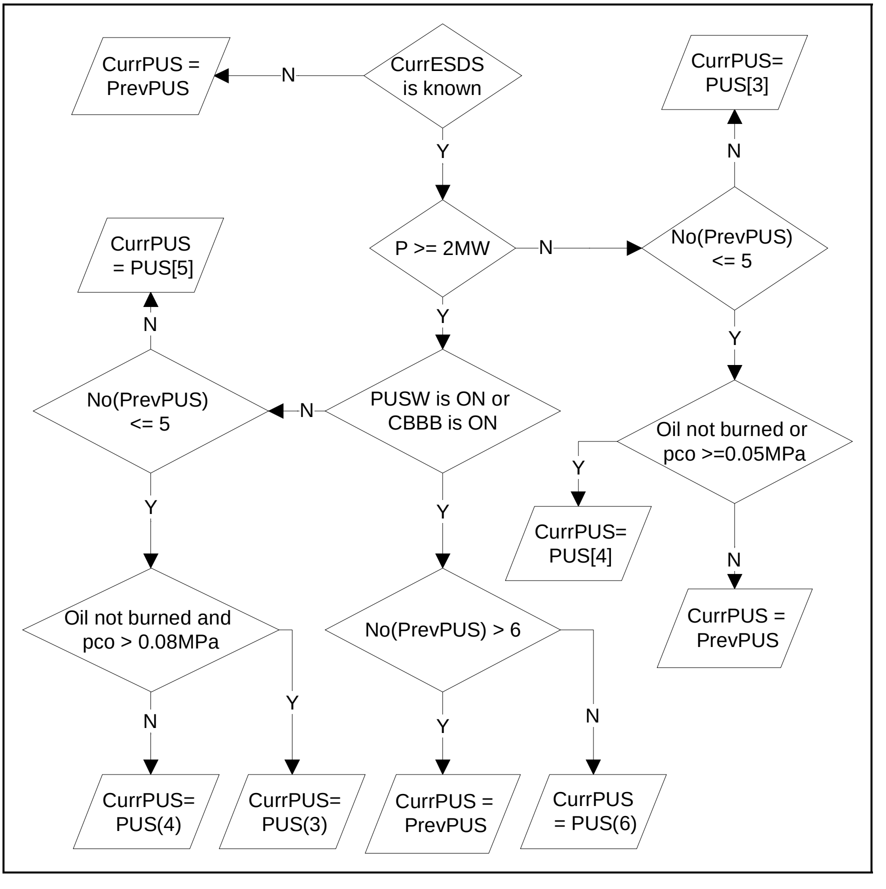

Fig. 1. Algorithm of power unit state generation

CurrPUS	–	current state of power unit
PrevPUS	–	previous state of power unit
No	–	number of power unit state according to Table 2
PUS[i]	–	power unit state of i number according to Table 2
CurrESDS	–	current state of electric switch gear devices
P	–	active load of power unit
PUSW	–	power unit switch
CBBB	–	circuit breaker to by-pass bus bars
pco	–	pressure in condenser

The analysed data was of different quality. To exclude the poor quality measurement data, a filter system was designed (Table 1). The system reflects the correct value ranges of the exploitation parameters for the power unit *200MW* (*OP-650* boiler and *13K215* turbine). The size of the filter window was expressed as a function of an active load of the power unit.

Table 1. Formulas of fiter system

No.	Parameter	Formula
1.	Amount of main steam on the left and right side	$\dot{M}_{p\acute{s}}[t/h] = \begin{cases} 0 \div 300 & \text{for } P < 110MW \\ f(x) \pm 20 \text{ where } x = \frac{P}{200} & \text{for } P \geq 110MW \end{cases}$ P - active load $f(x) = \frac{0.943238 + 567098.904568x - 944124.470704x^2 + 1026960.170082x^3 - 358343.972234x^4}{1000}$
2.	Shaft rotary speed	$n[1/\min] = \begin{cases} 0 \div 3120 & \text{for } P < 110MW \\ 2880 \div 3120 & \text{for } P \geq 110MW \end{cases}$
3.	Amount of burned coal	$\dot{M}_{Bi}[t/h] = \begin{cases} f(x) \pm \frac{100}{0} & \text{for } P < 110MW \\ f(x) \pm \frac{20}{40} & \text{for } P \geq 110MW \end{cases}$ where $x = \frac{P}{200}$ $f(x) = 85.02x$
4.	Amount of burned oil	$\dot{M}_{M}[t/h] = \begin{cases} 0 \div 20 & \text{for } P < 250MW \\ 0 & \text{for } P \geq 250MW \end{cases}$
5.	Temperature of main steam	$T_{p\acute{s}}[°C] = \begin{cases} 1.0 \div 555.0 & \text{for } P < 110MW \\ 500.0 \div 555.0 & \text{for } P \geq 110MW \end{cases}$
6.	Pressure of main steam	$p_{p\acute{s}}[MPa] = \begin{cases} 0.09 \div 14.0 & \text{for } P < 110MW \\ 11.0 \div 14.0 & \text{for } P \geq 110MW \end{cases}$
7.	Temperature of high pressure outgoing steam	$T_{pwHP}[°C] = \begin{cases} 1.0 \div 555.0 & \text{for } P < 110MW \\ f(x) \pm \frac{25}{25} & \text{for } P \geq 110MW \text{ where } x = \frac{P}{200} \end{cases}$ $f(x) = 240.000318 + 25.852837x + 130.634678x^2 - 92.735008x^3 + 13.439757x^4$
8.	Pressure of high pressure outgoing steam	$p_{pwHP}[MPa] = \begin{cases} 0.1 \div 4.0 & \text{for } P < 110MW \\ 1.0 \div 4.0 & \text{for } P \geq 110MW \end{cases}$
9.	Temperature of reheated steam	$T_{pwt}[°C] = \begin{cases} 1.0 \div 555.0 & \text{for } P < 110MW \\ 550.0 \div 555.0 & \text{for } P \geq 110MW \end{cases}$
10.	Pressure of reheated steam	$p_{pwt}[MPa] = \begin{cases} 0.1 \div 4.0 & \text{for } P < 110MW \\ 1.0 \div 4.0 & \text{for } P \geq 110MW \end{cases}$

No.	Parameter	Formula
11.	Temperature of low pressure outgoing steam	$T_{pwNP}[°C] = \begin{cases} 1.0 \div 60.0 & \text{for } P < 110MW \\ 1.0 \div 60.0 & \text{for } P \geq 110MW \end{cases}$
12.	Temperature of turbine extraction no 1 outgoing steam	$T_{U1}[°C] = \begin{cases} 1.0 \div 100.0 & \text{for } P < 110MW \\ 50.0 \div 100.0 & \text{for } P \geq 110MW \end{cases}$
13.	Temperature of turbine extraction no 2 outgoing steam	$T_{U2}[°C] = \begin{cases} 1.0 \div 190.0 & \text{for } P < 110MW \\ 150.0 \div 190.0 & \text{for } P \geq 110MW \end{cases}$
14.	Temperature of turbine extraction no 3 outgoing steam	$T_{U3}[°C] = \begin{cases} 1.0 \div 270.0 & \text{for } P < 110MW \\ 230.0 \div 270.0 & \text{for } P \geq 110MW \end{cases}$
15.	Temperature of turbine extraction no 4 outgoing steam	$T_{U4}[°C] = \begin{cases} 1.0 \div 400.0 & \text{for } P < 110MW \\ 310.0 \div 400.0 & \text{for } P \geq 110MW \end{cases}$
16.	Temperature of turbine extraction no 5 outgoing steam	$T_{U5}[°C] = \begin{cases} 1.0 \div 450.0 & \text{for } P < 110MW \\ 430.0 \div 450.0 & \text{for } P \geq 110MW \end{cases}$
17.	Temperature of turbine extraction no 6 outgoing steam	$T_{U6}[°C] = \begin{cases} 1.0 \div 330.0 & \text{for } P < 110MW \\ 289.0 \div 330.0 & \text{for } P \geq 110MW \end{cases}$
18.	Temperature of turbine extraction no 7 outgoing steam	$T_{U7}[°C] = \begin{cases} 1.0 \div 430.0 & \text{for } P < 110MW \\ 335.0 \div 430.0 & \text{for } P \geq 110MW \end{cases}$
19.	Pressure of turbine extraction no 1 outgoing steam	$p_{U1}[MPa] = \begin{cases} 0.012 \div 0.11 & \text{for } P < 110MW \\ 0.012 \div 0.029 & \text{for } P \geq 110MW \end{cases}$
20.	Pressure of turbine extraction no 2 outgoing steam	$p_{U2}[MPa] = \begin{cases} 0.060 \div 0.132 & \text{for } P < 110MW \\ 0.060 \div 0.132 & \text{for } P \geq 110MW \end{cases}$
21.	Pressure of turbine extraction no 3 outgoing steam	$p_{U3}[MPa] = \begin{cases} 0.090 \div 0.261 & \text{for } P < 110MW \\ 0.090 \div 0.261 & \text{for } P \geq 110MW \end{cases}$
22.	Pressure of turbine extraction no 4 outgoing steam	$p_{U4}[MPa] = \begin{cases} 0.090 \div 0.510 & \text{for } P < 110MW \\ 0.311 \div 0.510 & \text{for } P \geq 110MW \end{cases}$
23.	Pressure of turbine extraction no 5 outgoing steam	$p_{U5}[MPa] = \begin{cases} 0.090 \div 1.213 & \text{for } P < 110MW \\ 0.745 \div 1.213 & \text{for } P \geq 110MW \end{cases}$
24.	Pressure of turbine extraction no 6 outgoing steam	$p_{U6}[MPa] = \begin{cases} 0.1 \div 2.8 & \text{for } P < 110MW \\ 1.53 \div 2.8 & \text{for } P \geq 110MW \end{cases}$
25.	Pressure of turbine extraction no 7 outgoing steam	$p_{U7}[MPa] = \begin{cases} 0.1 \div 4.322 & \text{for } P < 110MW \\ 2.35 \div 4.322 & \text{for } P \geq 110MW \end{cases}$
26.	Temperature of heat exchanger no 5 outgoing water	$T_{XW5}[°C] = \begin{cases} 1.0 \div 180.0 & \text{for } P < 110MW \\ 100.0 \div 180.0 & \text{for } P \geq 110MW \end{cases}$
27.	Temperature of heat exchanger no 6 outgoing water	$T_{XW6}[°C] = \begin{cases} 1.0 \div 226.0 & \text{for } P < 110MW \\ 100.0 \div 226.0 & \text{for } P \geq 110MW \end{cases}$

No.	Parameter	Formula
28.	Temperature of feed water	$T_{wz}[°C] = \begin{cases} 1.0 \div 280.0 & \text{for } P < 110MW \\ 100.0 \div 280.0 & \text{for } P \geq 110MW \end{cases}$
29.	Pressure in condenser	$p_{sk}[MPa] = \begin{cases} 0.001 \div 0.12 & \text{for } P < 110MW \\ 0.001 \div 0.14 & \text{for } P \geq 110MW \end{cases}$
30.	Temperature of flue gases	$T_{sp}[°C] = \begin{cases} 1.0 \div 150.0 & \text{for } P < 110MW \\ 50.0 \div 150.0 & \text{for } P \geq 110MW \end{cases}$
31.	Amount of secondary injections	$\dot{M}_{wt}[t/h] = 0 \div 30$
32.	Content of oxygen in rotary air preheater outgoing flue gases	$O_2[\%] = \begin{cases} 0.1 \div 10.0 & \text{No(PUS)} \geq 6 \\ 0.0 \div 10.0 & \text{No(PUS)} < 6 \end{cases}$ where: PUS - power unit state No(PUS) - number of PUS according to(Table 3)
33.	Content of oxygen in rotary air preheater incoming flue gases	$O_2[\%] = \begin{cases} 0.1 \div 10.0 & \text{No(PUS)} \geq 6 \\ 0.0 \div 10.0 & \text{No(PUS)} < 6 \end{cases}$
34.	Temperature in degassing tank	$CO[ppm] = \begin{cases} 0 \div 2000 & \text{for } P < 110MW \\ 0.1 \div 2000 & \text{for } P \geq 110MW \end{cases}$

Applying the filter system, the shaft rotary speed and the content of *CO* in a flue gases were removed from the measurement vector because of the very poor quality of these measurements. The fuel-air-flue gases system combines with the water-steam system of the power unit only by the heat exchange process. The flow of a steam from a boiler to a turbine and the enthalpy of a boiler outgoing steam characterize the influence of the first of mentioned above systems on the considered issue. The main and the reheated steam are in the area of dry steam, where an enthalpy is exactly defined by temperature and pressure [8]. So the temperature of the boiler's outgoing flue gases, the amount of the burned fuel and the content of oxygen in flue gases could be removed from measurement vector. The influence of removed parameters on temperature difference in the condenser is expressed by values of the temperature, pressure and flow of the boiler's outgoing steam. After the complete analysis, the measurement vector consisted of the working medium parameters. The generated active load was the only exception, but it was included into the parameter vector as the basic parameter of the power unit condition.

The received data vectors were divided into two equal sets. The first set consisted of previously obtained data and was used to teach the fuzzy model. The second one consisted of the data recorded later and was used to test the generated model.

3. The idea of applying fuzzy analysis

According to the formula (4) it is possible to calculate the value of the temperature difference in the condenser for every data vector. The temperature of the condenser's incoming steam is not included in the measured data; however, it is possible to calculate it according to the formula (9), assuming the partial pressure of the condenser's upper part steam as the pressure in the condenser. Thanks to it, the value of the temperature difference could be calculated using the conventional method. On the base of this value, it is possible to assess the generated fuzzy model. The generated fuzzy model estimates the values of the function (5). A fuzzy modelling does not provide the additional information of a process but enables making an analysis and the conclusions in cases where a conventional model does not exist or is insufficient [9]. Therefore, if possible, at the beginning, an analysis of the measured data and a determination of their informational contents should be carried out. It should be stated if the data is sufficient to create an accurate model. If not, it will be difficult to forecast the model behaviour [10].

According to the theory mentioned above, the temperature difference value is a function of five variables (5). So, the main objective of the fuzzy model is to estimate the area of the solutions in six dimensional space. Unfortunately, these variables are not measured parameters. Thus, it is necessary to analyse each variable and decide whether it is possible to estimate the value of the variable in the form (11).

$$z_i = f(p_1, \cdots, p_n) \tag{11}$$

where: z_i – variable of temperature difference function,
p_i – measured exploitation parameter,
n – amount of exploitation parameters.

If it turns out possible, then the objective of the fuzzy model will change in order to estimate the solution area in a *k-dimensional* space where $k \in (6, n+1)$.

The unitary steam load of a condenser d_s can be expressed as a function of a condenser's incoming steam mass flux and a heat exchange surface. The heat exchange surface is a constant value, so:

$$d_s = f(\dot{M}_{ps}) \tag{12}$$

but the condenser's incoming steam mass flux is not a measured value. At the same time, we can say that the working medium quantity is a constant value because the loses are compensated by a make-up water flux. It is possible to fix the interesting points in the working medium cycle. On the basis of the main steam flow, main steam enthalpy and thermodynamic parameters of the cycle, according to the mass and energy balance, it is possible to calculate the value of a flow and enthalpy for each point fixed earlier. One of such points could be defined as the outlet of a low-pressure turbine. So it is possible to estimate the condenser load steam as a function of the measured parameters.

The temperature of the condenser's outgoing cooling water is one of the measured parameters.

The velocity of the water flow in the condenser pipes depends on the face area and the flow intensity of the cooling water. The face area is a constant value for a given condenser. The flow intensity can be calculated according to the mass balance of the condenser (1). In this formula we can find the flow and the enthalpy of the condenser incoming steam, the enthalpy of condenser drips, specific heat of the cooling water which is a constant value and the temperature of the condenser's incoming and outgoing cooling water. The flow and enthalpy of the incoming steam were analysed above. The enthalpy of the condenser drips can be estimated using their temperature and the pressure in the condenser. The temperature of the condenser's incoming and outgoing cooling water are the measured values. So it is possible to estimate the value of the velocity as a function of the measured exploitation parameters.

The existence of air in the condenser can be expressed as a function of drips overcooling which could be calculated on the basis of the temperature of the condenser's incoming steam and the temperature of the drips. Both of them are measurable values. Additionally, the heat exchange surface fouling factor results in condensed pressure that increases. Currently, during the power unit exploitation it could be assumed as a quasi-constant value. We must also notice that the surface fouling upsets the condenser mass balance. In this research, the flow of cooling water was estimated on the basis of the mass balance. Thanks to it, the results of the heat exchange surface fouling are included in the analysis.

Finally, we can say that the measurement vector includes the necessary amount of the information to be the basis of the fuzzy model generation process.

4. Implementation of fuzzy logic in the field of exploitation parameters analysis

The fuzzy modelling process was based on the analysis of the measurement data recorded on a real industrial object. The main problem was to choose only significant inputs for the fuzzy model. This issue was performed according to the fuzzy curves theory [11]. To analyse the measured parameters of the power unit, a software application was created. The application enables the analysis of any measured data recorded in a correct form using the fuzzy curves theory changing the analysis parameters. Using the software, the analysis of the power unit exploitation parameters was carried out. On the basis of the analysis results, the most significant parameters for the considered process were selected as follows:

1. T_{pwn} – temperature of low pressure turbine outgoing steam,
2. p_{sk} – pressure in condenser,
3. T_{wchd} – temperature of condenser incoming water,
4. T_{wchw} – temperature of condenser outgoing water,
5. T_{kond} – temperature of condensate.

To shorten the time of the calculations, the measurement data was reduced using the reduction radius that equals 1%. The reduction process separated the groups of the measurement vectors placed closer than the assumed distance in the solution space according to the formula (9):

$$\underset{m_i m_j \in M}{\forall} \left| m_i - m_j \right| < \tau \tag{13}$$

where: m – set of measurements,
τ – reduction radius.

This process decreased the amount of the measurement vectors to *2250*.

The fuzzy model generation was carried out on the basis of the measured data, using the genetic algorithms according to the iteration method [12]. The generation method was implemented in the form of software application. The application can generate a fuzzy model of any MISO or SISO objects. To check the model accuracy the quality measures presented below were used (14) – (18).

$$\delta_{\max} = \max\{ \underset{m_l \in M}{\forall} \frac{\left| y(m_l) - Y(m_l) \right|}{y(m_l)} \} \tag{14}$$

where: δ_{max} – relative maximum error,
$y(m_l)$ – output of object for m_l sample,
M – set of measurement samples,
$Y(m_l)$ – output of model for m_l sample.

$$\delta_{\min} = \min\{ \underset{m_l \in M}{\forall} \frac{\left| y(m_l) - Y(m_l) \right|}{y(m_l)} \} \tag{15}$$

where: δ_{min} – relative minimum error

$$\delta_{śr} = \frac{1}{2 \cdot p} \sum_{m_l \in M} (y(m_l) - Y(m_l))^2 \tag{16}$$

where: $\delta_{śr}$ – mean square error
p – amount of measurement samples

$$\delta_{śrw} = \frac{1}{(y_{\max} - y_{\min})}\sqrt{\frac{\sum_{m_l \in M}(y(m_l) - Y(m_l))^2}{p \cdot (p+1)}} \tag{17}$$

where: $\delta_{śrw}$ – relative mean square error

$$r_{yY} = \frac{\sum_{l=1}^{p}(y(m_l) - \overline{y}) \cdot (Y(m_l) - \overline{Y})}{\sqrt{\sum_{l=1}^{p}(y(m_l) - \overline{y})^2 \cdot \sum_{l=1}^{p}(Y(m_l) - \overline{Y})^2}} \tag{18}$$

where: r_{yY} – correlation function.

The created fuzzy model was tested using the testing data set. According to the project assumptions, the testing data set samples with the values exceeding the limits of the parameters established on the basis of the learning data set were removed. The testing data set consisted of 15420 samples. The results of the model testing are presented in the table at the end of this paper (Table 4). The value of the correlation function is on satisfying level. The number of rules is rather low so the response time of the model could be very short. The most important is the value of relative mean square error. This value is very small. It means that created fuzzy model is of the very good quality.

Conclusions

Analysing the obtained results, we can say that the quality of the fuzzy model is quite good, especially the value of the relative mean square error, which is very small. The experiment carried out proves the correctness of the algorithms and methods used. Looking at the results of the modelling of the temperature difference in the condenser, we can say that the implemented methods enable the creation of a model on the basis of the information in the entangled form. The industrial character of the considered problem makes the application of the designed solution easier.

Table 2. List of exploitation parameters

No.	Exploitation parameter	Comment
1.	Power unit operation point	
2.	Active load	
3.	Reactive load	
4.	Load of tap transformer	
5.	Demand load of primary load control	
6.	Demand load of secondary load control	
7.	Rotary speed of turbine shaft	
8.	Temperature of turbine incoming main steam	left and right side of the turbine
9.	Pressure of turbine incoming main steam	left and right side of the turbine
10.	Pressure of HP turbine outgoing steam	left and right side of the turbine
11.	Temperature of HP turbine outgoing steam	left and right side of the turbine
12.	Pressure of boiler outgoing reheated steam	left and right side of the turbine
13.	Temperature of boiler outgoing reheated steam	left and right side of the turbine
14.	Temperature of LP turbine outgoing steam	left and right side of the turbine
15.	Pressure in condenser	left and right side of the turbine
16.	Temperature of condenser incoming cooling water	left and right side of the turbine
17.	Temperature of feed water	
18.	Temperature of boiler outgoing flue gases	left and right side of the turbine
19.	Temperature of condenser outgoing cooling water	left and right side of the turbine
20.	Temperature of condensate	
21.	Flow of cooling water	
22.	Pressure in degassing tank	
23.	Flow of make-up water	
24.	Temperature of steam in turbine	extraction number 1,2,3,4,5,6,7
25.	Pressure of steam in turbine	extraction number 1,2,3,4,5,6,7
26.	Temperature of heat exchanger no 5 outgoing water	
27.	Temperature of heat exchanger no 6 outgoing water	
28.	Amount of secondary injections	left and right side of the turbine
29.	Amount of burned coal	
30.	Amount of burned oil	
31.	Flow of boiler outgoing steam	left and right side of the turbine
32.	Content of oxygen in rotary air preheater incoming flue gases	left and right side of the turbine
33.	Content of oxygen in rotary air preheater outgoing flue gases	left and right side of the turbine
34.	Content of CO in flue gases	left and right side of the turbine

Table 3. Operation points of power unit

No.	Name of operation point
1.	Overhaul
2.	Stand-by
3.	Total shutdown
4.	Start of start-up
5.	Running for supply of auxiliaries
6.	Synchronous stable operation
7.	Ready to automatic load control switching on
8.	Execution of automatic load control
9.	Declaration of primary load control operation
10.	Execution of primary load control
11.	Declaration of fast changeable load control operation
12.	Execution of fast changeable load control
13.	Load control execution with fixed current point of power generation
14.	Manual load control execution

Table 4. Quality measures of temperature difference fuzzy model

Minimum error [%]	0.0030
Maximum error [%]	44.1898
Correlation [%]	83.3495
Mean square error	0.1366
Relative mean square error [%]	0.0754
Amount of maximum error samples	1
Rules amount	21

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Reviewer:
Janusz A. KACPRZYK

Modelowanie rozmyte wartości parametrów eksploatacyjnych

Słowa kluczowe

Modelowanie rozmyte, algorytmy genetyczne, analiza rozmyta, duże systemy przemysłowe, modelowanie lingwistyczne.

Streszczenie

Do poprawnego sterowania procesem eksploatacji niezbędna jest znajomość wartości parametrów eksploatacyjnych w każdy momencie procesu. Jest to szczególnie istotne w przypadku dużych obiektów przemysłowych. Większość parametrów jest mierzona w sposób ciągły. Występują jednak parametry, które są wielkościami wyliczalnymi. Wartości parametrów wyliczalnych określane są na podstawie wielkości mierzonych. Nie zawsze jednak parametry wejściowe do obliczeń są zawarte w wartościach mierzonych w formie jawnej. W opracowaniu zaprezentowana została metoda modelowania rozmytego pozwalająca na stworzenie modelu procesu w przypadku, gdy dane wejściowe dostarczone są w postaci uwikłanej. Jako przykład zastosowania metody przedstawiony został sposób opracowania modelu rozmytego spiętrzenia temperatury w skraplaczu turbiny parowej *13K215*.