MODELLING HP STEAM GENERATOR WITH FUZZY FEEDFORWARD CONTROL SYSTEM

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Abstract

Currently, a lot of attention is given to the environment. The energy industry has a great influence on this situation. In this area, there is an effort to increase efficiency and achieve smaller energy losses and fewer environmental effects. One of the ways to achieve higher efficiency is to design a new control structure. Steam generator is one part of the thermal power plant. This paper is engaged in design of alternative high pressure steam generator output temperature control. Current feedback control system is designed with conventional PI controllers with variable parameters in the cascade connection. We have six valves as actuating values. This system is relatively complex and supplemented by a number of feedbacks accelerate. This paper describes a possible method of substituting an optimally set feedback PI-controller for fuzzy feedforward control. The principle is based on the direct relation between the value of power level and valve setting, which is applied through fuzzy logic. Testing and experiments proceed on a developed non-linear simulation model. The paper presents different variants of generating influencing values for the various deffuzification methods or a different selected power sequences. The resulting output temperatures are compared with obtained feedback control curves.

Keywords: steam generator, fuzzy logic, feedforward control, nonlinear model, cascade control structure.

Presenting Author's biography

Tomáš Náhlovský. Tomáš Náhlovský graduated from on Technical university of Liberec with a degree in Automatic Control and Computer Engineering. Currently, he is pursuing his PhD degree in Technical Cybernetics at Technical University of Liberec. His research interest lies in advanced technologies, control systems and modeling in the special focus on the power engineering. Tomáš Náhlovský passed out 3 month Erasmus internship at the Chemnitz University of Technology, Germany. He was concentrated on the Institute of System Theory by Prof. Dr. sc. techn. Steffen F. Bocklisch on the fuzzy control.

1 General

1.1 Non-linear model

It is necessary to have a model of technological unit for the control design strategy. Block structure of steam generator is shown in Fig.1. The full nonlinear model based on distributed parameters in space is developed by means of software called Matlab. Simulation model of high power steam generator - super heaters is based on some fundamental ideas and assumptions. The medium pressure steam generator is based on the same principles. An approach chosen as optimal is based on the calculation of thermal dynamics of the media directly in the real physical quantities. Model of control system can then work with the actual values of temperature, flow and pressure, as in real operation.

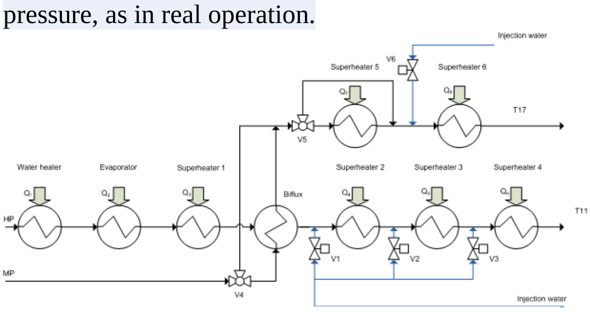

Fig.1 - The block structure of steam generator

An important prerequisite for construction of the model is a priori knowledge of the thermal inputs delivered to the various construction units. These thermal inputs can be ascertained from static balance calculations. Important is the influence of pressure. The model includes only the algebraic calculation of static pressure loss. Each of the heat exchangers will be described separately and we come out from balance equations of mass and energy in the distributed parameters [1] [2]. Considering to the structural dimensions of heat exchangers they are distributing parameters only in the axis of steam flow. These equations are discredited in space, adapted and the equations Eq.1 of steam thermal dynamics in the heat exchanger are finished.

$$\frac{d\mathbf{T}}{dt} = \frac{\dot{m}}{\Delta V}\cdot\mathbf{\Gamma}\cdot\mathbf{T} + \frac{L}{\Delta V}\cdot\mathbf{\Psi}_c\cdot\dot{\mathbf{q}} + \mathbf{\Omega}\cdot\frac{\dot{m}\cdot T_0}{\Delta V\cdot\rho_1} \tag{1}$$

T is the vector of the heated media temperature into individual sections.

$$\mathbf{T} = \begin{bmatrix} T_1 & T_2 & \dots & T_n \end{bmatrix}^{\mathrm{T}} \tag{2}$$

$$\mathbf{\Psi}_c = diag\left(\frac{1}{\rho_1\cdot c_{p1}} \quad \frac{1}{\rho_2\cdot c_{p2}} \quad \dots \quad \frac{1}{\rho_n\cdot c_{pn}}\right) \tag{3}$$

Moreover, the steam interaction must add with the surroundings, thus tube. It can be used to the equation Eq.4 of balance.

$$\frac{d\mathbf{T}_{Fe}}{dt} = \frac{1}{m_{Fe}\cdot c_{Fe}}\cdot\left(\dot{\mathbf{Q}}_{dodané} - \alpha\cdot S\cdot\left(\mathbf{T}_{Fe} - \mathbf{T}\right)\right) \tag{4}$$

These two sets of equations Eq.1, Eq.4 define the complete thermal dynamics of the media and tube heat exchanger. Nonlinear model is developed by Simulink in Matlab. With this model it is possible to upgrade the existing control system or completely remove it and replace it with another form of control. A more detailed description of the thermal dynamics of steam super heaters and other parts of the flow in the boiler are in [3] [4].

1.2 The current control system

Dynamics of steam temperature at the output of the superheaters is a high order and is complicated by the inherency of significant nonlinearities and time delay. In principle it is a multi-dimensional system with decentralized control. The result is the interaction between the controller loops. The cores of the current control system are conventional PID controllers and circuits of generating the desired values. A proportional, integral and derivative component of the controller has been fluctuating at given intervals, depending on the performance and the immediate parameters of the boiler. HP steam generator is controlled by 6 PI controllers and MP steam generator by 3 PI controllers with variable parameters in the cascade. It is shown in Fig.2 and Fig.3.

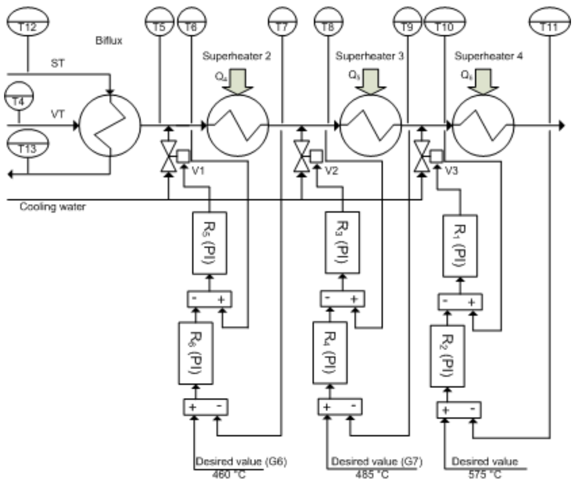

Fig.2 - The cascade control of HP steam generator

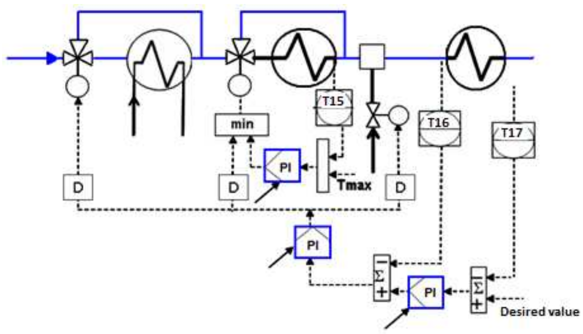

Fig.3 - The cascade control of MP steam generator

Conventional PI controllers are more difficult to balance with nonlinear phenomena and disturbance. The aim is to find new sophisticated control method that will respond better to possible changes and ensure quality control processes. In this context, the possibility of

- model predictive control
- robust control
- fuzzy control

are discussed.

1.3 The fuzzy strategy option

Concept for an alternative form of steam generator control using fuzzy principles can be achieved by means of:

1. Parameters of PI-controllers were set manually. These parameters can be adjusted using fuzzy algorithms.

2. PI-controllers can be substituted directly through the fuzzy PI-controllers. [5] [6]

In these cases, the cascade structure is maintained. Another option is to use fuzzy control theory of nonlinear dynamic systems. Providing that the current feedback structure is designed optimally, we can try to replace these difficult relations with feedforward fuzzy control and the resulting implementation is to give the same results as the previous optimally set PI-controllers. There are two options how to achieve this goal:

3. Through direct fuzzy setting of actuating values using IF-THEN rules.
4. Using the Fuzzy-Pattern classification - Fuzzy modeling with local models [6], [7]

This paper discusses the possibility of using method No.3.

2 Data base

A current control strategy uses cascade connect PI controller with variable parameters. The change of parameters is directly dependent on the performance and the immediate parameters of the boiler. This feature is used in the method of compensation for the feedforward fuzzy control. For the ideal setting of classical PI control, temperature, pressure, flow, temperature, are used data in various nodes of technological systems and their introduction into the feedback loops. These are difficult structures because they are used to accelerate coupling from the controller output to its input.

For each power level in range of 50-100% the values of these input parameters (temperature, pressure, flow, temperature) are generated, which ensure steady state of output temperature. There is a linear dependence of the input parameters on the value of electrical power level. Furthermore, there is a relation between the power level and actuating value, thus opening the valves because the input parameters affect the parameters of controller. Relations between variables are shown in Fig.4.

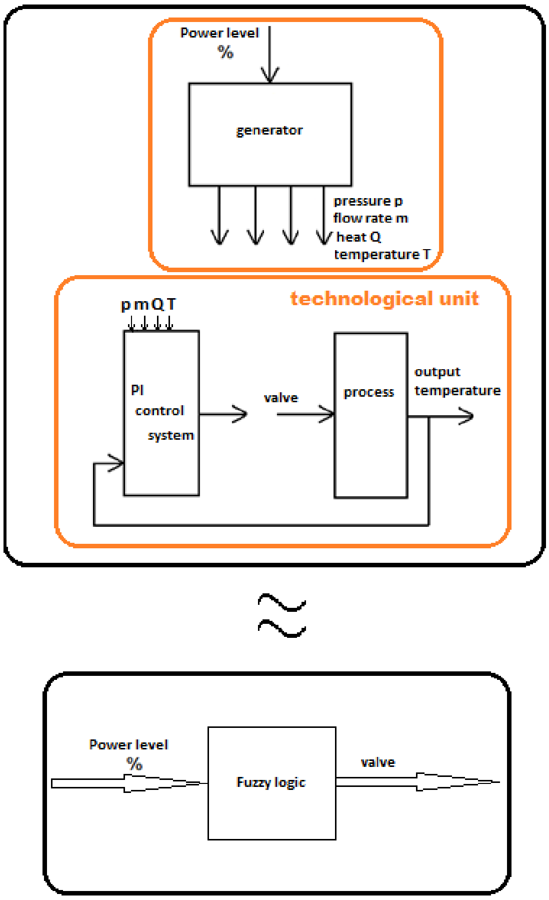

Fig.4 – relations between variables

Therefore we only use time waveforms of valve setting as a dynamic response to change power levels to design fuzzy control. These values can be determined from the nonlinear simulation model. Other measured variables: temperature, pressure, flow etc. We do not consider these to the design and we use the direct link between the power level and opening the valves. Entry into the fuzzy logic is a value of power level and at the output of the fuzzy logic generates the opening of the valve. Other measured values can be used for feedback monitoring.

3 Experimental design

The aim is to use fuzzy logic to generate depending on the current power level of such waveforms of actuating values, which generates a classical PI controller. The six valves are used to control and in this article we approached the design of valve V2. Other valves are designed similarly. Design consists of two parts. The first part is static.

3.1 The static part

There are time waveforms of individual valves for different changes of power levels. In Fig. 5, there are time waveforms of valve V2 for steps of power level from 100 to 90,100-80,100-70,100-60%. The graph shows that the waveforms show a dynamic similarity in the transient performance. Each waveform has a first drop, and next the local maxima and minima of similar form to the steady state.

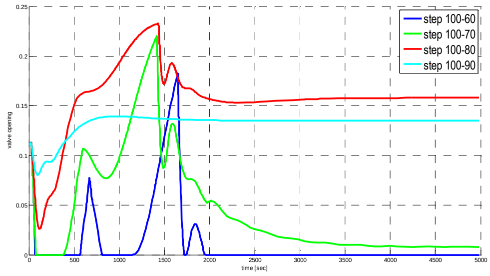

Fig.5 – Opening of the valves in time

Among these waveforms, we can find similarities that facilitate the design of fuzzy. First, steady-state values of valves are marked for each power level (100, 90, 80, 70, and 60%) after transient performance. These values in the design of fuzzy have the membership degree $\mu = 1$ and membership functions for individual performance levels are done. In Fig. 6 are shown fuzzy membership functions for steady-state values of valve V2.

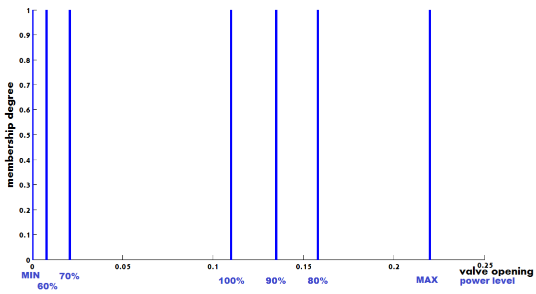

Fig.6 – opening of the valves in time

The smallest valve openings is 60% and further increase the value of the sequence 70, 100, 90 and 80%, which is the highest value of the valve opening. On the Fig.7 is an example for waveform of valve V2 for changing the power level 100-70%. At the start waveform size of the valve opening corresponds 100% and at the end 70%. Another step is a sign of other important points in the graph. The graph shows that in the waveforms are included local maxima or minima. The values of these peaks can be assigned to the values of power levels. They are assigned to correspond with the values of the valve opening for steady power level. Oddities may occur during the waveform - maxima and minima.

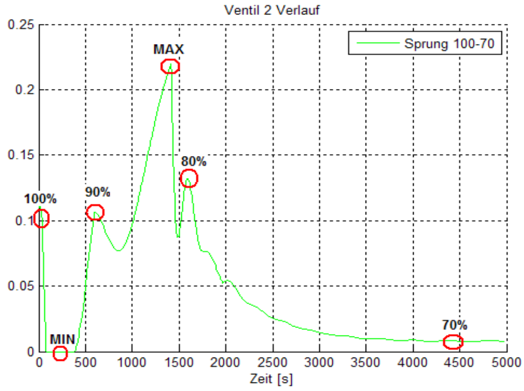

Fig.7 – mark of power sequence

By designation of significant points we obtain a sequence of 100-Min-90-Max-80-70, after which the fuzzy logic switches. For the lucidity switching is drawn in 3 figures.

First, membership functions are suggested for transitions between levels 100 and Min. Fig.8. The second graph Fig.9 is realized by switching from the Min-90-Max and the last picture transitions between the Max-80-70 are indicated Fig.10.

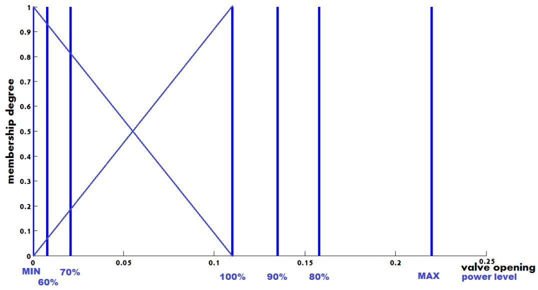

Fig.8 – switching between 100-Min

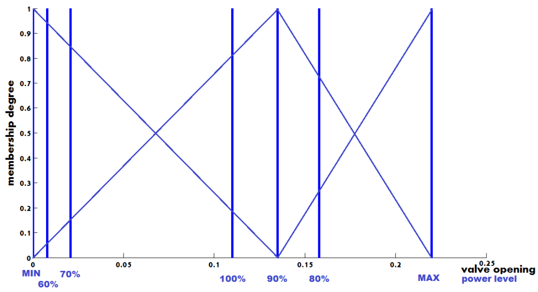

Fig.9 – switching between Min-90-Max

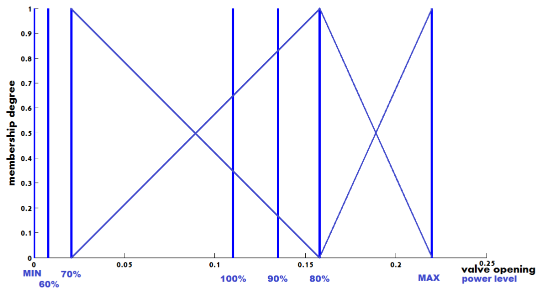

Fig.10 – switching between Max-80-70

The next step is to identify the type of membership function. You can choose triangular functions, trapezoidal or Gaussian. In our model, the type of triangle function is chosen. After modeling this section the change of power level 100-70% is generated at the output of fuzzy control waveform of valve V2. It is shown in Fig.11. In comparison with Fig.7 this waveform accepts the static part, but not its dynamic part.

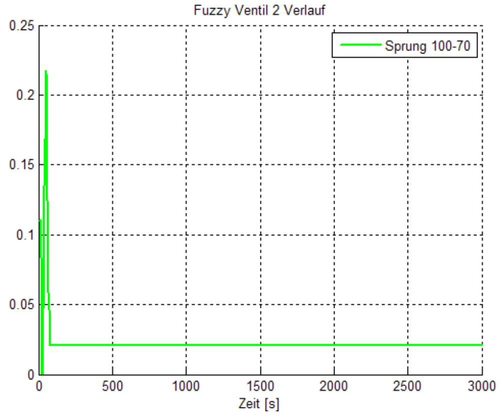

Fig.11 – valve opening

3.2 The dynamic part

With regard to that the value of the valve is set according to current power levels, it is necessary to consider another part in the design. During the desired change of power level, it will switch very quickly. In approximately 100 seconds. Therefore, the response at the output of fuzzy logic is also very fast. With regard to that the technological unit is extensive, there is a time delay and the complex system response is hundreds of seconds slower. Therefore, we need the second part in the design; which will ensure the dynamic part of the process. We put a delay block with at least one member of the dominant time constant - exponential function between power levels and the fuzzy input. Fig.12. This section provides slowing-down switching power levels to reflect the real situation.

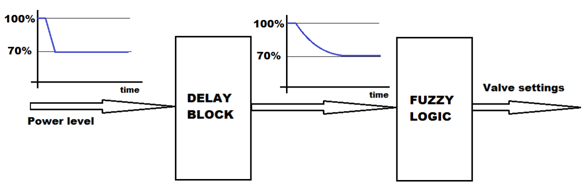

Fig.12 – Fuzzy logic with delay block

From the Fig.7 we get a table of data where power levels can be assigned to the appropriate time. Tab.1.

Time [sec]	Power level [%]
0	100
614	90
1596	80
5000	70

Exponential function is shown below Eq.5:

$$Powerlevel = a \cdot \exp^{-b \cdot time} + const. \qquad (5)$$

E-function parameters are calculated by using the method of least squares. Fitting an exponential function points is shown in Fig.13.

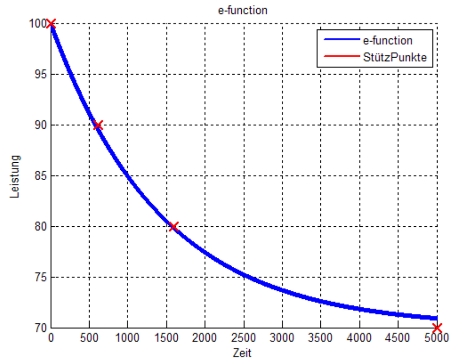

Fig.13 – fitting exponential function

4 Achieved results

4.1 Valves waveforms

On the Fig.14 is a comparing the waveforms of valve V2 between PI control system and fuzzy feedforward control.

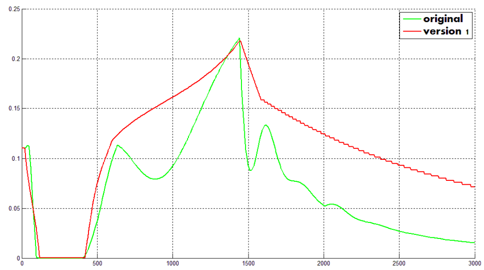

Fig.14 – comparing valve waveform V2 fuzzy and PI

On the pictures Fig.15 and Fig.16 are images of other valves for the various possibilities of fuzzy set. There are changes in the use of other deffuzification methods or other indications of power levels in waveform (Not necessary only in local extremes).

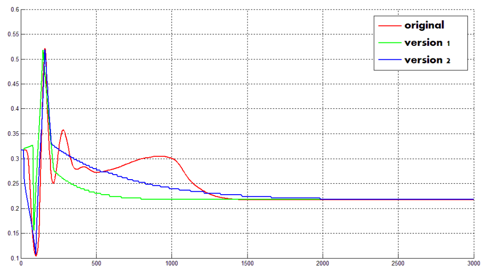

Fig.15 – comparing valve waveform V5 fuzzy and PI

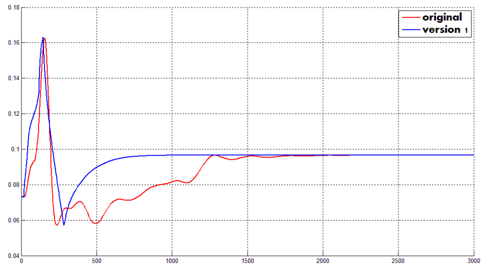

Fig.16 – comparing valve waveform V6 fuzzy and PI

4.2 Outputs temperatures

The pictures show two controlled output temperature. We compare the classical PI control system and fuzzy feedforward control. While using fuzzy feedforward control it is achieved a better waveform for the final temperature of MP steam generator (green color). Fig 17. Waveform of the output temperature steam generator HP is worse. Fig 18.

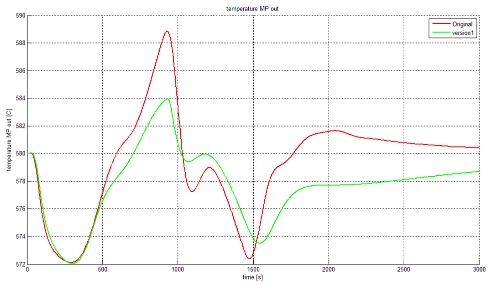

Fig.17 – MP output temperature

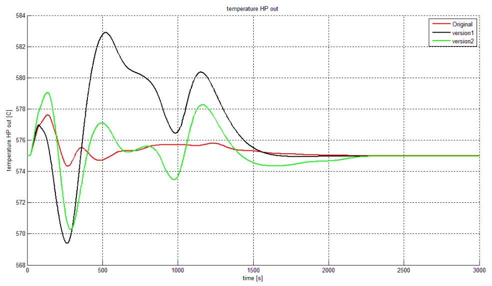

Fig.18 – HP output temperature

The article describes the possibilities of modeling fuzzy feedforward control which is achieved by simplifying the control structure, which is only depending on the value of performance levels. Feedforward fuzzy controls designed above are confronted with the waveforms obtained by a classic control and they are presented in the article.

5 ACKNOWLEDGEMENT

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