Thom’s Catastrophe Theory used in Soft Computing as Tool for Real-Time Control of Steam Production

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Abstract: *This paper includes the description of steam production process control by the application of Thom’s catastrophe theory. The steam production can be featured by Van der Waals’ curves which compose a surface. The transformation of surface on the P-T plane is a typical peak catastrophe, therefore, the complex technology of steam production consists of catastrophe events. Catastrophe events, the water-steam-water transfers can be described by IF-THEN sentences. As IF-THEN sentences are also used in fuzzy logic control, so catastrophe descriptions include the opportunity the application of soft computing, the fuzzy neural control.*

Keywords: *real-time, catastrophe, fuzzy*

1 Introduction

The control of extremely slow or fast processes gives a lot of trouble in monitoring of changes which means that some values occurred during running of process would be missed or mistaken. When the sampling rate is high, then a lot of unnecessary data will be collected, and the data processing will require longer duration, therefore real-time feature of control operations could be lost. When the sampling rate is low, then critical points of controlled technology might be taken over, therefore the operation will be running out of optimum control and a lot of important data will be missed. These problems would be concentrated in such real-time controlled systems where the controlled technology includes extreme fast and extreme slow sub-technologies. These troubles might be eliminated by the application of Thom’s catastrophe theory in soft computing methods.

2 Control of steam production

The technological system of steam production at heat power station has been involved into a multilevel dynamical control system. The control system has been divided into hierarchical units which have been running autonomously, and are connected to any subsystem. The central control system has collected the pre-processed data originated from the subsystems, and computed the generalized data to describe the temporary statement of steam production technology. The control subsystem is the local supervisory control of a technological unit of steam production.

Subsystems of steam production are the following ones:

- feed water level control in the steam drum,
- temperature control of outlet steam,
- combustion control which consists of the following subsystems:
- burner control,
- control of inlet fresh air quantity,
- control of removal of flue gas
- control of outlet steam pressure.

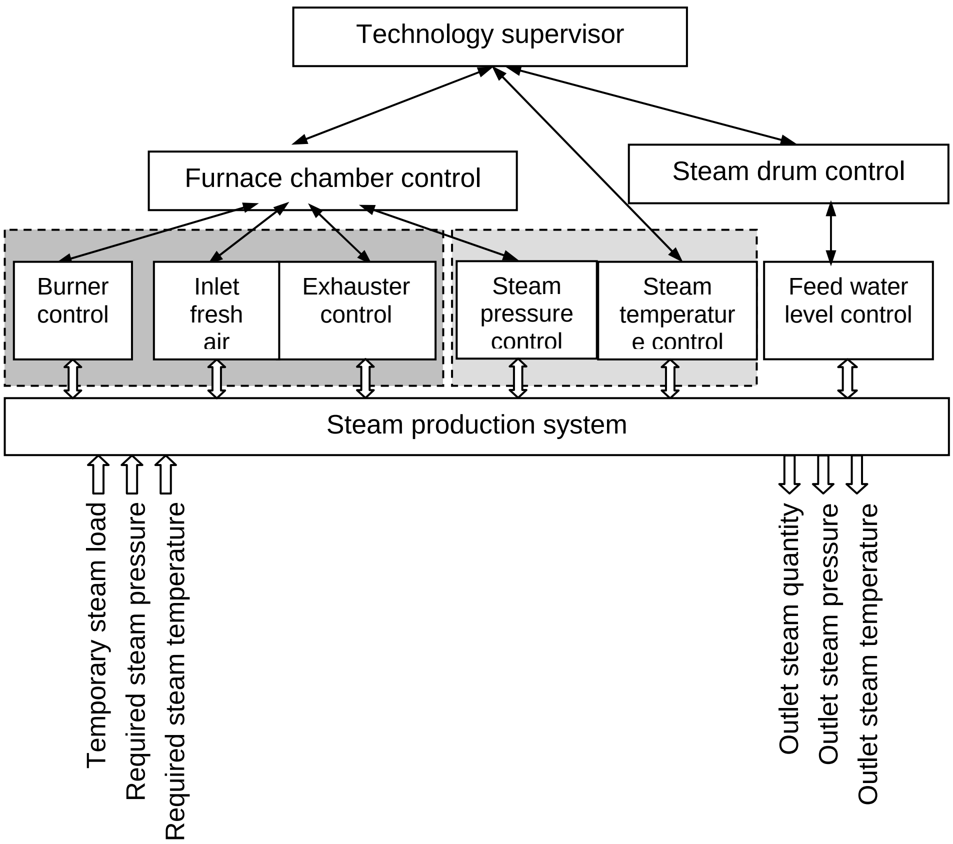

Figure 2.1. Hierarchical control strategy for the large-scale system of steam production

The process control is based on a hierarchical control strategy with the following features:

- the hierarchical system consists of decision-making components structured in a pyramid shape,
- the system has an overall goal, the required quantity of steam with required features,
- the various levels of hierarchy in the system exchange information among themselves iteratively,
- as the level of hierarchy goes up, the lower-level components are faster than the higher-level ones.

The hierarchical control system of steam production in the heat power station includes three levels as it can be seen in Figure 2.1. They are the following: level of technological operations, level of large-scale subsystem control, and level of supervisory control of technology. The controlled output parameters of the system are the steam quantity, the outlet steam pressure, and the outlet steam temperature which are influenced by the the temporary steam load, the required steam pressure, and the required steam temperature.

The steam production system has three subsystems, the system of steam generator colored with gray, the system for adjusting output parameters colored with light gray, and the feed water level control. The control system includes a large-scale system for the furnace chamber, a large-scale system for setting the output steam parameters, and a large-scale system to regulate the level of feed water in the steam drum. These large-scale systems have to be divided into small-scale subsystems by the application of method decomposition, and the supervisory process makes the coordination of subsystems.

2.1 Control system for the steam production technology

The steam production technology has two main units, the steam generator, and the temperature setting unit shown in Figure 2.2. The steam generator produces the steam featured with p_{st1}, T_{st1}, and the temperature setting unit, the superheater will regulate the temperature of output steam. Black colored arrows mean controlled parameters.

The heat production is set by the combusted quantity of fuel $\dot{V}_{fl}$, water level in the drum is set by the regulation of feed water quantity $\dot{m}_{fw}$. The combustion requires a proper quantity of fresh air $\dot{m}_{fa}$, and the flue gas must be exhausted.

The output steam of steam generator $\dot{m}_{st1}$ is flown to the superheater, where the required temperature of outlet steam is set by superheating and water injection. All of these parameters, the pressure and the temperature of outlet steam depends on the steam load. In

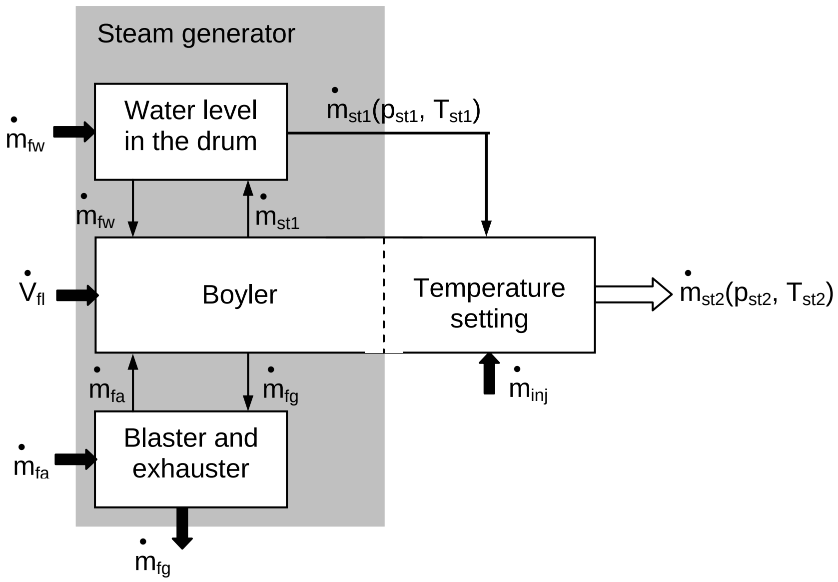

Figure 2.2. Controlled parameters of steam production technology

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2.2. Control system for the steam generator

Technological subsystem, the steam generator requires hierarchical control. All the controlled parameters signed with black colored arrows are depended on each other, and the output data. Changing of outlet steam features, the steam load, and the temperature, and the pressure occur the changing of input settings. It seems, the control system requires a *multiple inputs/outputs fuzzy inference system.* MFIS applied for control the steam production system can be seen in Figure 2.3.

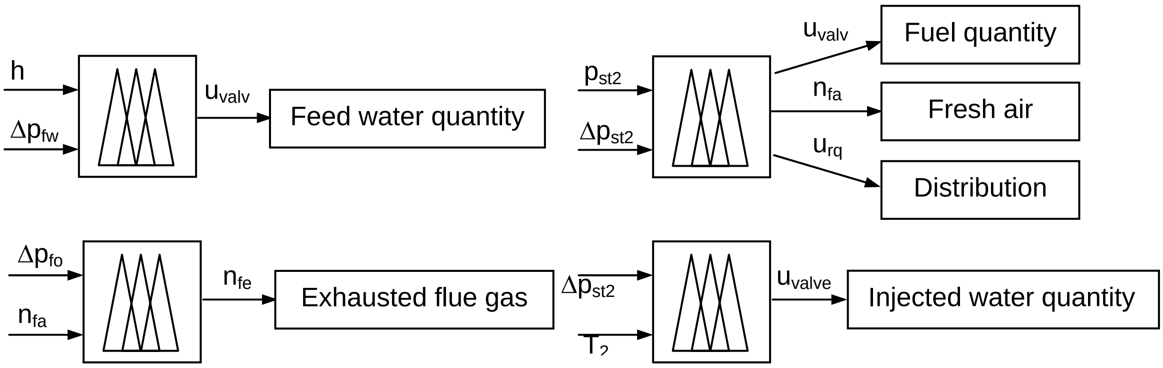


Figure 2.3. Structure of FISs for the control of steam production system

2.2.1. Fuzzy system for feed water level control in the steam drum

The control will start after the setup of the drum has been finished, i.e. the drum has been filled by water over the level *lower interlock*, at least. The water level in the steam drum is controlled by the measured values of actual water level height *h* and steam load $\dot{m}_{st1}$ in accordance with the following rules:

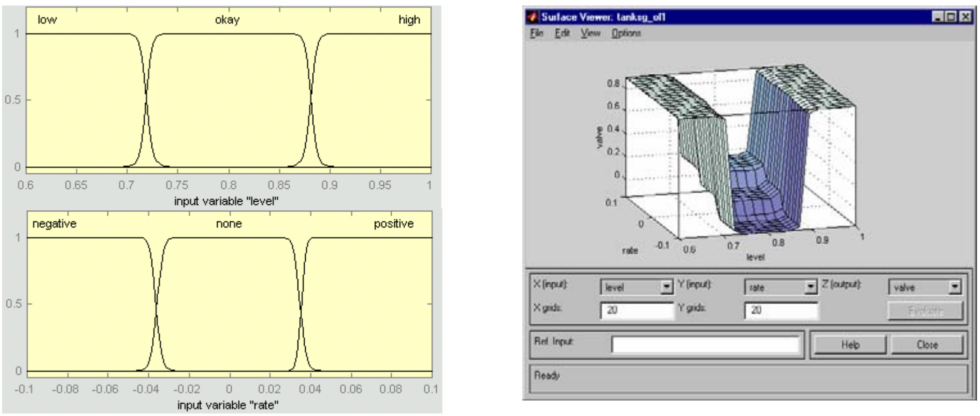


Figure 2.4. MFs of FIS for control of feed water level in the steam drum

Description of FIS has been developed with MATLAB fuzzy toolbox.. MFs of the FIS shown in Figure 2.4 are bell-shape ones at the inputs, and the output is constant value of voltage for setting the discharge area of feed water valve computed by Sugeno's rule.

Groups of inputs and outputs are the following ones:
Input1 consists of three MFs which are *low, high,* and *optimum*.
Input2 includes the direction of changing of water level: *negative*, *positive*, and *none*.
Output1 group of outputs is described by the followings which are voltage values for changing the discharge area of feed water valve: *close_fast, close_slow, open_slow*, and *no_change.*

Three ramps inside the optimum range of level are meaning the activities of control system. When the working point is on the upper ramp the valve is closing slowly, when the working point is on the lower ramp the valve is opening slowly, and when the working point is on the medium ramp the valve does not change. Changing between ramps is staggered. Otherwise, when the level is equal or under the lower interlock or equal or over the upper interlock levels the valve will close fast and an alarm signal will be generated.

2.2.2. Fuzzy system for control the furnace chamber

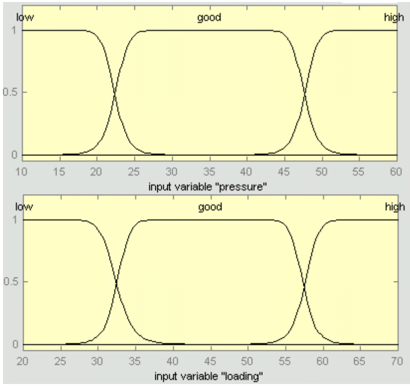
Processes in the furnace chamber require control for the burner's power by changing the quantity of combusted fuel, and control for internal pressure of furnace chamber. The blasted fresh air quantity is set by changing the revolution number of blaster ventilator, and the quantity of exhausted flue gas is set by changing the revolution number of exhauster ventilator. The exhauster has to be produce the appropriate pressure to output the generated flue gas

The required power of burners are depended on the steam load and the output pressure. Since these parameters affect on each other, the fuzzy logic system is a *two-input three-output Sugeno FIS.* The control system is based on the following preconditions:

- if the steam load is smaller than the technical minimum value then the steam production will be stopped;
- if the steam load raises over the maximum then a request will be sent to the load distributor of supervisory system to change the load.

MFs shown in Figure 2.5 are bell-shape ones at the inputs, and the outputs are constant values of voltage for setting the discharge area of fuel valve and revolution numbers of blaster and exhauster ventilators computed by Sugeno's rule.

Groups of inputs and outputs are the following ones:
Input1 'pressure' includes three MFs: *low, good,* and *high*.
Input2 'loading' has the following three MFs: *low*, *good*, and *high*.
Output1 'fuel_valve' group of outputs is described by the followings which outputs are voltage values for changing the discharge area of fuel valve of burner's: *close_fast, close_slow*, *no_change*, *open_slow*, and *open_fast*.



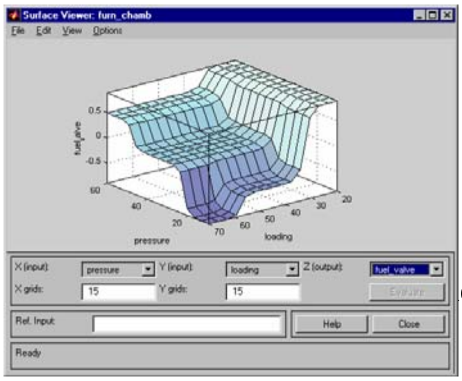


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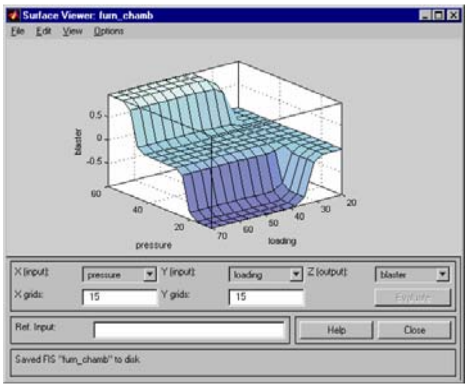
Figure 2.5. MFs of FIS for the furnace

Figure 2.6. Fuzzy control for setting the fuel valve by Sugeno's rule



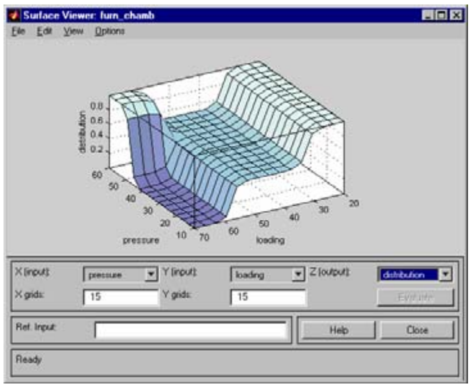


Figure 2.7. Fuzzy control for the blaster ventilator by Sugeno's rules

Figure 2.8. Fuzzy control for request changing of load distribution by Sugeno's rule

Output2 'blaster' includes rules for setting the revolution number of blaster ventilator by the followings:*reducing*, *no_change*, and *rising*.
Output3 'distribution' includes rules for request of changing the load distribution among the steam generators by the followings: *disconnect*, *no_change*, and *request*.

The setting of fuel valve is shown in Figure 2.6. When the loading is under the technical minimum then the burner will switched off because the operating of steam generator would be no economic.

Figure 2.7 shows how the revolution number of blaster ventilator is controlled by the pressure and outlet quantity of steam. It seems that the control process is also influenced by the steam load and pressure under the technical minimum and over the maximum capacity.

When output parameters of steam generator has changed sharp then those changes affects on the outlet steam quality. Therefore, load distribution among the steam generators the steam load and pressure under the technical minimum and over the maximum capacity.

When output parameters of steam generator has changed sharp then those changes affects on the outlet steam quality. Therefore, load distribution among the steam generators must be modified. Figure 2.8 shows the control of distribution request by single steam generator to the distribution system.

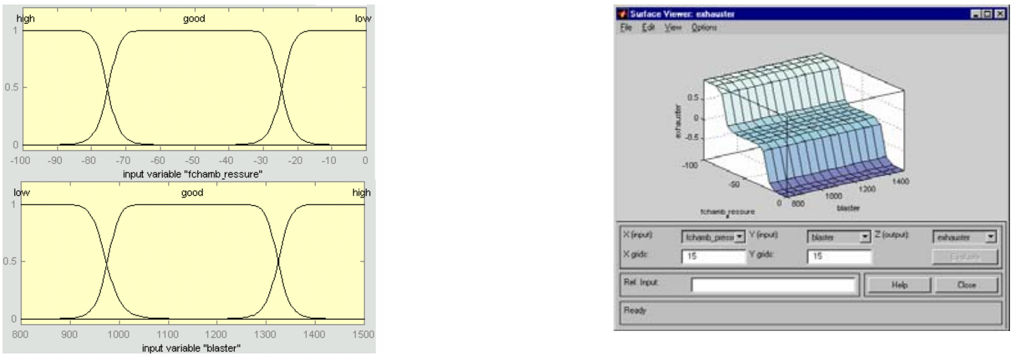


Figure 2.9. MFs of FIS for control of revolution number of exhauster ventilator

A controlled parameter of furnace chamber is the chimney draught too, which is necessary to remove the flue gas. The produced chimney draught is set by the power of blaster ventilator and the power of exhauster ventilator. The revolution number of exhauster ventilator is controlled in accordance with the required value of chimney draught and revolution number of blaster ventilator. The FIS for control the revolution number of exhauster ventilator is a *two-inputs single-output Sugeno FIS*.

Membership functions of the FIS shown in Figure 2.9 are bell-shape ones at the inputs, and output is constant values of voltage computed by Sugeno's rule for setting the revolution number control of exhauster ventilator.

Groups of inputs and outputs are the following ones:

Input1 'fchamb_pressure' has three MFs: *low*, *good*, and *high*.

Input2 ‘blaster’ means the appropriate revolution number of blaster ventilator which has been set in accordance with the required fresh air quantity for the combustion described above.
Output1 ‘exhauster’ includes rules for setting the revolution number of exhauster ventilator by the followings: *reducing*, *no_change*, and *raising*.

2.3. Fuzzy system for control of outlet steam temperature

The outlet steam temperature is controlled by setting of injected water quantity which is changed by the setting of discharge area of injected water valve. The temperature of outlet steam is controlled by the temporary steam load measured by orifice differential and the measured temperature before the second superheater. The inputs of temperature setting device are the temporary steam load computed from the orifice differential Δp_{st2} measured at the output, and the intermediate temperature T_2. Therefore, the FIS for control the outlet steam temperature is *two-inputs single-output Sugeno FIS*.

MFs of the FIS shown in Figure 2.10 are bell-shape ones at the inputs, and output is constant values of voltage computed by Sugeno’s rule for setting the discharge area of injected water valve.

Group of inputs and outputs are the following:
Input1 includes the following MFs: *low*, *good*, and *high*.
Input2 consists of the following MFs: *low*, *good*, and *high*.
Output1 ‘inj_valve’ includes rules for setting discharge area of injected water valve by the followings: *open_fast*, *open_slow*, *no_change*, *close_slow*, and *close_fast*.

Figure 2.10 includes control function of discharge area of injected water valve where the discharge area is setting by the voltage switched on the motor of valve.

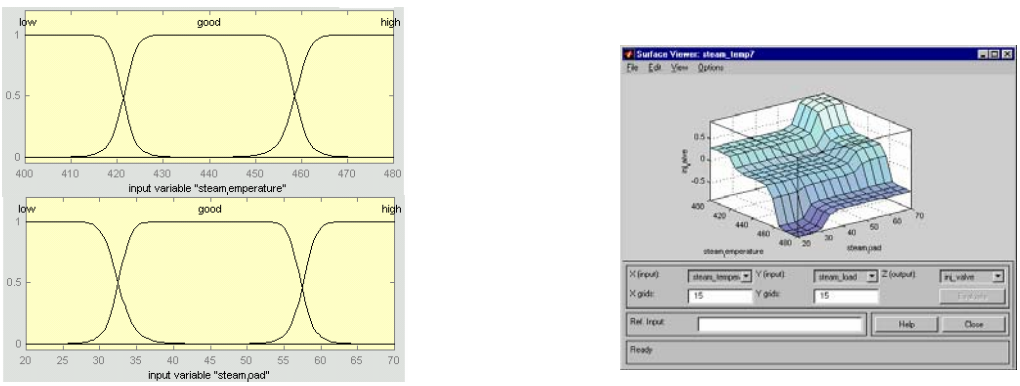


Figure 2.10. MFs of FIS for control of discharge area of injected water valve

2.4 The supervisory control as fuzzy neural network

Heat power stations include more steam production systems with different capacities in individual steam load. The optimum of energy application depends on the distribution of steam load among the individual boilers. The suitable energy application will minimize the environment pollution, therefore it is required that the steam load on heat power station would be divided in accordance with the ratio of nominal loading of individual boilers.

The scheme of supervisory system is shown in Figure 2.11. It seems, the computation of m_i is made by the supervisory control, and the influences on fuzzy neurons, the control subsystems of individual boilers are propagated backwards. Input variables are the measured parameters on the output, but there are some secondary parameters measured in the individual

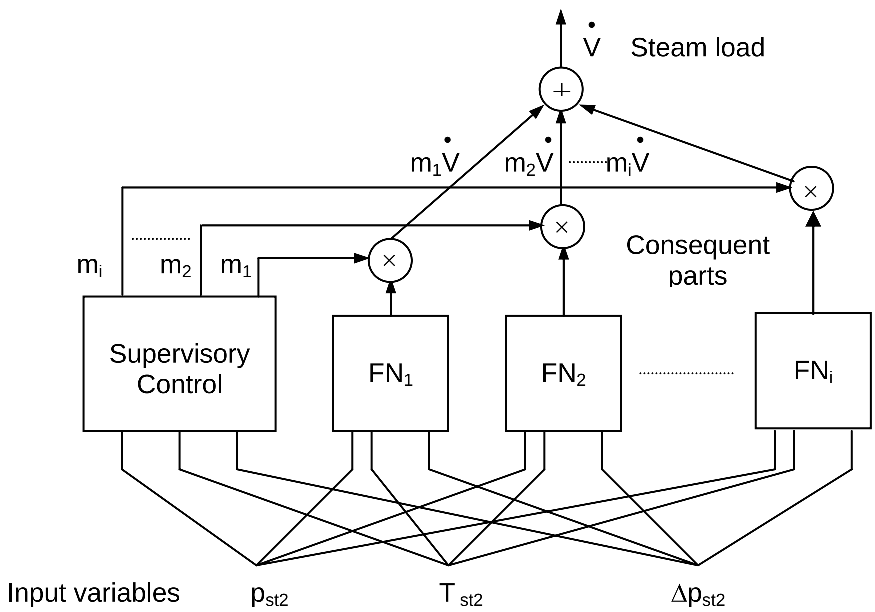


Figure 2.11. Scheme of supervisor system for the heat power station

subsystems.

The *Supervisory Control Device* consists of fuzzy neurons which calculate the proper multipliers m_i. All multipliers affect on their own control unit belonged to a boiler. Influences on the individual boilers are actions to change the discharge areas of outlet steam valves.

Description of FIS has been developed with MATLAB fuzzy toolbox.. The FLC is a *two-inputs single-output Sugeno FIS*. Membership functions of the

FIS shown in Figure 2.12 are bell-shape ones at the inputs, and the output is constant value of multipliers m_i.

Groups of inputs are the following ones:
Input1 includes the following MFs: *no_req*, *req*.
Input2 includes the following MFs: *decr*, *no_change*, and *incr*.
Output1 'multipl' includes values of multiplier m_i for computation the discharge area setting of injected water valve by the followings: *full_open*, *open_slow, no_change, close_slow,* and *full_close.*

. Figure 2.12 shows the control function for setting the discharge area of steam valve where the discharge area is computed by the product of temporary steam load and modifier coefficient m_i, the multiplier. The value of multiplier m_i is between 0 and 2, where 0 means the steam valve must be closing full, and 2 means the steam valve must be opening until maximum. When $m_i=1$ there are no change in the distribution of steam load. It seems in Figure 6.14 that if variable 'distribution' has fuzzy value over 0.5 then the output valves of boilers are opening or closing continuously. If there is no distribution request then the discharge area of output valves will be changing to the nearest stable working point where $m_i=1$. The change of steam load on the outputs of large-scale subsystems, the individual boilers will occur changing in the parameters of the produced outlet steam. That means the technological units of boilers will be operated in accordance with the temporary steam load.

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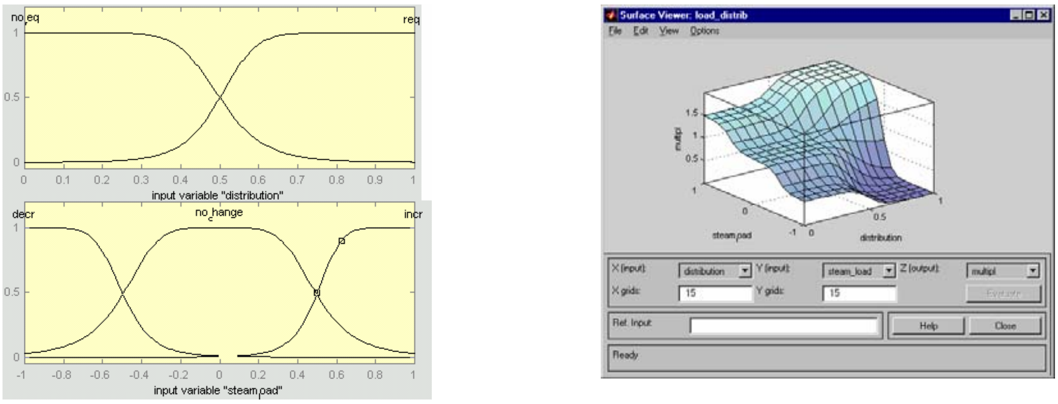

Figure 2.12. MFs of FIS for control of steam load distribution

Description of FIS has been developed with MATLAB fuzzy toolbox.. The FLC is a *two-inputs single-output Sugeno FIS*. Membership functions of the FIS shown in Figure 2.11 are bell-shape ones at the inputs, and the output is constant value of multipliers m_i.

3 Conclusion

It can be say that *processes featured by catastrophe events can be controlled by fuzzy logic control.* The result of application of Thom's catastrophe theory in soft computing is that t*he number of linguistic fuzzy rules is depended on the order of catastrophe function used to describe the control process.* Application of catastrophe theory occurs the opportunity to reduce the number of fuzzy rules. Reduction of number of fuzzy rules results simplicity in control process without changing the accuracy. And the shape of surface of membership values will be the same as the surface composed by fully ruled fuzzy logic system.

A very important feature of the common application of catastrophe theory and soft computing, that *the temporary steam load is distributed by the supervisory system in accordance with the ratio of nominal loading of individual boilers*.

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