Fuzzy Controller for the Control of Nuclear Reactor's Power-Control Rods

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Abstract. *A fuzzy PI-controller for the control of the position of power-control rods in a nuclear reactor is given in our article. The reactor is represented by the mathematical model based on the pressure expression. The proposed control system was designed by using Matlab Fuzzy Toolbox. It was tested by typical input signals. The simulation of the control process and the presentation of the obtained results are done in Simulink.*

Keywords. Fuzzy controller, nuclear reactor model, Matlab, Simulink

1 Introduction

The fuzzy controllers have gone long way from theory to praxis. They are used in such applications as washing machines, elevators and others. All this applications are not critical. But some applications, e.g. nuclear power plants, have to by controlled precisely to ensure the security and stability is not compromised.

The stability of a nuclear power plant's fission reaction is mostly controlled by the insertion or removing of the control rods in the reactor chamber. With this process we can stabilize the reaction and extract energy from it.

2 Nuclear reactor model

In this work we used modified nuclear reactor model from [1]. This model is based on pressure only. Shut down reactor has a pressure of 0% and the optimum pressure of a working reactor is 100%.
The equation of this nuclear reactor model is

$$p(t)=p(t-1)+\int v(t)\,dt-p_k-p_o-p_s \quad (1)$$

where the variables represents
p(t) – pressure in reactor,
v(t) – speed of control rods movement,
p_k – pressure reduced with the full insertion of the control rods,
p_o – pressure reduced with the drain from the reactor,
p_s – pressure reduced by loses in reactor.

The control rods reduce the pressure in reactor by the value of p_k. With the control rod ejection this value is diminishing. When the control rods are 70% out of reactor, the value of pressure reduction is 0 pp. With the continuing ejection of the control rods, there is an increase of pressure caused by them by the value

$$\int v(t)\,dt-p_k \quad (2)$$

With this, it is ensured that the working band of the control rods is in the upper part of the reactor chamber when they are nearly fully ejected from the chamber.

3 Nuclear reactor in Simulink

The nuclear reactor model in Simulink is made from basic blocks such as Sum, Integrator and

Constants. The scheme of the nuclear reactor is in Fig. 1.

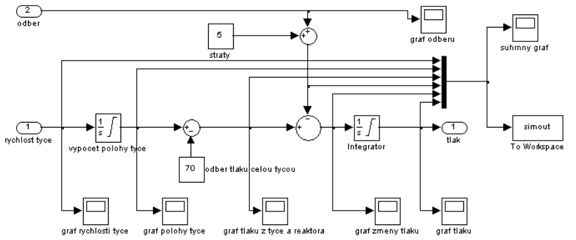

Figure 1. Nuclear reactor model in Simulink

This model is placed in his own block and through I/O ports it communicates with the environment. The environment represents the fuzzy controller and the changing drain. The scheme of the environment is in Fig. 2.

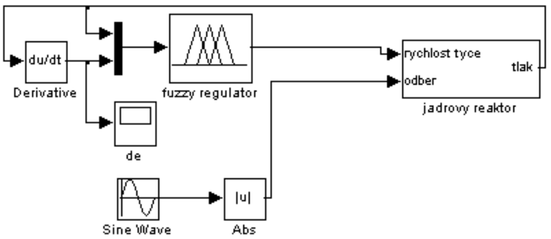

Figure 2. Environment of the nuclear reactor

The drain simulates the power drain from the reactor when it is in operation.

4 Fuzzy controller proposal

Before we begin with the creation of the fuzzy controller, we need to identify the input and output variables and their ranges for our controller, which are based on the variables of our nuclear reactor model.

Our fuzzy controller is of the fuzzy PI type. So it has two input variables and one output variable. The two input variables are the pressure in the nuclear reactor (*p*) and the change of this pressure (*dp*). The output of the fuzzy controller is the velocity of the control rods in the nuclear reactor (*v*).

The range of the pressure variable is from 0% in shut down reactor to 200% in critical reactor. The optimum pressure, 100%, is in the middle of the range. The range of the change of the pressure variable is set to -20 pp to +20 pp. The range of the only output variable is -20 pp/step to +20 pp/step.

The control rods are in position 0% when they are fully inserted in the reactor and in position 100% when fully removed from the reactor. The increase or decrease of the pressure depends on the position of the control rods.

Every variable has 5 membership functions. The membership functions for the input variable *p* are shown in Fig. 3.

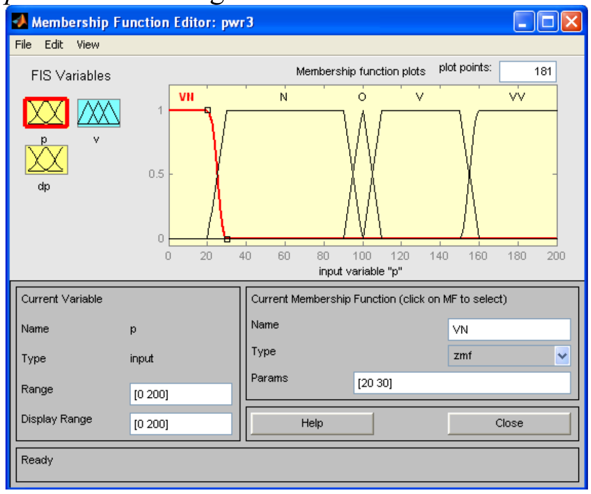

Figure 3. Membership function for variable p

Because there are two input variables, there are 25 linguistic rules at all. They are organized in Table 1.

Table 1. Fuzzy controller rules

p/dp	**VZ**	**Z**	**N**	**K**	**VK**
VN	RH	RH	RH	PH	S
N	RH	RH	PH	S	PD
O	RH	PH	S	PD	RD
V	PH	S	PD	RD	RD
VV	S	PD	RD	RD	RD

From this rules we can display in Matlab the control surface of our fuzzy controller. It is depicted in Fig. 4.

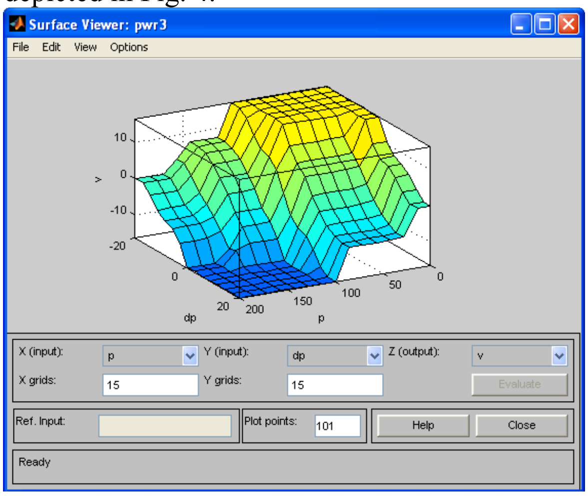

Figure 4. Control surface of the fuzzy controller

5 Process simulation in Matlab

The proposed fuzzy controller was tested together with the nuclear reactor model in Matlab. The simulation environment was Simulink.

5.1 Test parameters and conditions

The fuzzy controller was connected to nuclear reactor model as shown in Fig. 2. As nuclear reactor drain served sinusoidal signal with the amplitude of 10 pp and frequency 0.05 rad/step. Its graph is shown in Fig. 5. The duration of the simulation was 200 steps.

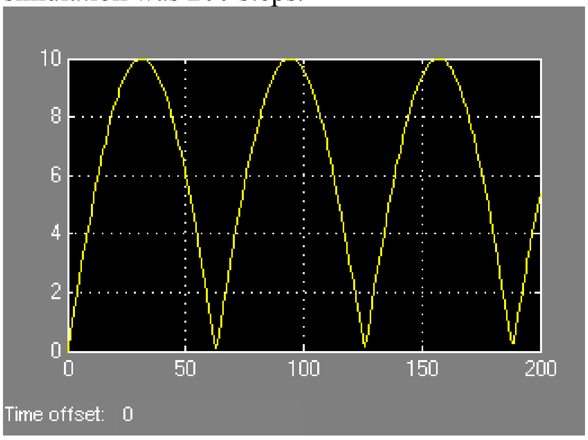

Figure 5. Graph of the reactor drain

The starting pressure in the nuclear reactor was 0%. The control rods were fully inserted into the reactor, their starting value was 0%. As is shown in Fig. 5, the drain was 0 pp in the beginning. The losses in the reactor were 5 pp and constant through the entire duration of simulation.

5.2 Simulation process

The fuzzy controller attempted to maintain the pressure in the reactor at 100%. As you can see in Fig. 6, it succeeded in its task.

The pressure was all the time on or in the surroundings of the 100% mark. There were some small disturbances around the time when the drain changed its tendency from decreasing to rising.

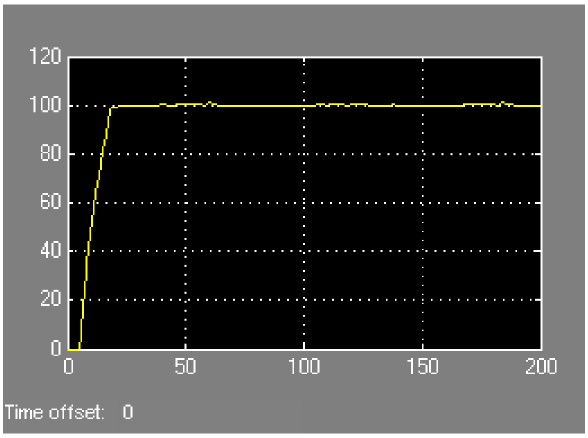

Figure 6. Pressure in nuclear reactor

The fuzzy controller's response to the change in pressure in reactor we can see in Fig. 7.

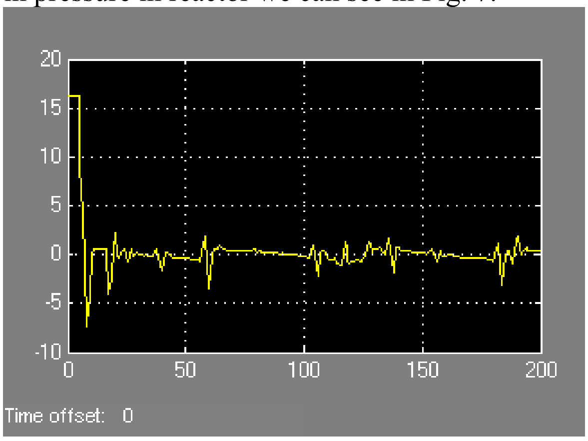

Figure 7. Fuzzy controller response

The control rods were fully inserted in the beginning and the controller issued an order to quickly remove the control rods from reactor. A first few steps in simulation noting happened because the control rods were decreasing the pressure. When the control rods reached and exceeded the 70% mark of their position, the pressure began to rise. As the pressure approached 100%, the controller issued an order to slow down the removing velocity of the control rods and then to slowly insert the control rods into the reactor. When the pressure reached optimum, the control rods only corrected the change of pressure in response to the drain.
In Fig. 8 we can see the position of the control rods in the nuclear reactor as response to the change of pressure in reactor during the simulation.

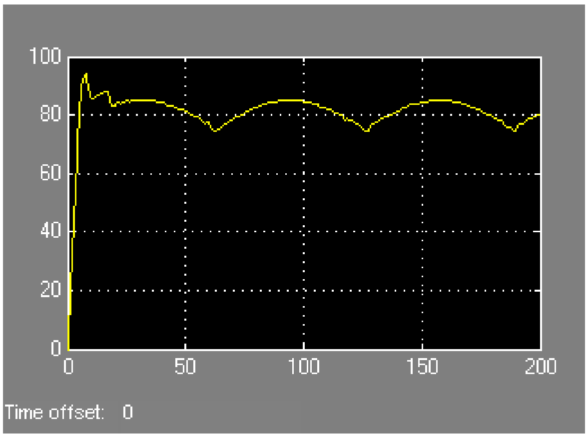

Figure 8. Position of the control rods

The control rods moved in the range from 75% to 85%. This 10 pp range represents the change in the drain from the reactor and the loss of the pressure in reactor.

The change of pressure in the reactor is shown in Fig. 9.

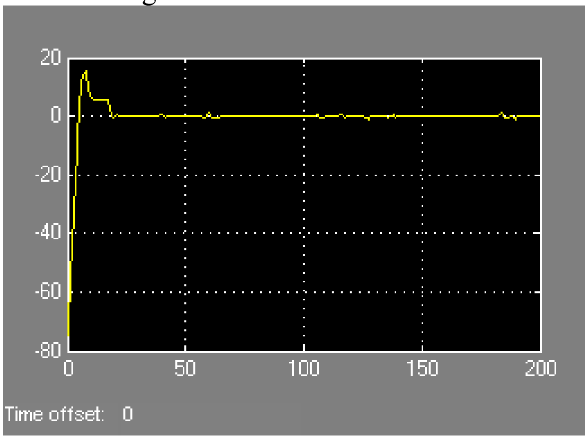

Figure 9. Change of pressure in reactor

In the beginning, when the control rods were inserted under the 75% value, there was a tendency to decrease the pressure. But the pressure in reactor cannot be negative, so the pressure was 0% until the control rods were removed above the 75% value. From there on the pressure begun to rise. When the optimum pressure were achieved, it changed only slightly.

6 Conclusion

From the obtained results we can state, that our fuzzy controller has the ability to control our simple nuclear reactor model. The optimal pressure in the reactor was maintained throughout the simulation at 100% or at least it deviated from optimum only for a short period of simulation. The control rods did not do unnecessary movements and corrected only the change of drain from the reactor. In the simulation there were no oscillations that could compromise the stability of the system.

References

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