Rule Based Controller For Pressurized Water Type Nuclear Reactor

Santhiya M, Pappa N.

Abstract: In this study, a fuzzy logic controller (FLC) is designed for controlling the megawatt power output of a Nuclear power plant which uses Pressurized Water type Nuclear Reactor (PWR). By using the mathematical equations related to thermal equilibrium and kinetics, a model is developed. This model is based on Quark reactor and it is validated with the data available from the Nuclear Energy Agency. The reactor power level of nuclear reactor is controlled with the help of reactivity as the operating variable. The designed Fuzzy Controller is compared with conventionally tuned PID controller.

Index Terms: PWR, Reduced Model, Nuclear Power, PID, FLC.

1 INTRODUCTION

The major complexity in the nuclear power plant is the control of nuclear reactor power. The safety of power plant depends on the proper operation of the nuclear power plant. The reactor dynamics are highly nonlinear and very complex to design. The usage of nonlinear controllers is needed for monitoring the reactor power level. Whenever there is a change in power level in different time, the dynamics inside the nuclear reactor changes. The initial studies are carried out in applying the fuzzy control for nuclear research areas such as radiation prevention, fuel utilization, nuclear waste disposal, etc[1]. The control of power plants involves the knowledge of numerous and tedious parameters such as fuel temperature, reference temperatures, coolant flow rates, coolant temperature, insertion frequency of control rod, catalytic rate, disturbances in the plant, etc. The risks involved in nuclear power plant are very high when compared to conventional type plants. The fuzzy logic can also be used in risk analysis of power plants due to ageing process[2]. The scores based on risk priority numbers are calculated and it is used for the detection of problems in nuclear power plant. The use of neural networks and self-tuning controllers for the trajectory tracking is done for the load following operation of the reactor[3]. The control of various parameters using fuzzy logic controller is proposed in various works [4-9].

2 MODELING OF THE NUCLEAR REACTOR

The mathematical model of a PWR reactor is developed based on the point kinetics to describe the neutron balance in the core and on thermal equilibrium relations to describe the energy exchange between the different loops.

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The thermal feedbacks are due to fuel temperature and coolant temperature changes. The model consists of four sub models such as neutron kinetics, fuel temperature, average coolant temperature model and the basic power model. Thus, these sub models need to be calibrated for each particular plant and situation considered. The equations governing the nuclear reactor dynamics are given below.[10]

$$\frac{dP}{dt} = \beta\frac{P}{\Lambda}\left[\alpha_f\left(T_f - T_f^0\right) + \alpha_{av}\left(T_{av} - T_{av}^0\right) + \rho_{in} - 1\right] + \sum_{i=1}^{6}\lambda_i c_i \quad (1)$$

$$\frac{dC_i}{dt} = \beta_i\frac{P}{\Lambda} - \lambda_i C_i \text{ where } i = 1 \text{ to } 6 \quad (2)$$

$$\frac{dT_f}{dt} = -A_1\left(T_f - T_{av}\right) + A_1\frac{T_f^0 - T_{av}^0}{P^0}P \quad (3)$$

$$\frac{dT_{av}}{dt} = A_3\left(T_f - T_{av}\right) - A_3\frac{T_f^0 - T_{av}^0}{T_{av}^0 - T_{in}}\left(T_{av} - T_{in}\right) \quad (4)$$

The initial conditions for C_i are obtained from (2)

$$C_i^0 = \beta_i\frac{P^0}{\Lambda\,\lambda_i}, i = 1, \ldots, 6 \quad (5)$$

The model response at initial power of 738.637 MW and the reactivity of 0.06 is compared against the Quandry based reactor kinetics (Quark) code. The developed model containing the three important subsystems for the nuclear reactor is shown in the Figure 2.1.

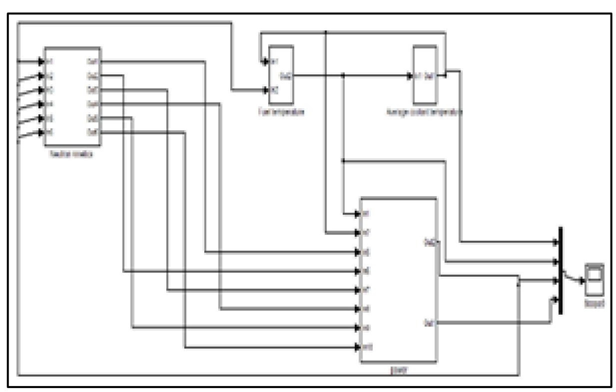

Fig 2.1 *Simulated model of nuclear reactor using SIMULINK*

3 CONTROL OF NUCLEAR REACTOR

3.1 PID Controller

The nuclear reactor of Pressurized Water Nuclear Power plant is controlled by using the conventional tuning rules such as direct synthesis method, standard form optimization minimum ITAE polonyi and standard form optimization binomial polonyi. The overshoot and settling time are taken as measurement indices for controller design. The following table describes the performance metrics of the various controller tuning rules.

TABLE 1
PERFORMANCE CRITERIA COMPARISON

Criteria	*Minimum ITAE Polonyi*	*Binomial Polonyi*	*Direct Synthesis*
Overshoot	*90 MW*	*75 MW*	*No*
Settling Time	*25 Sec*	*26 Sec*	*500 Sec*
Kicks	*No*	*No*	*Yes*

From the table 3.1, it is clear that the conventional tuning rules are not suitable for the desired performance criteria. So the PID controller tuning is done by using the optimization algorithm.

3.2 Genetic Algorithm based PID Controller (GAPID)

The most commonly used optimization algorithm for the tuning of PID controller is Genetic Algorithm. This algorithm uses Survival of the fittest concept for the selection of parameters. It mostly mimics the genetics occurring in the natural manner which leads to more arbitrariness in the selection. The main limitation of traditional algorithms used for optimization is local minima condition. Since this genetic algorithm has natural genetics, it is not affected by the local minima problem. The PID parameters such as K_P, K_I and K_D are optically tuned by Genetic Algorithm. The result obtained shows the GAPID has better outputs than conventionally tuned PID controller.

3.3 Fuzzy logic controller

Fuzzy logic system evaluates the input variables in continuous manner between 0 and 1. The input variables for the fuzzy operation are error and derivative of the error. The control signal is the reactivity which can be changed by the insertion of rods into the reactor. Seven triangular membership functions are taken for framing the Fuzzy rule-based Inference System. The control signal gets altered depending on the rules framed for decision making. The Table 3.2 depicts the fuzzy rules for the manipulation of control signal (reactivity).

TABLE 2
RULES FOR FUZZY DECISION MAKING

EC \ E	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	ZO
NM	PB	PB	PM	PM	PS	ZO	NS
NS	PB	PB	PM	PS	ZO	NM	NM
ZO	PB	PM	PS	ZO	NS	NM	NB
PS	PM	PM	ZO	NS	NM	NB	NB
PM	PS	ZO	NS	NM	NM	NB	NB
PB	ZO	NS	NM	NB	NB	NB	NB

Where, NS – Negative Small, NB – Negative Big, NM – Negative Medium, ZO- Zero value, PS – Positive Small, PB – Positive Big, PM – Positive Medium.

4 RESULTS

4.1 Model Validation

The reduced model output response validated against the Quandary based reactor kinetics (Quark) code is plotted in the figure 4.1.

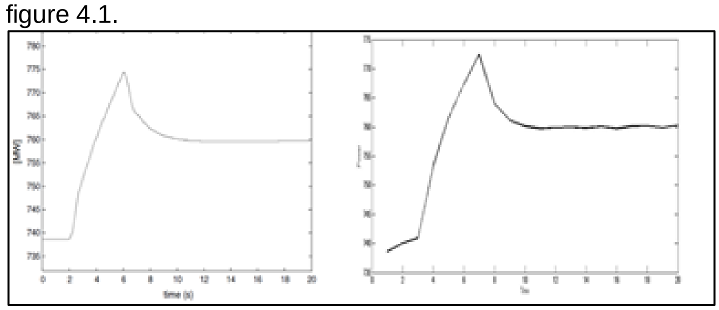

Fig 4.1 *Comparison of Simulated and Literature model*

The above plot shows the validation of the simulated model with the model available from the literature.[10]

4.2 PID Controller Response

The responses obtained from the direct synthesis method, standard form optimization minimum ITAE polonyi method, standard form optimization binomial polonyi method and the Genetic Algorithm tuned optimal PID controller are compared in the Figure 4.2.

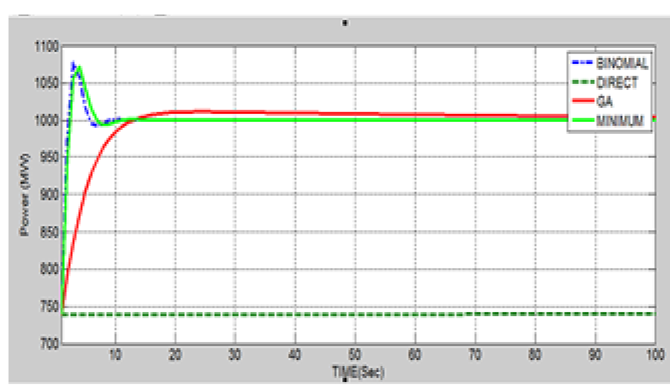

Fig 4.2 *PID controller responses*

4.3 Rule based Controller

The response for the servo operation is shown in the figure 4.3. The output power is set at 1000 MW, 1300 MW and 800 MW at 0 S, 200 S and 300 S respectively. From the figure, it is inferred that the desired performance criteria get satisfied by using Fuzzy logic controller.

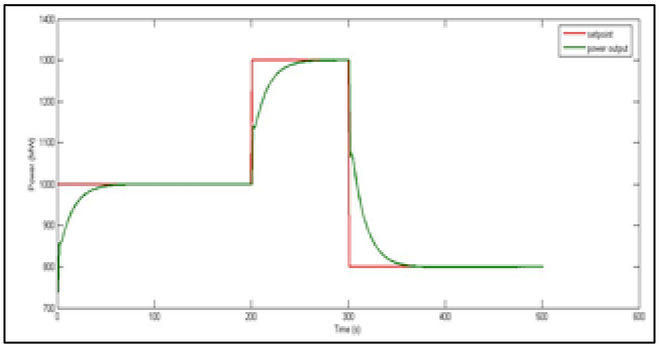

Fig 4.3 *Servo operation*

The disturbance rejection capability of the controlled nuclear reactor is plotted in the figure 4.4. For regulator operation, the fuel temperature of the power plant is taken as the disturbance variable.

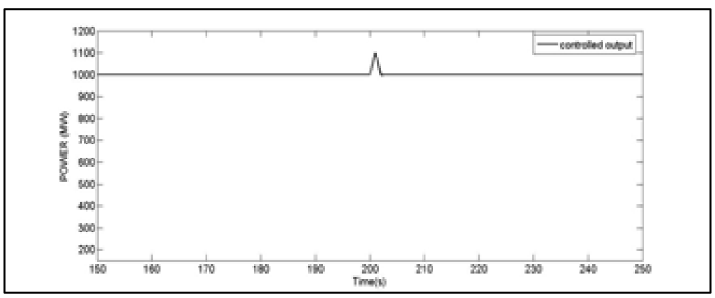

Fig 4.3 *Regulatory operation*

5 CONCLUSION

The nuclear reactor model has been simulated using Simulink and it has been validated against the Quark code available from the Nuclear Energy Agency. The nuclear power is controlled by using the control rod movement so that the reactivity can changes. With the information of the process, the rules are designed for Fuzzy Logic Controller. The designed fuzzy logic controller has been compared with the some conventional PID controller tuned by different rules. Thus, it can be concluded that the designed fuzzy logic controller (FLC) is best suitable for both servo and regulatory operation within the operating region.

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