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Fuzzy Logic Based Reactivity Control in Nuclear Power Plants

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ABSTRACT: The advent of rule-based expert systems and multivalued logic has paved way for the evolution of fuzzy control, it differs from traditional control theory - that needs mathematical modelling of the control processes. Rather than deriving the controller via quantitative and mathematical aspects, fuzzy control replicates the control knowledge directly from domain experts, who control the processes. This represent a typical characteristic of an expert system where control is intrinsic to human's behaviour and experience, rather than the process being controlled. It is this distinct feature that makes fuzzy control applicable for dealing with those problems where the process is so complex and nonlinear. In case of nuclear power plants control using conventional modelling is extremely tedious, wherein, it is the rule based structure combined with fuzzy set theory that makes the implication of possible fuzzy control. In this paper the methodology involved in designing the single-input-multiple-output fuzzy logic controllers for reactivity control element of a nuclear reactor is presented.

KEYWORDS: Fuzzy Logic, Reactivity Control, Membership Functions, Mamdani, Centroid Method.

I. INTRODUCTION

Considering the implication of fuzzy logic to nuclear reactors, it poses a tremendous challenge because of its intense safety regulations. Still, demonstrating the implication of intelligent control in an actual plant is a vital step in prototyping the next generation nuclear power plants. India has a flourishing and largely indigenous nuclear power program and expects to have 20,000 MWe nuclear capacities on line by 2020 and 63,000 MWe by 2032. It aims to supply 25% of electricity from nuclear power by 2050. The possibility of cutting down human intervention by automated control systems leading to both a secure and an optimized control of power generation needs advancement over existing systems. Apart from control of this huge system using conventional approach, fuzzy logic is a paradigm for an alternative design methodology which can be applied in developing both linear and non-linear systems for embedded control. In general fuzzy logic controllers have comparable or better performance compared to conventional controllers. Simulation results show the feasible of control in application of FLC technique to the nuclear power plant. Still future work can be extended to parameter tuning using PID or Hybrid heuristic approaches to seek further possibilities.

II. METHODOLOGY

Plant selection and its identification follows with LMFBR (Liquid Metal Fast Breeder Reactor). In case of these reactors fast neutrons are used to sustain the fission reaction and are characterized by the absence of moderating material. Ideally they have less nuclear waste and their by-products have a shorter half-life and undergo disintegration. But they are very sophisticated in establishing and are expensive to operate. So these reactors are inherit of high breeding ratios and fuel burn up. Because of these sophistications reactor of this particular kind is selected for implication of fuzzy control. Since fuzzy implication involves a thorough study of the input and output parameters, initially all the parameters are listed and their significance are analysed. From the parameters, the required control is obtained from deriving the fuzzy rule base for every control component. Then the rule bases are implied and the required output is obtained. The performance characteristics of Fuzzy controller are derived and the entire process is then simulated using MATLAB – Simulink environment.

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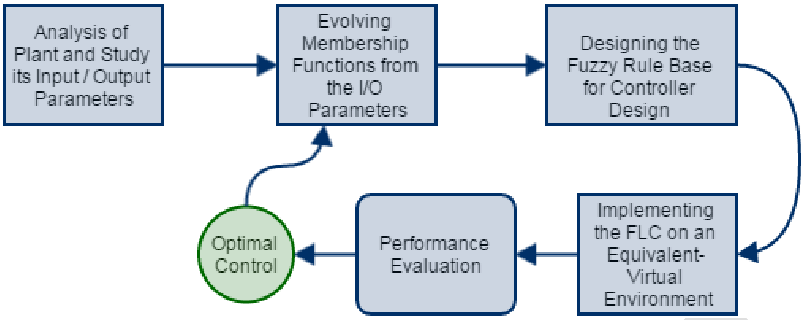

Figure 1: Metholdology involved in deriving an Optimatimized Fuzzy Logic Controller

Based on the plant inputs & outputs the membership functions and fuzzy rule base are defined, then the parameters are tweaked until an optimal state is achieved as shown in *Fig.1*. The process of designing the fuzzy inference engine is done using Mamdani method. It is the commonly employed because of its simple structure of 'min-max' operations. Initially the antecedent for each rule is evaluated and a conclusion for each rule is obtained then they are aggregated and finally defuzzified using centroid method where the fuzzy sets are converted into respective crisp values.

III. PLANT DESIGN AND CONTROL

The unique feature of Fast Breeder Test Reactor (FBTR) is the use of sodium as coolant. The entire power plant is divided into different functional blocks assigned according to their functions.The functional blocks of the entire system is illustrated in *Fig.2*where the end product being the electrical power output.

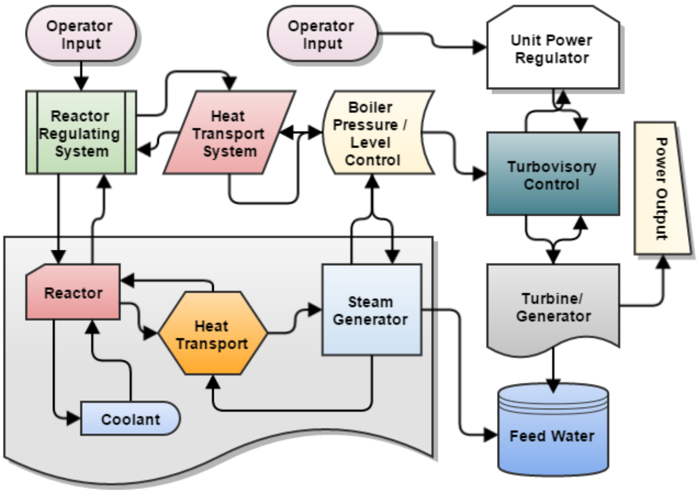

Figure 2: Overall Systems and Functional Elements

The primary sodium of the Heat Transport System (HTS) removes the heat energy- generated by the fissioning of the fuel in the reactor. About 95% of the heat energy released in the reactor is transferred to water in the boiler. In the Steam-Feed water System the water in the boilers is tuned to steam by the heat transferred from the Heat Transport System. The steam generated flows to the turbine where it exerts force on the turbine blades causing rotation of the turbine shaft. In the process, heat energy is converted to mechanical energy. The turbine drives the generator to produce electrical energy. The mechanical energy is converted to electrical energy and the chain of conversions is completed. The heat energy that cannot be used is given up in the process of condensing the exhaust steam to water in the condenser and the energy is transferred to the condenser cooling water. The condensate is pumped back to the boiler through different stages of feed heating as feed water to complete the steam-feed water cycle.

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Program Name	Measured Parameter	Variable Controlled	Variables Manipulated
Reactor regulating system	Reactor power	Neutron flux	Rod position
			Zone water level
Boiler level control	Boiler level	Boiler pressure	Feed water inlet
	Steam flow		
Heat transport system	System pressure	Sodium pressure	Primary pump
		Pressurizer level	Pressurizer coolant and heaters
Coolant control	Reactivity	Flow of coolant	Coolant feed
	Temp. of reactor		
Turbine governing	Steam pressure	Steam flow rate	Throttle valve
			Nozzle valve

Table 1: Table involving various control parameters involving system's inputs and outputs

All modules are tabulated*table.1* for observation only, however only the reactor regulating system is considered as the process plant to be controlled using fuzzy logic. But in the actual realization of the entire nuclear plant, implication for intelligent control requires all modulesthat are dependent on each other featuring simultaneouscontrol.

IV. MODELLING REACTIVITY CONTROL

The Reactor Regulating Systemadjusts the reactivity control elements to maintain reactor power at the desired set point and, when required, to manipulate the reactor power level between set limits at specific rates. It also monitors and controls power distribution within the reactor core.

A. Computing the Inputs & Outputs:

The reactor control system is an integrated system comprising of reactor flux, thermal power measurements, reactivity control devices, and control programs. Based on the position of Rods and desired output power the motion on Adjustor rods (A-Rods) and Control rods (C-Rods) are controlled. C-Rods have a special clutch mechanism to be dropped/poised in and out of the reactor. The A-Rods are provided to shape the neutron flux for optimum reactor power and fuel burn up, and to supply positive reactivity. Both rods have sensors embedded to sense their pace of travel and control mechanism for precise position control. Desired poweris computed from DP - power difference, N_R – actual reactor power, N_D - desired reactor power as given by the *eqn.1*

$$\mathrm{DP} = \frac{N_R - N_D}{N_D} \qquad (1)$$

B. Fuzzification:

Inputs are converted into fuzzy sets as - five linguistic variables for desired power and similarly for the Position of rods the linguistic variables are declared as perthe table and their corresponding ranges are referred in the membership diagram.

PS- positive small	**PORA-** current position of rod-A	**DP-** desired power	**MOPC-** motion of position for C-rods	**MOPA-** motion of position for A-rods
PM- positive medium	**NZ-** near zero	**NS-** negative small	**NM-** negative medium	**NL-** negative large
NWL- near withdrawal limit	**AC-** around center	**NIL-** near insertion limit	**IL-** insertion limit	**PL-** positive large
IM- insertion medium	**IB-** insertion big	**WL-** withdrawal limit	**NA-** no access	**IS-** insertion small
WB- withdraw big	**WM-** withdraw medium	**WS-** withdraw small		

Table 2: Fuzzified Inputs of the System

C. Membership Functions:

After Fuzzification of the intended inputs and outputs their respective membership functions are devised. Based on the nature of variation the type and parameters of the membership functions are chosen.

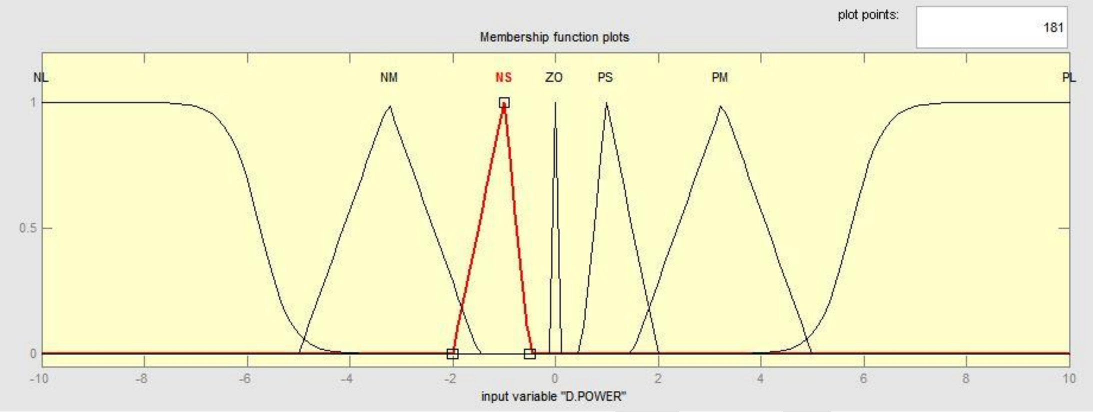

Figure 3: Membership Functions Plotted For DESIRED POWER

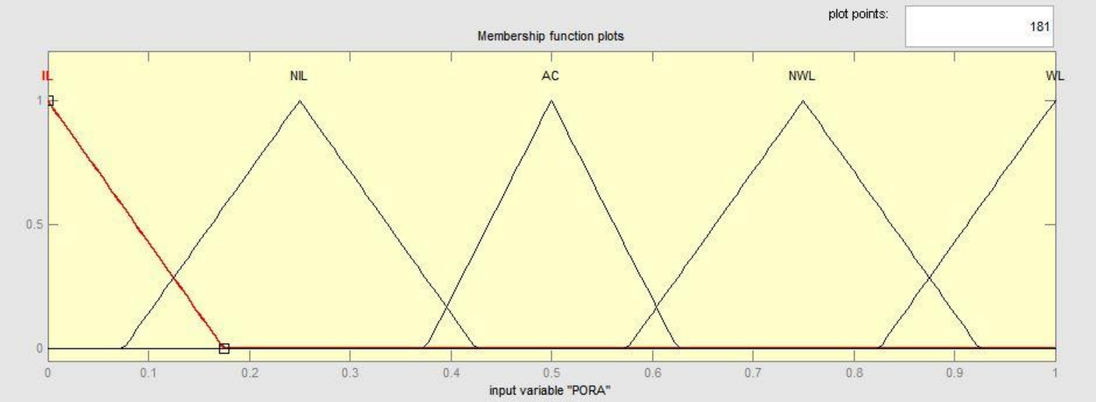

Figure 4: Membership Functions Plotted for POSITION OF ADJUSTOR RODS

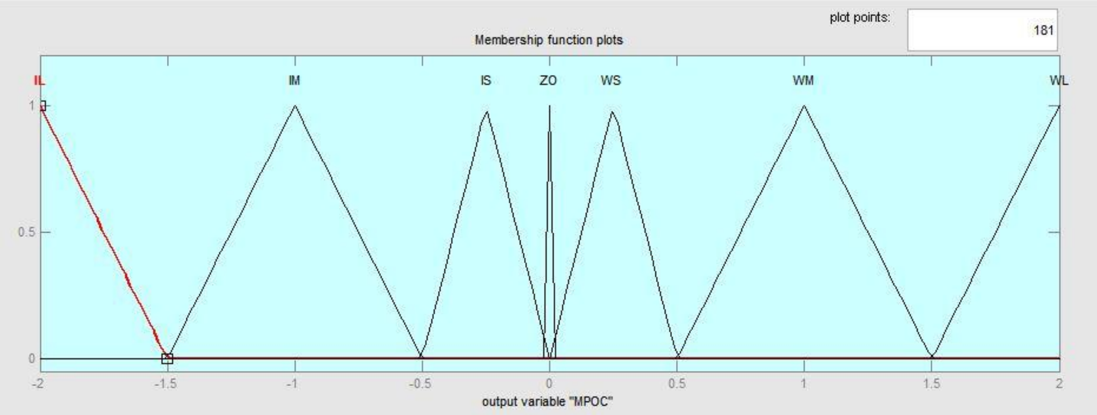

Figure 5: Membership Functions Plotted for MOTION OF CONTROL RODS

D. Rule-Base Model:

Fuzzy logic rule base modelling involves the formulation of linguistic variables that are overlapped over their control space. The complex non-linear relations between them are mapped by the inference engine, although several methods are used to define the result of the rule; min-max based inference is employed because of its simplicity.

PORA	IL		NIL		AC		NWL		WL	
DP	**MPOA**	**MPOC**	**MPOA**	**MPOC**	**MPOA**	**MOC**	**MPOA**	**MOC**	**MPOA**	**MOC**
NL	WB	NA	WB	NA	WB	NA	WS	WS	NA	WB
NM	WM	NA	WM	NA	WM	NA	WS	WS	NA	WS
NS	WS	NA	WS	NA	WS	NA	WS	NA	NA	WS
NZ	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PS	NA	IS	IS	NA	IS	NA	IS	NA	IS	NA
PM	NA	IS	IS	IS	IM	NA	IM	NA	IM	NA
PL	NA	IS	IS	IS	IB	NA	IB	NA	IB	NA

Table 3: The Rule Base for Fuzzy Inference Engine

E. Equivalent System Model:

Adjustor rods and Control rods are the mechanical elements, wherein their positionis tracked using displacement sensors and controlled using PID based position control system. As their position for intended power output is complex to model it is controlled by FLC (Fuzzy Logic Controller) and this entire system is realised in Simulinkas by*Fig.6*

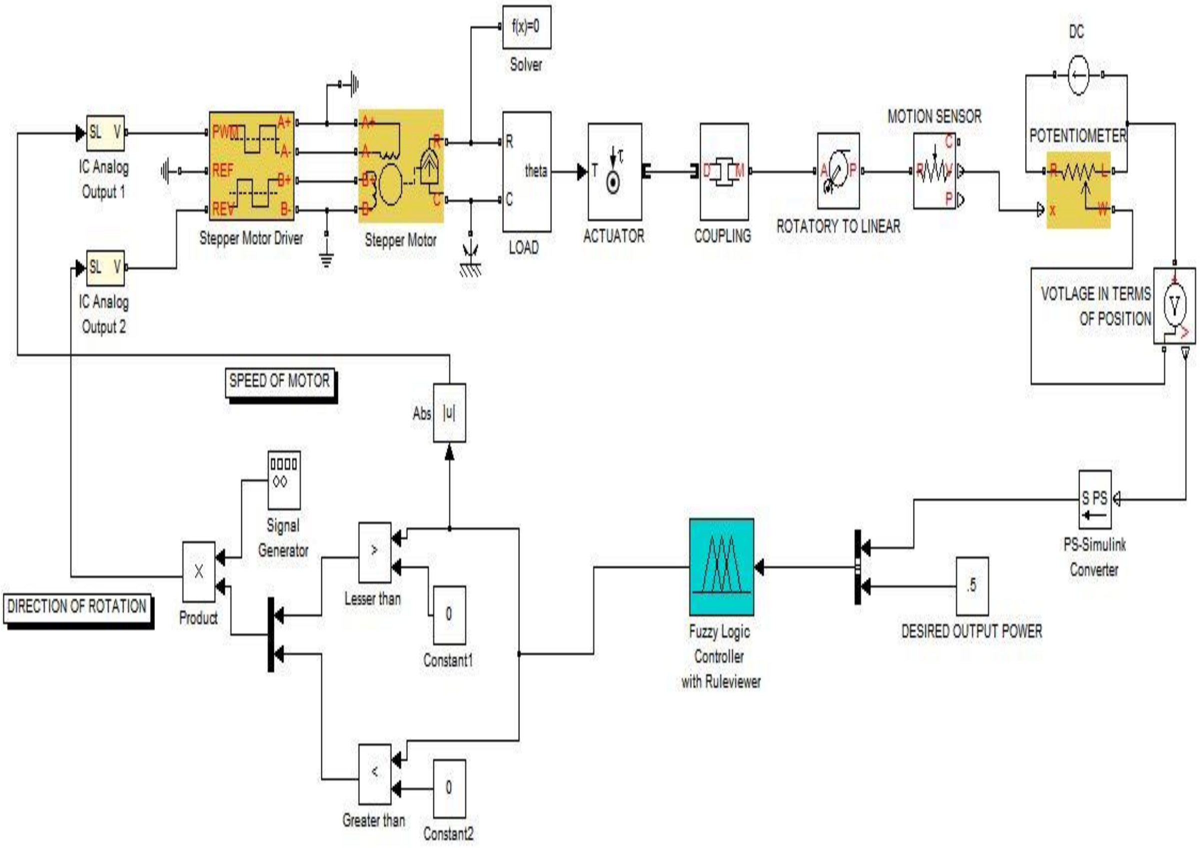

Figure 6: Simulink equivalent model in MATLAB-Simulink Environment

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F. Simulated Results:

Simulation of the system yielded promisimg control through fuzzy logic. The relationship mapping between the various inputs and outputs are shown as a 3-Dimensional surface graph in *Fig.7*, and the actual control outputs for positon of Adjustor/Control-Rods for desired output power is shown by *Fig.8*

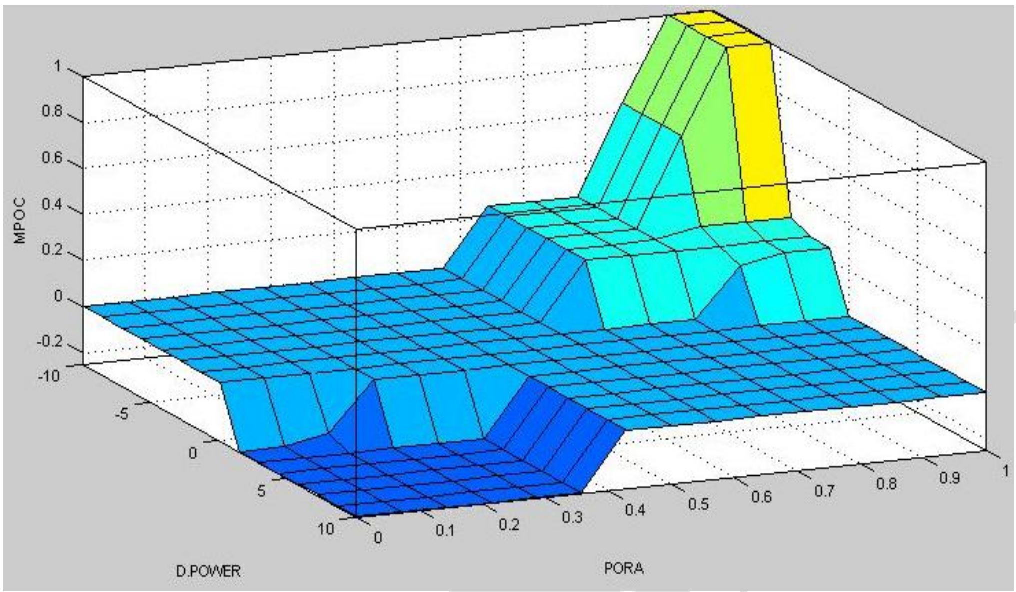
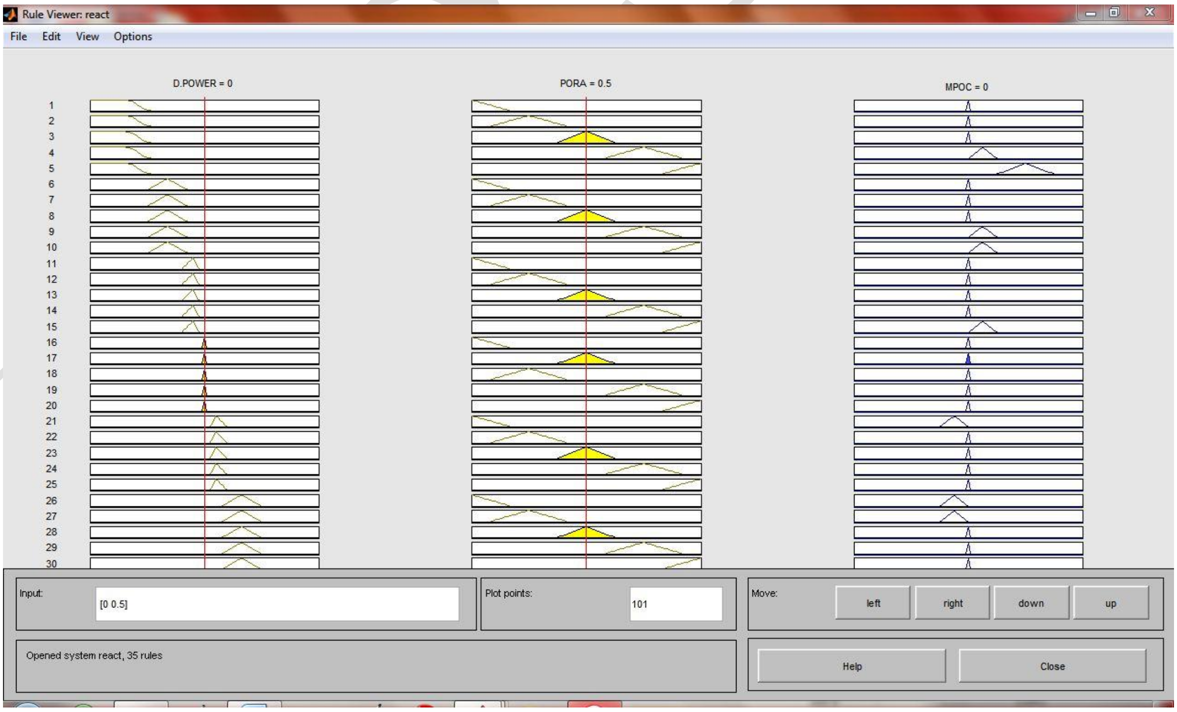


Figure 7: Mapping of Inputs and Outputs depicted using a 3D Surface graph



Input: [0 0.5]

Plot points: 101

Opened system react, 35 rules

Figure 8: GUI showing the overall system input and output achieved by fuzzy control

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V. CONCLUSION

The process of modelling single-input-multiple-output fuzzy logic controllers for reactivity control element of a nuclear reactor is presented and the Simulation results illustrate the feasibly in application of possible Fuzzy control. These fuzzy models have been developed to cope with nonlinearity and uncertainty. Also, these nonlinear fuzzy models are able to cover a wide range of operational conditions. Still it poses a tremendous challenge for implication because of its intense safety regulations future work involves further optimization of fuzzy controllers by learning techniques derived from neural networks an Adaptive control of nuclear power plants as a Neuro-Fuzzy approach.

REFERENCES

[1] Zuheir Ahmed, "Data-driven controller of nuclear steam generator by set membership function approximation", Annual of nuclear energy, Vol. 37, pp. 512-521, 2010.

[2] B. H. Cho and H. C. No, "Desin of stability-guaranteed fuzzy logic controller for nuclear steam generators," IEEE Transactions on Nuclear Science, vol. 43, no. 2, pp. 716–730, Apr. 1996.

[3] Arslan, G. and K. Y. Lee "Stability Analysis of a Fuzzy Logic Controller". Proceedings of American Control Conference 3301-3305, 1997.

[4] M. G. Na, "Design of an adaptive predictive controller for steam generators," IEEE Trans. Nucl. Sci., vol. 50,no. 1 , pp. 186–193, Feb. 2003

[5] Heger,A.S., N.K.Alang-Rashid and M. Jamshidi, " Application of Fuzzy Logic in Nuclear Reactor Control" Part I: An Assessment of State of-the-Art. Nuclear Safety, 36, 109-121, 1995.

[6] M. G. Na, "Auto-tuned PID controller using a model predictive control method for the steam generator water level," IEEE Transactions on Nuclear Science.,vol. 48, no. 5, pp. 1664–1671, Oct. 2001.

[7] Huang, Z.,"Fuzzy Logic Controller Design for Overall Control of a Nuclear Power Plant", MS thesis in Electrical Engineering, the Pennsylvania State University,2001.

[8] Ramaswamy, P., R. M. Edwards, and K. Y. Lee,"An Automatic Tuning Method of a Fuzzy Logic Controller for Nuclear Reactors"IEEE Transactions on Nuclear Science. 40, 1253-1262, 1993.

[9] E. Irving, C. Miossec, and J. Tassart, "Toward efficient full automatic operation of the PWR steam generator with water level adaptive control," in Proc. Int. Conf. Boiler Dynamics and Control in Nuclear Power Stations, British Nuclear Energy Society, London, U.K., 1980.

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