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NUCLEAR REACTOR CONTROL USING TUNABLE FUZZY LOGIC CONTROLLERS[1]

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Abstract

Nuclear reactor operation is a human intensive task; one of the features of a problem for which fuzzy controllers present the most suitable solution. The performance of the fuzzy controllers can further be improved through tuning. In this work, application of a fuzzy controller in real-time control of a nuclear reactor is presented. The fuzzy controller is tuned on-line using direct gradient search method.

Introduction

This paper presents the results of a study on the application of fuzzy logic to control an AGN-201M nuclear research reactor. The study extends the scope of existing work on the application of fuzzy logic in nuclear reactor control (for example, Bubak et al. 1983; Bernard 1988; Kinoshita et al. 1988; Terunuma et al. 1990; Akin and Altin 1991; Alang Rashid, 1992; Alang Rashid and Heger, 1992a and 1992b; and Kuan et al. 1992) by using a new, on-line, tuning algorithm and by implementing a tunable fuzzy logic controller (FLC) on a real nuclear reactor. The new tuning method and the results of power-up and power-down experiments are presented.

FLC Tuning

The FLC uses max-min inferencing, centroid defuzzification scheme, and Gaussian-like membership functions for all of its primary fuzzy sets. Controller tuning is done on-line using a new method based on estimation of the centroids of the controller's output primary fuzzy sets. The centroids are estimated by a direct gradient search method in which the centroid values are determined using

$$c_i(k+1) = c_i(k) - K\frac{\partial e^2(k)}{\partial c_i}$$

where $c_i(k)$, $i = 1, 2, \ldots, N$ is the centroid of the ith primary fuzzy set of the FLC output variable at sampling instant k, N is number of FLC output primary fuzzy sets, e(k) is error between actual and demand reactor power levels, and K is a positive constant of magnitude less than unity. With centroid defuzzification scheme, the ith centroid update equation can be rewritten as

$$c_i(k+1) = c_i(k) - 2K\,e(k)\,a_i(k)$$

where $a_i(k)$ is a weighted contribution of the FLC rule antecedent to the FLC ith output primary fuzzy sets. The tuning method has the advantages that the FLC rules are not modified, the number of parameters adjusted are bounded by the number of FLC output primary fuzzy sets, and the tuning is implemented on-line.

FLC Setup

Inputs to the FLC are error, ER, and error change, DE. At any sampling instant k, ER(k) represents the error

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[1] This work was completed while NKAR was at the Chemical and Nuclear Engineering Department, University of New Mexico, USA.

e(k), defined earlier, and DE(k) = (ER(k) - ER(k-1)). The FLC output, RD(k), corresponds to the position of the control rod in the reactor core. This position controls the reactor power. The FLC output gives the duration and the direction of control rod movements that are defined by four primary fuzzy sets: OL, OS, IS, and IL, where O denotes control rod out (reduce power), I denotes control rod in (increase power), L denotes long duration, and S denotes short duration. The FLC control rules are derived from general control principles, based on nuclear reactor point kinetic equations, that relate ER and DE with RD. Four control rules are used.

The FLC is implemented on a Macintosh II equipped with an input-output board for interfacing the AGN-201M reactor. AGN-201M is a thermal reactor used for students' laboratory experiments. In this implementation, the FLC requires only the reactor power level signal, and drives only one control rod. The power level signal is sampled every 2 seconds.

Test Problems and Results

The FLC is tested in two conditions of reactor control: step setpoint increase from steady-state operating condition of 25 %FP (full power) to 50 %FP and step setpoint decrease from 50 %FP to 25 %FP. In both cases, the FLC was used to adjust the actual power level to the desired level as fast and accurately as possible.

Fig. 1(a) shows the reactor power trace for a step setpoint increase without the FLC tuning. Fig. 1(b) shows the result of the same experiment with tuning in place. The tuning procedure improved the FLC performance by reducing both the magnitude and duration of power overshoot. Fig. 2 shows variations of the FLC output centroids as a result of the tuning. The time at which the centroid curves peaked corresponds to the time at which reactor power crosses the demand level. This behavior is expected since, at this point, the gradient of the error is zero. Similar performance improvement is exhibited for the case of step setpoint decrease shown in Fig. 3 (a and b). Variations in the FLC centroids for the step setpoint decrease are shown in Fig. 4. This tuning method allows the FLC centroids to vary and adapt to the changing plant operating conditions. By allowing the centroids to change, the process of FLC tuning is facilitated, because the FLC needs not search for one parameter settings that is optimal over the whole range of plant operating conditions.

Discussion and Conclusion

Application of general control principles instead of specific control rules is partly the reason for the occurrence of overshoot (undershoot). Specifically, the control rules are devoid of knowledge of the role of delayed neutrons in nuclear reactor operation that reactor operators used so successfully in preventing over- and undershoot. Notwithstanding the utilization of the general control rules, tuning improves the FLC performance. This demonstrates that tuning is an integral part of FLC design process. In real implementation, tuning should be done on-line, and as far as possible should not require repetitive experiments. The gradient method that is developed in this research shows the promise to be of value in this respect.

This research extends the scope of existing work on the application of fuzzy logic in nuclear reactor control. We feel that fuzzy logic has role to play in nuclear reactor control. More research, however, needs to be done before it can gain followers in the nuclear industry.

Acknowledgement

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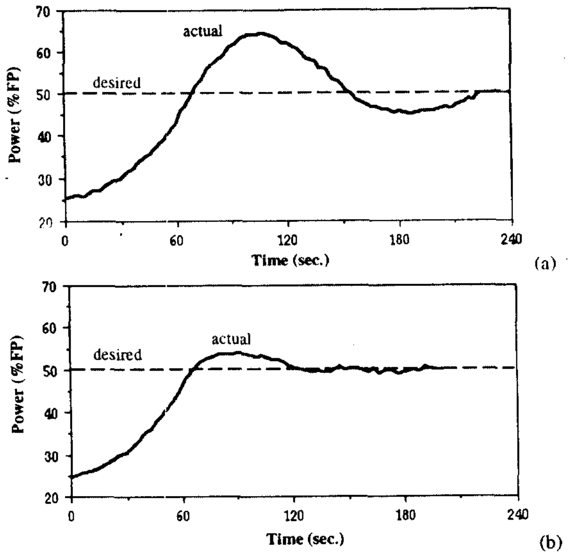

Figure 1. Reactor power trajectory for step increase:
(a) untuned FLC, (b) tuned FLC.

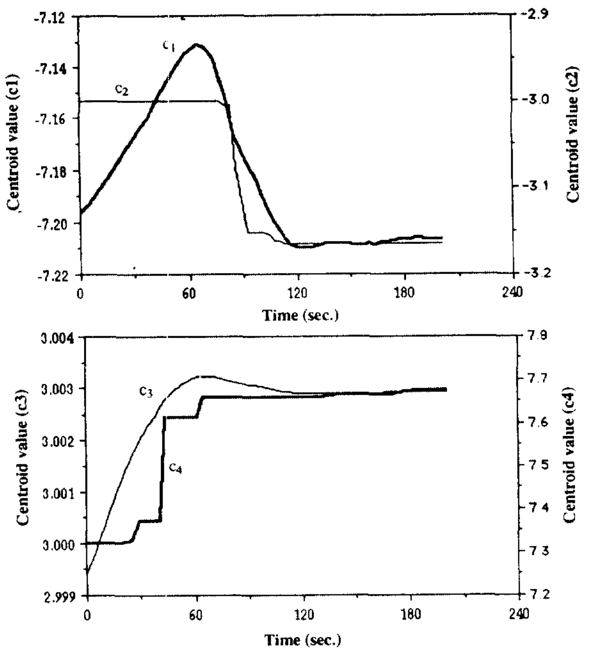

Figure 2. FLC centroids adapting to the step increase:
c1 = OL, c2 = OS, c3 = IS, and c4 = IL.

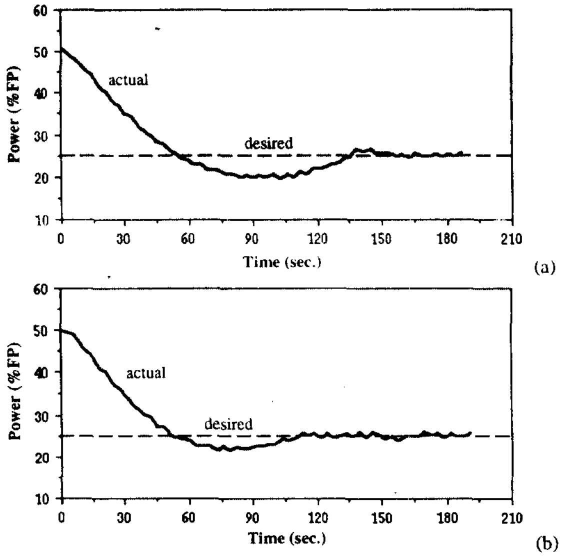

Figure 3. Reactor power trajectory for step decrease:
(a) untuned FLC, (b) tuned FLC.

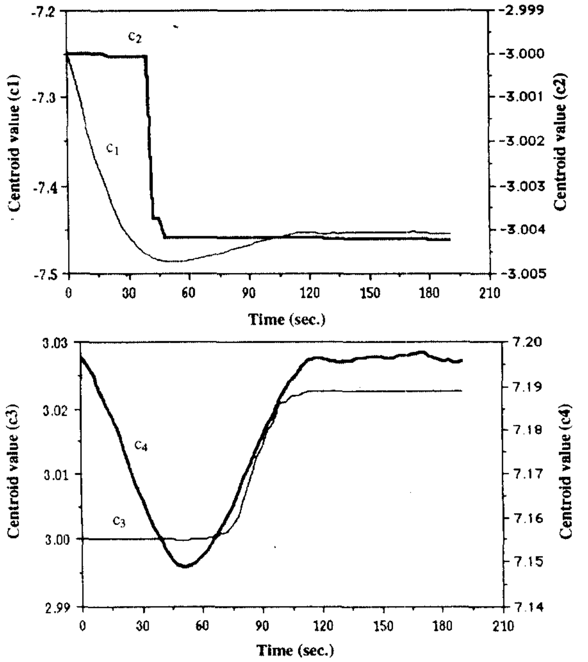

Figure 4. FLC centroids adapting to the step decrease:
c1 = OL, c2 = OS, c3 = IS, and c4 = IL.