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2. Demonstration of Decision Analysis Techniques for Steady-State Reactor Control, *J. Bernard, D. Lanning, K. Kwok (MIT), A. Ray (Draper Lab)*

This paper describes a digital algorithm that uses decision analysis techniques (i.e., artificial intelligence) to control the steady-state power of the 5-MW(th) Massachusetts Institute of Technology (MIT) research reactor. The MIT and the Charles Stark Draper Laboratory are conducting a systematic experimental program to develop robust methods for the direct digital control of reactors. The final controller design will probably have a three-tier structure with the first component being a supervisory program that will measure (or calculate) reactivity, period, and power in real-time and then determine, via nonlinear relationships, when the core's excess reactivity should be changed in order to limit transients. This supervisory component adds an additional safety factor by preventing any automatic control function from challenging the normal reactor safety system. Its background and capabilities have been presented elsewhere.[1,2] The second component is a decision analysis program that will select the means of control when several roughly equivalent methods are available. For example, following a demand change, should rod motion be initiated or should inherent feedback mechanisms be allowed to accomplish the adjustment? This component is the subject of this paper. The third component, which is still in development, will use either state analysis or time-optimal techniques to provide a predictive capability for control strategy decisions.

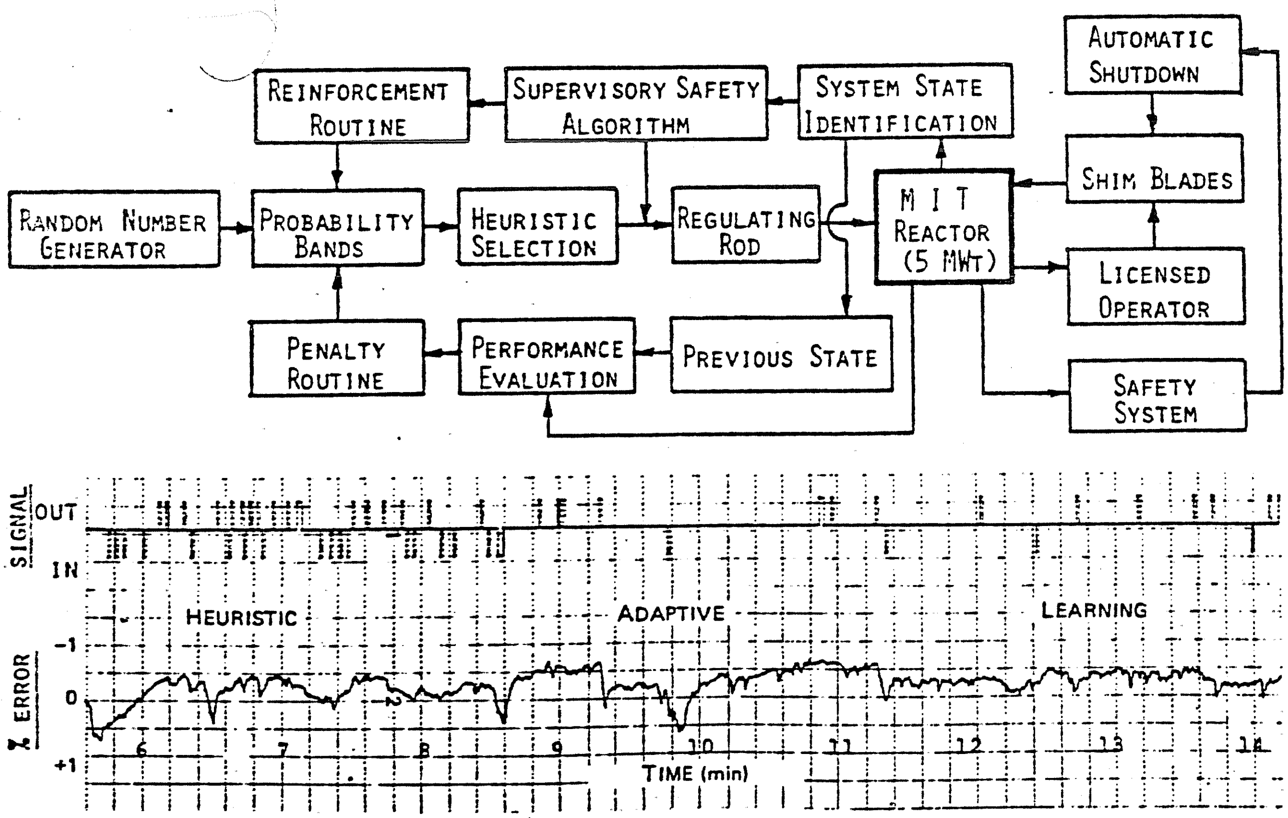

Fig. 1. Schematic and output of decision analysis controller.

Nuclear reactor control is principally the domain of licensed operators who rely on written instructions and personal experience. For example, when raising power, procedures might require that period be kept longer than 50 s and experience might suggest lengthening the period once power is within 80% of desired. Decision analysis is the mathematical analog to this approach. Its advantage is that, given the enormous memory of a computer, every past control action can be quantified. The technique is as follows:

1. Heuristics or "thumb rules" such as "move the control rod at maximum speed" are defined. Each heuristic quantifies a possible control action. Each is assigned a probability band.

2. Criteria for determining the reactor state are defined. Typical parameters are the power deviation, period, and rod position.

3. A means of selecting a specific heuristic is created. Usually, this consists of a random number generator with the heuristic whose probability band includes the random number being the one selected.

4. Performance criteria are established to evaluate how well the use of a given heuristic improved or maintained the controller's objectives.

5. A penalty routine is created to reduce the probability band associated with heuristics whose performance is poor.

6. A reinforcement section is set up that correlates the performance of each heuristic with each state and, whenever the reactor is in a given state, enlarges the probability band of the heuristic whose performance is best for the state.

Controllers based on subcomponents 1, 2, and 3 reflect pure heuristic (i.e., random) control. Those that include the performance criteria and penalty routines are referred to as "adaptive" while those that also use the reinforcement section are true learning theory programs. Additional information is given by Macdonald and Koen who studied such techniques via computer simulation.[3]

The MIT research reactor uses six shim blades for performing reactor startups, overriding xenon, and accomplishing major power changes. A regulating rod is used for fine control. It is intended for decision analysis to be used to determine whether power changes should be initiated by temperature feedback, the regulating rod, or a shim blade. Currently, the reactor's technical specifications do not permit automatic control involving the shim blades so an alternative demonstration was conceived to prove the feasibility of this approach. The decision analysis technique was used to adjust the regulating rod's position, thereby maintaining power constant despite both internal reactor noise and xenon/temperature transients. The rod could either be held constant or driven at full speed in a preselected direction. Penalties were assessed for both the initiation of counter-productive rod motion and the failure to take prompt corrective action. Reinforcement credit was given for either maintaining power within the desired band (0.25%) or returning to the band. Figure 1 shows a typical recording of the controller's performance. The upper trace indicates rod motion while the lower one is the percent deviation in the reactor power. The control is marginal at the outset when it is essentially random. It improves as the penalty routine takes effect and becomes satisfactory once the reinforcement section cuts in.

This experiment has demonstrated that decision analysis techniques can be used to control reactor power at steady state. Additional work is planned to demonstrate the desirability of such control.

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3. Computer Program for Power Changes and Load Following, *Daniel V. Wilder (Duke Power, Clover SC)*

PURPOSE

The primary purpose of this computer program is to assist the control room operator as follows:

1. Enable the operator to determine if a given series of load maneuvers is physically possible, using the time constraints and methods for making reactivity changes that he specifies.

2. Warn the operator of any operating limits or interlocks that could be reached or exceeded during the maneuver.

3. Give the operator a printout of the predicted behavior of important plant parameters.

Another purpose of this program is to enable the plant chemistry group to determine in advance how much waste will be generated and how much boric acid and/or water will be needed during the load maneuver. The program can also be used to reduce total waste generation.

In addition, the station reactor engineering and operations groups will use the program to:

1. Attempt to develop some general operating philosophies to be used during load changes.

2. Provide a means to evaluate the effectiveness and desirability of various operating options such as the reduced temperature return-to-power strategy.

INPUTS

The program user will input a desired series of load changes and a set of initial conditions such as initial control rod positions, boron concentration, cycle burnup, etc. The user will also input a set of preferences for making reactivity changes. These preferences will be made by assigning a ranking of 0, 1, 2, or 3 to the options of moving control rods, changing boron concentration, and using reduced temperature strategies. A "1" is assigned to the most desired option, a "2" for the second choice, etc. A "0" is assigned to any options that are not to be used at all.

OUTPUTS

The following parameters are output as a function of time:

1. power (planned and actual)
2. control rod positions
3. temperature deviation ($T_{avg} - T_{ref}$)
4. boron concentration
5. xenon worth
6. cumulative acid addition
7. cumulative water addition
8. total waste generation.