NucE 505 Nuclear Reactor Control

Spring Semester 2016

Professor Asok Ray and Dr. James Turso, P.E.

This three credit course presents control theory and its application to nuclear reactor plant control. Important nuclear reactor dynamics which can pose potentially significant operational problems are analyzed using both time and frequency domain system descriptions. A major emphasis is the introduction and application of elementary control theory to specify reactor design parameters that improve inherent reactor stability and performance for integration in a power producing system. A secondary objective is the design of feedback control for automatic control of reactor power including control rod drive mechanisms and power and temperature sensing devices. Although the course will be primarily taught from the perspective of the most commonly deployed power reactor design, the pressurized water reactor (PWR), the dynamics associated with other reactor designs will also be discussed. The course will stress, qualitatively and quantitatively, how a reactor safely controls itself and inherently provides load-following capability and what factors contribute to reactor accidents, such as experienced at Three Mile Island in 1979. The course project will be the development of a reactor plant control system (e.g., steam generator pressure control using control rod drives to control average coolant temperature across the reactor), and a Matlab/Simulink simulation of a commercial power plant providing the essential dynamics observed during selected operating scenarios. The students will be guided through the model’s development as the course progresses; using data from the specified plant’s design documentation.

A summary of the topics covered is given below:

1. **Neutron kinetics:**
   - Point kinetics and response to reactivity step
   - System characteristic equation and inhour equation
   - Time varying reactivity: problems, sources and characteristics
   - Linearization of nonlinear reactor kinetics
   - Core reactivity and its effect of reactor operation

2. **Laplace methods:**
   - Review using Spring-mass-damper system as an example. Complex variables. Laplace Transform. Transfer function
   - System response to sinusoidal input

3. **Bode and Frequency Domain Design Methods:**
   - Rules for sketching Bode magnitude and phase plots. Proportional, Proportional-Integral, and other compensation

4. **Root locus analysis:** Pole location and impact on stability.

5. **Modeling, Analysis, and Simulation of Representative Reactor Plant:** Nuclear plant dynamic model development, use of Matlab and Simulink and a simulation and analysis tool for nuclear plant control
6. Development of Proportional-plus-Integral-plus-Derivative (PID) control. Emphasis is place on dynamic implications of implementing PID controllers on plant systems, and how plant response can be tailored by design of controller gains. Time-Domain analysis and performance specifications of feedback control systems. Implications of control system dynamics on overall nuclear plant response.

6. Application to reactor analysis and control:
Feedback control system characteristics and design objectives. Reactor kinetics with two temperature feedback model. Control rod characteristics and drive dynamics effects in feedback control. Reactor kinetics and control with two temperature feedback model. Xenon and other poison dynamics. Boiling and void dynamics. Review of nuclear plant instrumentation stressing implications to plant control

7. Introduction to State Space methods and application to reactor control:
Develop state space model of nuclear reactor and apply stability analysis and control system design methods (e.g., state feedback).

Prerequisites: NucE403 (Reactor Physics) and NucE430 (Thermal-Hydraulics) (or the equivalent if BS received from a university other than PSU) or permission of the instructor.


Reference Book:
Control of Nuclear Reactors and Power Plants, M.A. Schultz, 2nd edition, McGraw Hill (1961). This classic and still useful text book on reactor control will be supplemented with course notes. An up-to-date text book providing a general introduction to feedback control is also required.

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<th>Grading:</th>
<th>INSTRUCTOR and OFFICE HOURS:</th>
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<tr>
<td>Midterm Exam 25%</td>
<td>Professor Ray <a href="mailto:axr2@psu.edu">axr2@psu.edu</a></td>
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<td>Homework 50% (Drop Lowest - Excluding Last HW)</td>
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<td>Last HW 5%</td>
<td>Dr. Turso <a href="mailto:Jat127@psu.edu">Jat127@psu.edu</a></td>
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<td>Term Project 20%</td>
<td>Office Hours: To be determined</td>
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Grading: