CHAPTER 5: REACTOR CONTROL AND PROTECTION

MODULE 2: REACTOR REGULATING SYSTEM

Introduction

The general objective for the reactor regulating system is to provide smooth, steady and safe operation of the reactor within the design parameters of the reactor system. The reactor regulating system must be available or else the reactor must be in a guaranteed shutdown state. Manual control of the reactor regulating system is not allowed (or feasible).

The set power and the rate at which the power is changed are limited to ensure a safe power change with no danger of fuel damage. A reactor power request greater than 105% F.P. will not be recognized by the regulating system - this is an absolute control limit.

Operator entries can be made to raise or lower power. All entries are in the form of a change of setpoint at a particular rate of change.

All reactor control is carried out by the digital control computers under the direction of the reactor regulating system (RRS) programs. Should the controlling computer stall, the back up computer will assume control in a bumpless fashion. If both computers stall, the reactor system will fail safe with the zones filling.

Reactivity Balance

During steady state reactor operation, the neutron multiplication factor (k) must be held equal to 1. To raise power (reactor supercritical) k must be increased (k>l) and vice versa to lower power. This variation from k being equal to 1 ($\Delta k = k-1$) will be very small and hence changes in reactivity are usually measured in milli k (k/1000).

The source of positive reactivity within the reactor is the fuel (neglect booster rods). A control balance (k = 1) can be achieved by manipulating the negative reactivity devices (adjusters, poison, etc).

The reactor operation will produce quantities of Xe-135, a neutron absorber, which will tend to complicate the reactivity balance. In the steady state, Xe-135 will present an equilibrium poison burden (in the order of -28 mk) to the reactor which can easily be accommodated by the reactor design and fuelling.

However, during reactor maneuvering Xe-135 transients can occur following power changes (about 2.5 mk for each 10% power change). These short term (12 hours) excursion must be compensated for by the Reactor Regulating System.

Following a prolonged outage, the Xenon load will be very small. A moderator poison load (a few ppm of boron or gadolinium) is used to "simulate" the Xenon until its load returns to normal. There is a practical limit to the ppm poison level in the moderator (reactivity banking) that is allowed (it is only a temporary negative shim).

Reactivity Mechanisms

In order to control the flux of a large CANDU reactor, the following reactivity mechanisms need to be manipulated.

1. zone level
2. adjuster rods or booster rods
3. moderator level
4. control absorbers
5. poison addition
6. shut down rods (withdrawal only)

From these available methods, it is important to choose one method of "first line" control for normal day to day operation. This preferred method must therefore be capable of fulfilling the following requirements:

- That reactor power and rate of change of reactor power is fully controllable as selected by the operator.
- That the control system must be able to prevent large flux tilts within the reactor.

The. method chosen to satisfy the above requirements is the zone level control system. It must be capable of providing a fine and relatively fast acting control response. The system must also possess sufficient reactivity capacity to compensate for normal reactivity changes due to temperature fluctuations, slight xenon transients and refuelling. The total reactivity provided by the zone system is approximately 5 mk and the average rate of response is 45 μk/sec.

To provide control of the spatial flux distribution in the reactor, the core is divided into divided into 14 separate zones, and the control system must be capable of controlling the flux in each zone individually, as well as for the reactor as a whole. This spatial distribution will satisfy the demands of flux tilt control. At low power flux tilts are not important, the reactor can then be controlled in a bulk manner with all zone levels changed in unison. The liquid zone control system must be available at all times or the reactor must be shut down.

Control Sequencing (Limit Control Routine (LIMCR))

Recall that the preferred method of reactor control is by the manipulation of zone level and that the total reactivity worth of the zones is effectively 5 mk (± 2.5 mk if the zone level is 50%).

Power error correction may require a larger change of reactivity than the zones are capable of providing. For example, a freshly fuelled reactor would probably have a high average zone level and any positive power error (power greater than setpoint) would require an increase in zone level to reduce power to the setpoint. If the required increase is not possible to achieve without zone level exceeding say 90%, then some other reactivity adjustment (eg, moderator level) must be used.

LIMCR is the control program which ensures that zone level control remains the first line method of reactor control.

The methods used to achieve this differ according to the reactivity mechanisms available at the particular location.

500MW CANDU

Figure 1 shows Power Error displayed on the horizontal axis and Average Zone Level on the vertical axis. The ideal operating state would be with a zone level of 50% and zero power error.

As an example consider the reactor operating state to be in the region H1. Zone level adjustment alone is not capable of reducing the power error to zero. An adjuster rod(s) will be lowered into the reactor core. When the reactor operating state has been shifted to region N1 the adjuster indrive will cease.

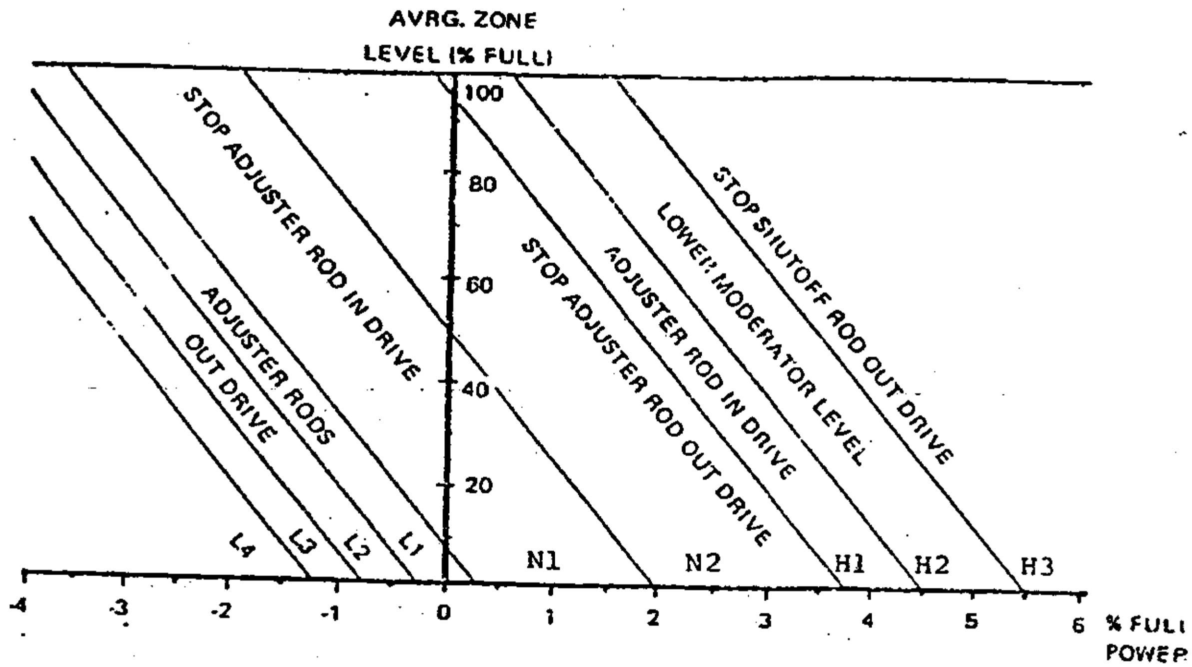

Figure 1: Power Error = $P_{ACT} - P_{DEM}$.

Now consider reactor operation in regions L1, L2, L3 and L4. In this instance at least one adjuster rod will be selected to be withdrawn. When the reactor state has been shifted to region N2, adjuster rod withdrawal is stopped.

Note that the two regions N1 and N2 provide a deadband or hysteresis to prevent adjuster rod cycling.

Unless the reactor is operating in region H3 shutoff rod outdrive will be in effect (normally fully out). Similarly operating in regions H2 or H3 will initiate a lowering of moderator level.

800MW CANDU

The first 800MW CANDU design included booster rods as the principal reactivity mechanisms to provide poison override capability instead of adjuster rods.

The operation is best described with reference to Figure 2. The normal operating range of zone level control is between 20% and 80%. The first control reaction to, say, a negative power error which cannot be handled by zone level manipulation would be to drive out control absorbers. If the power error still existed then boosters, in a predefined order, would be driven into the core after the required operational prerequisites have been fulfilled.

The preferred reactor operation is once again by zone level control with absorbers and boosters fully out of the core.

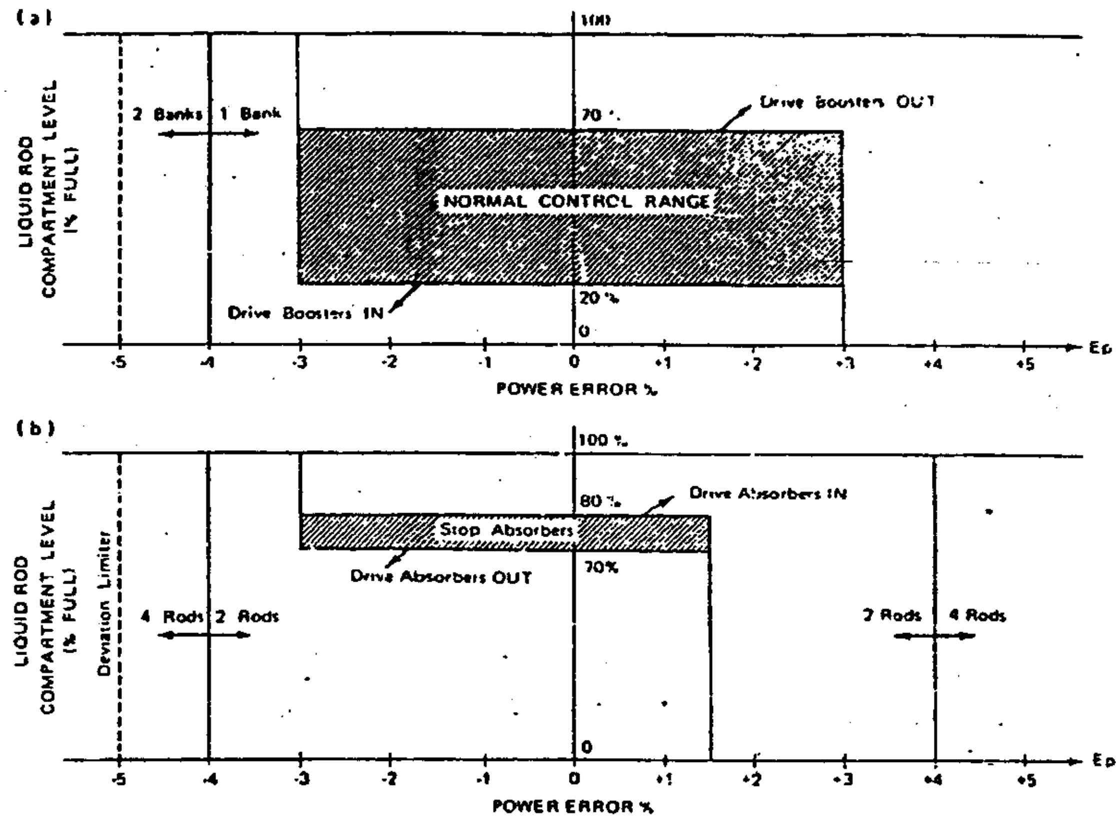

Figure 2: 800MW CANDU Limit Control Diagram.

Note the position of the absorbers is "infinitely" variable between the fully out and fully in limits. Boosters, once having started to be driven in either direction, go to either fully in or fully out.

Setbacks and Stepbacks

Setbacks and stepbacks are the methods used to quickly reduce reactor power in the event that certain control parameters exceed their predetermined limits. The systems are entirely separate from the shutdown systems and are present to reduce the frequency of operation of the safety systems.

A stepback is effected by opening the clutches on the control absorbers thus allowing them to drop into the reactor, making it subcritical. It is possible to limit the fall of these absorbers by re-energizing the clutches after a short, predetermined, period. The reactor will now be operating at a lower power state than previously. If the reenergizing is not performed soon enough the reactor power will drop towards zero.

If the need for a power reduction is not so urgent a "setback" will occur rather than a stepback. The reactor power is lowered at a controlled rate, by filling of the liquid zone compartments. The setback will terminate either when the variable causing it has returned to within its limits or when a predetermined power level is reached. The rate at which power is reduced and the power level at which the setback ends may be different for each variable.

Typical Setback Conditions

Condition	Terminal Reactor Power
Turbine Trip	0.6 F.P.
H.T.S. Pump Fail	0.65 x Initial Power
V.L. Pressurizer Level	0
Loss of Booster Cooling	0

Typical Stepback Conditions

Condition	Rampdown Rate (%/sec)	Endpoint % F.P.
High Local Flux	0.1	40
High Pressurizer Level	0.1	2
High Boiler Pressure	0.5	8
Zone Water Pres Low	0.2	60

Flux Mapping

Flux mapping is a method of monitoring the three dimensional power distribution within the reactor so that individual fuel bundles and fuel channels can be operated within their design limits.

This flux mapping uses a large number of incore detectors located spatially throughout the reactor. These detectors have vanadium emitters and their response, unlike those with platinum emitters, is entirely due to neutrons. The speed of response is, however, slower than incore detectors fitted with platinum emitters.

It should be emphasized that this flux mapping is a monitoring system that will provide information to other control systems within the RRS as required. An example would be, as previously described, to initiate a reactor setback in the event of a locally high neutron flux.

Assignment

1. State the purpose of the Reactor Regulating System.

2. Briefly describe, using a diagram helps, the need for both linear and logarithmic control of a CANDU reactor.

3. Briefly describe, with the aid of simple sketches, the construction and operation of ion chambers and incore detectors.

4. Briefly describe why it is necessary to measure reactor thermal power.

5. In a few lines, describe the function of the following control routines:
   (a) Boron Correction Factor (BORCF)
   (b) Limit Control Routine (LIMCR)

6. Briefly explain how the RRS handles:
   (a) a single control computer stall
   (b) a dual control computer stall.

7. State the requirement for the setback and stepback function and how it is achieved.

8. List two conditions which will result in:
   (a) setback
   (b) stepback

9. Briefly describe the method of producing a three dimensional neutron flux profile for the reactor.