

B. ENERGY BALANCE

ENABLING OBJECTIVES:

- 4.3 For a typical CANDU system, state the basic parameters that must be monitored/controlled in the reactor, heat transport system, boilers and feedwater system.
- 4.4 Describe how the boiler pressure is used to control the overall energy balance of the station.
- 4.5 Describe the reactor leading or lagging mode of plant operation.
- 4.6 Describe the function of each of the following control programs:
 - a) Reactor Regulating System;
 - b) Boiler Pressure control;
 - c) Boiler Level control;
 - d) Unit Power Regulation.

MEASURED PARAMETERS

Before we can control any process, we must first measure it. There are thousands of devices in the station measuring pressures, temperatures, fluid flows, tank levels, neutron flux, device positions, electric current, voltage, chemical concentration, pH, etc. Some processes are controlled manually and some automatically using devices called controllers.

Control for many processes is done locally while others are controlled remotely from the **main control room (MCR)**. Process parameters are measured at the source and the measurement signals transmitted to the MCR electronically. The most important measurements are duplicated or triplicated. Remember that there are independent, triplicated instruments for the regulation system and for each of the special safety systems. Many processes are controlled by the station computers.

This section first reviews the main parameters monitored to verify compliance with the golden rule of reactor safety (control, cool, and contain) during normal operation. (During shutdown, or after an upset, there are many other similar parameters to be measured.)

The next section begins a description of the automatic control of the entire energy flow path, from the reactor through the steam/feedwater system to generator output.

For **control** of reactor power, the positions of the reactivity devices (e.g. liquid zone control levels) are monitored to observe that they are responding correctly. Power is monitored by neutronic instruments sensitive to neutron flux. Coolant flows and temperatures across the core are used to help determine thermal power output.

Adequate **cooling** is assured if there are capable heat sinks in place. In normal operation this means HTS pressure is monitored. Low pressure could indicate a HTS break with loss of coolant. High pressure could indicate poor heat removal from the HTS. We also monitor boiler pressure to make sure there is an adequate temperature difference between the coolant and the secondary side. A boiler level measurement indicates enough inventory to continue removing heat from the HTS.

To make sure that an adequate heat sink continues to be available we monitor HTS inventory (storage tank level and, where applicable, pressurizer level). We also monitor secondary side inventory by measuring: feedwater flow; steam flow; deaerator and condenser pressures, levels, and temperatures. Any unusual reading could indicate that a loss of the heat sink is about to occur.

To see if **containment** is in place we monitor each of the boundaries. Radioactivity in the coolant indicates failure of fuel sheaths and release of fission products from the ceramic pellet. HTS pressure is monitored; it will drop if there is a break in the HTS. Similarly, a break in the pressure boundary is indicated by high containment pressure or high radiation level. Also, high moderator level or high moderator pressure could indicate rupture of a pressure tube into the calandria.

It is the operator's task, in the control room and in the field, to monitor and adjust these various parameters as required. For systems with automatic control the operator must verify that the control is working properly, and respond appropriately if it is not. It is vital that the operator know the normal system conditions and their response to changes; and understand the systems and the instrumentation principles well enough to respond correctly to a fault.

BOILER PRESSURE CONTROL (BPC)

At power, boiler pressure is an excellent indicator of how well the reactor power output is matched to the steam load. The boiler is the link between

the primary and secondary side, and BPC is the hub of the control scheme. BPC matches the primary and secondary side either by:

- adjusting reactor power or,
- adjusting steam flow.

For overall unit control, it is very important to match the **heat supply** to the boilers with the **heat removal** from them. When the two balance, the energy stored in the boiler water and steam does not change.

Consequently, boiler pressure and temperature stay constant. If the heat input to the boiler exceeds the heat output, the surplus heat is deposited in the boiler, thereby raising its pressure and temperature. The opposite happens when the heat input is below the heat output. In this case, heat is withdrawn from the boilers causing the boiler pressure and temperature to drop. These cases are summarized in the table below.

CASE	EFFECT
Heat input = Heat output	p, T stay constant
Heat input > Heat output	p, T rise
Heat input < Heat output	p, T drop

During transition periods, boiler pressure measurements change faster than temperature measurements. Therefore, to control the heat flow through the boilers, we monitor boiler pressure, and not boiler temperature.

Certain operating states or upsets disturb the heat flow through the boilers. This causes the boiler pressure to change. During warming of the boilers and the HT system, boiler pressure rises gradually from atmospheric pressure to 4-5 MPa, depending on the station. During the remaining operating states only a transient pressure rise occurs. The largest boiler pressure transient occurs on a turbine trip from full power or a full load rejection.

It is important to realize that even a small mismatch between the boiler heat input and output, if allowed to last long enough, can eventually cause a large boiler pressure change. In reality, it is counteracted by appropriate corrective actions as described in the next topic. These actions mitigate boiler pressure changes such that it varies only slightly from its setpoint.

UNIT MODE OF OPERATION

To keep boiler pressure at its setpoint, BPC must try to maintain a proper balance between the boiler heat input and output. This can be achieved by varying either the reactor power (heat input) or the steam flow (heat output). This brings us to the two modes of BPC operation. The main difference between these two modes of operations is from where the reactor power setpoint comes.

REACTOR LAGGING MODE

In this mode of operation the turbine-generator load is set by the operator. The BPC program requests variations in reactor power to maintain a constant boiler pressure. This control mode is termed **reactor lagging mode** or turbine leading mode because the reactor power responds to changes in the turbine output power. This is the preferred mode of BPC operation in most CANDU stations. Its name reflects that when this mode of control is used, changes in reactor power lag behind changes in turbine generator output.

REACTOR LEADING MODE

In this control mode the station loads are made to follow the reactor output. The BPC program controls the steam governor valves to match steam flow to the turbine with reactor power. This is called **reactor leading mode** operation as the turbine power adjusts to the reactor power output. This is achieved by the BPC program adjusting turbine load to maintain a constant boiler pressure. The reactor power setpoint is adjusted depending on reactor operating conditions. This mode is used at low reactor power levels, during startup or shutdown when the boiler pressure is insensitive to reactor power. It is also used in some upset conditions when it may not be desirable to manoeuvre reactor power.

IMPORTANT PROGRAMS

Control programs loaded on control computers perform the function of overall station control. These are independent programs that share and communicate important data. The major control programs are described below.

Table 4.1 summarizes the programs with the parameters measured and the different variables controlled and manipulated. A simplified general layout of the station control system is illustrated in Figure 4.2.

Table 4.1

Program Name	Measured Parameter(s)	Variable(s) Controlled	Variable(s) Manipulated
RRS	<ul style="list-style-type: none"> Reactor Bulk Power 	<ul style="list-style-type: none"> Neutron flux 	<ul style="list-style-type: none"> Zone water level Rod Position
BPC	<ul style="list-style-type: none"> Boiler pressure Reactor power Steam Flow 	<ul style="list-style-type: none"> Boiler pressure 	<ul style="list-style-type: none"> Reactor setpoint Steam flow
UPR	<ul style="list-style-type: none"> Electrical output 	<ul style="list-style-type: none"> Electrical output Steam flow 	<ul style="list-style-type: none"> Steam flow
BLC	<ul style="list-style-type: none"> Boiler level Reactor power Feedwater flow Steam flow 	<ul style="list-style-type: none"> Level (Inventory) 	<ul style="list-style-type: none"> Feedwater flow
HTSP	<ul style="list-style-type: none"> HTS Pressure 	<ul style="list-style-type: none"> D₂O Pressure Pressurizer Level (where applicable) 	<ul style="list-style-type: none"> D₂O Feed & Bleed and/or pressurizer steam bleed & heaters (where applicable)

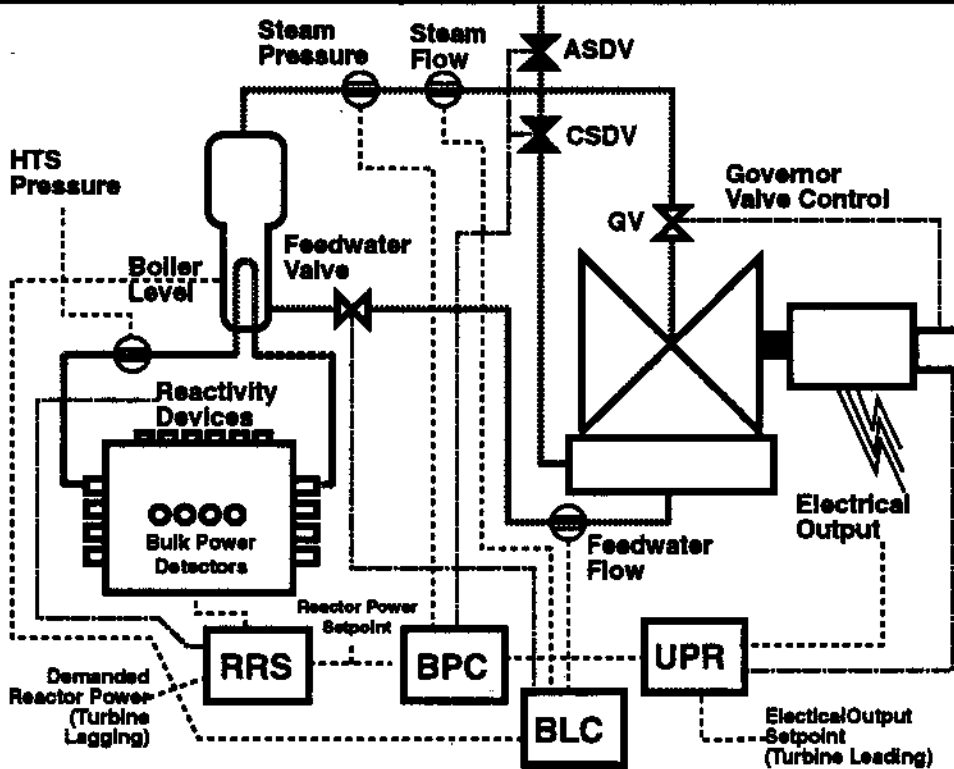


Figure 4.2
 Simplified Layout of Station Control System

REACTOR REGULATING SYSTEM (RRS) REACTOR POWER CONTROL

This program adjusts the reactivity control devices to maintain reactor power at the desired setpoint and, when required, to manoeuvre the reactor power level between set limits at specific rates. It also monitors and controls power distribution within the reactor core to optimize fuel bundle and fuel channel power within their design specification. The reactivity control devices include:

- liquid zones,
- control absorbers,
- adjusters.

BOILER PRESSURE CONTROL (BPC)

This program controls boiler pressure to a constant setpoint, by changing reactor setpoint (reactor lagging mode), or adjusting the turbine load (reactor leading mode). BPC always has control of the steam reject valves (ASDVs & CSDVs).² If BPC cannot prevent high boiler pressure by adjusting either steam flow or by adjusting reactor power, the boiler pressure is reduced by steam reject valves (SRVs).

UNIT POWER REGULATION (UPR) TURBINE LOAD CONTROL

This program manoeuvres the unit power in the reactor lagging mode, by adjusting the turbine load setpoint, to maintain the generator output at the level demanded by the local operator, or a remote control center. In reactor leading mode UPR has only a monitoring function and takes no active part in control.

BOILER LEVEL CONTROL (BLC)

BLC is used to control the water level in each boiler under all unit power conditions from 0% to 100% full power. This program controls the feedwater valves to maintain the water level in the boiler sufficient for the reactor power level setpoint.

² Atmospheric steam discharge valves (ASDVs) discharge excess steam to the atmosphere. Condenser steam discharge valves (CSDVs) discharge steam to the condenser.

HEAT TRANSPORT SYSTEM PRESSURE AND INVENTORY CONTROL (HTSP)

This program controls the heat transport pressure control system to maintain heat transport pressure at a fixed setpoint. In stations with a pressurizer, pressurizer level is also controlled.

Separate programs are also installed to provide a number of miscellaneous control and alarm functions for:

- PHT System Control,
- Moderator Temperature Control,
- Turbine Runup and Monitoring,
- Fuel Handling System Control.

ASSIGNMENT

1. What are the major parameters measured in each of the following?
 - a) Reactor
 - b) Heat Transport System
 - c) Boilers
 - d) Feedwater System
2. Why is boiler pressure used as the major parameter for overall unit control?
3. What is the difference between reactor leading and lagging mode?

4. Fill in the following table.

Control Programme	Purpose
RRS	
BPC	
BLC	
UPR	