CHAPTER 7: OVERALL UNIT CONTROL

MODULE 2: BOILER PRESSURE CONTROL

MODULE OBJECTIVES:

At the end of this module, you will be able to:

1. Briefly explain, in writing, the role of BPC during:

a) Warmup;
b) Cooldown.

2. Briefly explain, in writing and with a sketch, how BPC maintains the turbine at its operating setpoint.

3. Briefly explain, as a sequence of control events, how Boiler Pressure Control counters:

a) Reactor Trip;
b) Load Rejection.

4. Briefly describe, in a few lines, how BPC functions during an increase in unit power output.

Introduction

The Boiler Pressure Control (BPC) in a typical CANDU generating station will perform the following functions:

(1) . To control boiler pressure under normal operating conditions to a specified setpoint.

(2). To warmup or cool down the heat transport system at a controlled rate.

Since, under saturated conditions, steam pressure and temperature are uniquely related, boiler pressure is used to indicate the balance between reactor heat output and steam loading conditions. Steam pressure measurement is used since it provides a faster response than a temperature measurement. The Boiler Pressure Control is a digital control loop with a sampling period every 2 seconds.

Basic Principles

A steam generator (boiler) is simply a heat exchanger and as such it obeys the following relationship with respect to heat transfer from one side of the boiler (tubes) to the other (shell).

$$\dot{Q} = U.\,A.\,\Delta T$$

where:

$\dot{Q}$	=	**the rate of exchange of heat from the HTS to the boiler water (kJ/s).**
U	=	**heat transfer coefficient of the tubes (kJ/s/m^2)**
A	=	**tube area (m^2)**
ΔT	=	**temperature difference between HTS and steam generator.**

A and U are a function of boiler design and therefore $\dot{Q}$ is proportional to ΔT. If reactor output increases then more heat must be transferred to the boiler water. $\dot{Q}$ has to rise, therefore ΔT must also increase.

This increase in ΔT can be achieved by either allowing the average HTS temperature to increase as reactor power increases or by arranging that the boiler pressure falls, and therefore boiler temperature falls, as reactor power increases.

At units fitted with a pressurizer the first method is employed. At units without pressurizer, the second method is used.

BPC Operation for Units having a Pressurizer

Under normal operating conditions BPC manipulates the reactor power output in order to control boiler pressure at its setpoint. The turbine/generator, which is the heat sink for the boilers, is controlled to an operator specified setpoint.

"Alternate" or "Reactor Leading" Operation

If the unit is operating in the reactor leading mode - at low power or unusually high power conditions - the reactor power setpoint is specified by the operator. Boiler pressure is then controlled to its setpoint by manipulation of the steam loads, i.e., turbine and steam discharge valves.

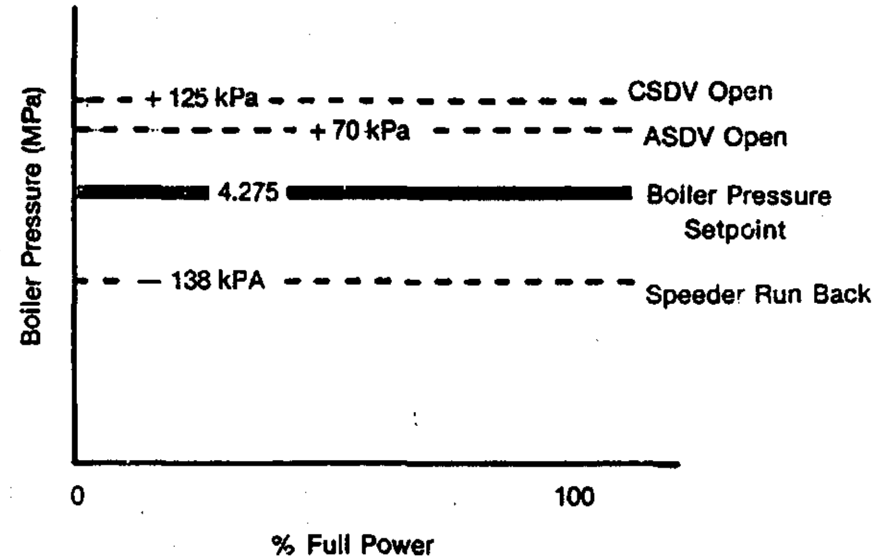

Figure 1: Boiler Pressure and Reject Valve Setpoints.

Steam Discharge Valve Control

The Atmospheric Steam Discharge Valves (ASDV) and Condenser Steam Discharge Valves (CSDV) are, under normal operating conditions, closed due to the introduction of a bias signal. If, for any reason, the boiler pressure rises above its setpoint by 70 kPa the ASDVs will open. If the rise in boiler pressure is greater than 125 kPa above setpoint the CSDVs will start to open.

If the positive boiler pressure error is not corrected by the ASDVs and CSDVs a reactor setback will be initiated to correct the thermal mismatch.

If the boiler pressure is below the setpoint the speeder gear will run back to unload the turbine. A new, lower, operating point should be established with boiler pressure at its setpoint but with reduced electrical output.

Response to Reactor Trip

Under these conditions heat input to the boilers has been reduced rapidly towards zero. The turbine output must also be quickly reduced to avoid a gross energy mismatch which will reduce drastically the pressure and temperature of the HTS.

The reduction in heat input will cause a drop in boiler pressure below the setpoint. The speeder gear will run back to ensure the heat balance between reactor and unit output is re-established at the decay heat level. Any shrinkage in the HTS inventory will be made good by transfer of D_2O from the pressurizer to the HTS or by additional feed from the pressurizing pumps.

Load Rejection

Under these conditions two control corrections must be made.

Firstly the potential turbine overspeed must be prevented. The governor/speeder gear will limit turbine speed and prevent an overspeed trip. In addition the Intercept Valves (IV) will close to prevent steam being fed to the low pressure turbine and the Release Valves (RV) must be opened to dump steam to prevent reheater over pressurization. When the turbine speed has re-stabilized at 1800 rpm the IV's will re-open and the RV's will close.

The second requirement is to reduce reactor output. This is ensured by the initiation of a reactor stepback to 2% FP at the instant of load rejection.

Note that poison prevent operation may be necessary to prevent a poison outage, i.e., the unit will be run at 60-70% using its alternative heat sinks - the CSDVs.

BPC Operation for Units without a Pressurizer

Units with only feed and bleed systems for Heat Transport pressure control are normally run as base load, reactor leading, stations. The response of the Heat Transport System to transients caused by power maneuvering is very limited. The Boiler Pressure Control System has a role in limiting the potential swell and shrink of the HTS inventory by maintaining the HTS average temperature essentially constant over the full operating range.

To control the boiler pressure, (the controlled variable) the following manipulated variables are used:

(a) Reactor Power
(b) Turbine Steam Flow
(c) Steam Reject Valve (SRV) Steam Flow

The boiler pressure will be decreased from 5 MPa to 4 MPa as unit power is raised from 0 to 100% full power. This is also the turbine operating ramp. The SRV setpoint is a parallel ramp set 100 kPa higher than the turbine ramp.

Should the boiler pressure rise by more than 100 kPa excess pressure will be released by the small SRVs. If the positive pressure transient is not corrected by the small SRVs the large SRVs will start to open. Opening of the large SRVs will initiate a reactor setback.

If the boiler pressure falls below the turbine setpoint the speeder gear will run back to a point where the decreased turbine power will be matched to the, now increased, boiler pressure.

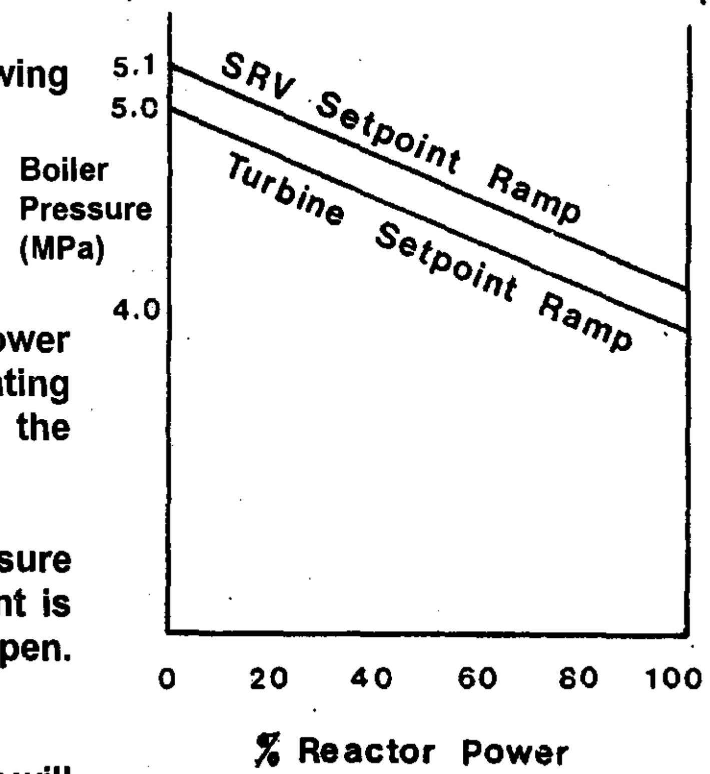

Figure 2: Turbine and SRV Setpoint-Ramps.

Response to Reactor Trip or Setback

The limited response of a feed and bleed HTS to large transients has already been mentioned. It is necessary therefore that, for the transient produced by a reactor trip, control should be as immediate as is possible. The speed of response is enhanced by using a feedforward signal. It will act on the disturbance which will eventually cause the control error to appear.

The BPC is a digitally system executing every two seconds. If the present reading of reactor power is less than it was two seconds previously, the control system will decide that the reactor has been tripped or setback. A fast speeder gear runback will be initiated thus anticipating the error and stabilizing the energy balance at a lower level.

Load Rejection

The problem is again a gross energy mismatch, with maximum input (reactor) and minimum output (electrical power). The solution is to find an alternate heat sink as soon as possible. This heat sink will be the SRVs.

Again use is made of a feed forward signal, in this case the pressure differential existing across the ESV, GSV combination. Under normal conditions, with both valves fully open, this pressure difference will be minimal and relatively constant. The load rejection will cause the ESV to close with a resulting rapid increase in the differential pressure (boiler side increases, turbine side decreases). This increase in ΔP is used as a feed forward signal which triggers the Fast Boiler Pressure Control (FBPC) program. This program executes every 0.5 seconds instead of the normal 2 seconds. The FBPC program opens the large SRVs fully thus providing an effective heat sink in a much shorter time. In addition, the opening of the SRVs will trigger a reactor setback. Again this accelerated control action should limit the size of the HTS pressure transient and prevent a reactor trip.

The potential turbine overspeeding must be controlled by the governor/speeder gear. The Intercept Valves and Release Valves operate to stop steam flow to the LP turbine. The ESV will reopen approximately five seconds after closing when the governing system should once again be in control.

Warmup and Cool Down Operation

Warmup Mode

At some point in the start up procedure for a CANDU unit the reactor heat sink must be transferred from the shutdown cooling system to the normal primary heatsink, i.e., the boilers. This transfer is usually effected at a HTS temperature of approximately 170°C depending upon location.

Once the boilers have been established as the primary heatsink the temperature of the HTS can be raised at a pre-determined rate by manipulation of the boiler pressure.

The procedure is as follows:

Consider a steady reactor thermal output, say 2% full power. The energy train can be made to balance by discharging steam to atmosphere from the boilers via ASDVs or SRVs, i.e., 2% heat input and 2% output.

If we restrict the output from the boilers by closing the reject valves slightly we now have an energy imbalance at the boiler stage. More heat energy is entering the boilers than is leaving and the boiler pressure and temperature will therefore increase.

Recall the equation describing heat transfer between the HTS and the boilers:

$$\dot{Q} = U.\ A.\ \Delta T$$

To maintain the ΔT constant the HTS temperature will have to increase since $\dot{Q}$, U and A are all constant quantities. Eventually we will have reached a situation where, for a constant heat input from the reactor, we have raised both boiler and HTS pressures and temperatures. The warmup process can now be continued by requesting an increase in boiler pressure which will be accomplished by a further closing of the steam discharge valves.

Cooldown Mode

This mode is used to cool the HTS when bringing the unit down from a full power operating state. Again use is made of either the SRVs or the ASDVs to control boiler pressure.

In this instance the process is initiated by an opening of the steam discharge valves. Again, for a steady reactor thermal output, the change in boiler pressure, and therefore temperature, must cause a change in HTS temperature in order to maintain a constant ΔT between HTS and Boilers.

In theory this progressive opening of the discharge valves should reduce boiler pressure to atmospheric but in practice, as boiler pressure falls, the discharge rate of the valves is insufficient to drop the boiler pressure further. When the valves are fully open BPC has lost control of the cooldown.

Thus, when the discharge valves reach their fully open state, the heat sink for the system is transferred to the shutdown coolers. Again, according to station design, this transfer will take place at approximately 170°C.

Boiler Pressure Response to A Requested Increase in Electrical Output

A request for increased electrical output will create an error signal between the existing output and the new setpoint. This error signal will cause the speeder gear to run up and thus increase the steam flow to the turbine. This increased steam flow will result in an increased electrical output and eliminate the error which has been created.

The increased steam flow will inevitably cause boiler pressure to fall. However, the increased governor valve opening results in an increased steam pressure on the turbine side of the governor valve. This pressure increase is used as a feedforward signal which can be used to modify the reactor power setpoint in advance of the negative boiler pressure error developing.

In practice the feedforward signal will limit the size of the negative boiler pressure transient but is unable to eliminate it completely. The resulting drop in boiler pressure is used as a feedback signal to the boiler pressure control program. This will cause a further adjustment to be made to reactor power output and thus return the boiler pressure to its setpoint.

Assignment

1. **Briefly state the two main functions of the Boiler Pressure Control System.**

2. **Briefly explain how the Boiler Pressure is manipulated to achieve a controlled warm-up mode.**

3. **Briefly explain the method of cooling the HTS by means of Boiler Pressure control.**

4. **Briefly explain in writing, and with a sketch, how the turbine is kept at it's operating setpoint by the BPC.**

5. **For either type of HTS (Feed and Bleed or Pressurizer) list a detailed sequence of control reactions in the event of:**

   (a) **Load Rejection**

   (b) **Reactor Trip.**

6. **Describe briefly the BPC's role in a demanded increase of unit power output.**