Lesson 5: General Digital Control Program Concepts

Module #1: Moderator Temperature Control Program

This lesson provides an introduction to digital control program concepts using the CANDU Moderator Temperature Control (**MTC**) application as an example.

System Description

- The Moderator is the **heavy water D_2O inventory** (used to slow the fission neutrons to thermal energy levels) inside the calandria which is circulated by a main pump through a heat exchanger before being returned to the calandria (so this is a closed system).

- The moderator D_2O fluid is warmed to about 61 C at the moderator outlet by fission process heat and must be cooled by the control of recirculated cooling water flow through the heat exchanger.

- The heat exchanger outlet temperature (calandria inlet temperature) is approximately 35 C at full power so the moderator D_2O can be expected to rise by about 26 C as it is transported through the calandria.

Assignment

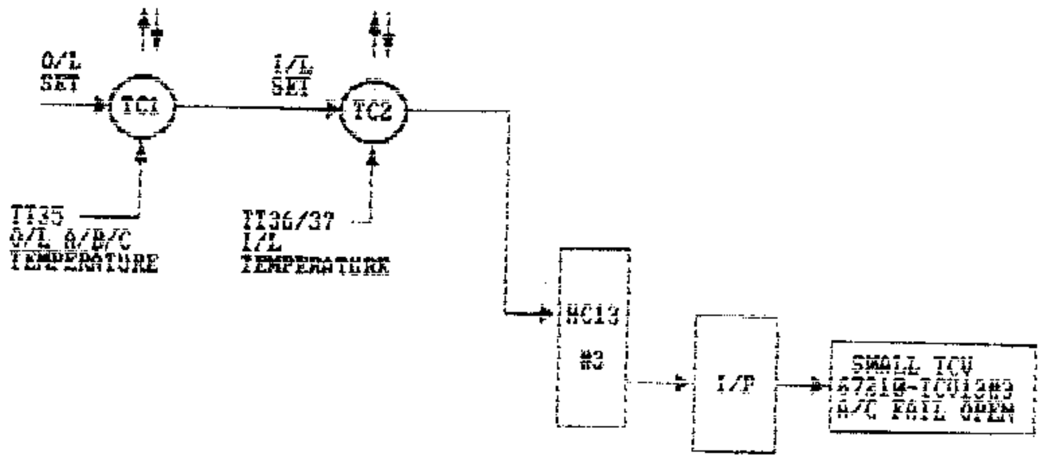
Make a simple process sketch of this system to show the Moderator Temperature Control System. You need only show one pump and one heat exchanger - label the direction of flow for the moderator inventory. You should also label both the calandria outlet and calandria inlet temperature points along with a representative large and small temperature control valve which regulates the low pressure service water flow to the heat exchanger.

MTC Program Description

- The function of the Moderator Temperature Control (MTC) program is to control the ***temperature*** of the moderator heavy water (D_2O) at the calandria outlet to a selected setpoint (usually 61 C at power).
- The MTC is a switched critical computer task which runs every 2 seconds.
- This control program will read the ***calandria inlet*** and ***calandria outlet temperature*** signals and use the ***signal selection routines*** to calculate a ***working*** calandria outlet temperature parameter ($\mathbf{T_{mo}}$) and a ***working*** calandria inlet temperature parameter ($\mathbf{T_{min}}$) for control sensing purposes.
- The normal at power operation setpoint ($\mathbf{SET_{Tmo}}$) is 61 C but the operator has the option of changing this setpoint via the operator keyboard.
- During ***start-up operations***, the moderator temperature setpoint would be gradually raised from say 20 C (cold shutdown state) to 61 C (the full power operating temperature) in small increments (so as to allow thermal stabilization) via manual keyboard entry commands.

- The actual temperature control is achieved by modulating ***six temperature control valves*** (i.e. there are three valves per heat exchanger;TCV13#1/#2/#3, and TCV14#1/#2/#3) which regulate the flow of the low pressure service water flow to the two large moderator heat exchangers (each rated at ***50% FP capacity***).

Figure #1 The Cascade Control Configuration for Moderator Temperature Control



MTC Program Description…(continued)

- There are ***two large valves*** (for example TCV-#1/#2) working in parallel and ***one small valve*** (TCV-#3 say adequate for 40% FP, season dependent) for each heat exchanger.

- The control scheme is a ***cascade control*** method utilizing ***moderator heat exchanger outlet temperature*** (i.e. the calandria inlet temperature), the ***calandria outlet temperature*** and a ***feed-forward*** term based on ***linear reactor neutronic power***.

- For normal operation, the calandria outlet temperature is controlled to the setpoint temperature of 61 C by the operation of the six temperature control valves which control the flow of cooling water to the two heat exchangers. The setpoint value can be changed at any time by the operator via the setpoint display for MTC.

MTC Program Description…(continued)

- There are ***two large valves*** (for example TCV-#1/#2) working in parallel and ***one small valve*** (TCV-#3 say adequate for 40% FP, season dependent) for each heat exchanger.

- The control scheme is a ***cascade control*** method utilizing ***moderator heat exchanger outlet temperature*** (i.e. the calandria inlet temperature), the ***calandria outlet temperature*** and a ***feed-forward*** term based on ***linear reactor neutronic power***.

- On loss of ***Class IV power*** (the regular power supply to the plant equipment), the service water supplies are interrupted by the loss of pumps and then the recovery ***electrical load is reduced or shed*** (i.e. this is accomplished by closing the large TCV's to reduce the service water pump load).

- Class III power will be established (from ***standby generators***) and service water flow to the heat exchangers will be available after 180 - 240 seconds at a reduced rate.

- The only other control program that MTC interfaces with is the ***Reactor Regulating System*** (i.e. RRS) from which the Linear Reactor Power (***Plin***) is obtained.

Moderator Outlet Temperature Selection

- The moderator ***outlet temperature*** is measured by three RTD's (63210-TT35A/B/C) each of which has a range of 0-100 C.

- If all of these temperature signals are ***rational*** (i.e. within preset signal voltage limits) then the ***median*** signal is selected (i.e. reject the high and reject the low signal) for control purposes as T_{mo}.

- Actually, prior to selecting the median signal for control, the three rational signals are also checked for ***validity*** against each other and if they are all within 3 C of each other, then the median signal is still selected.

- However, if only two signals are within 3 C, then the ***drifted*** signal is alarmed and the ***highest valid*** temperature is selected as T_{mo}.

- If none of the three rational signals are within 3 C of each other, then this condition (i.e. not validated) is annunciated and the median rational signal is still selected as T_{mo}.

- If one of the three calandria outlet signals is not rational then that signal is ***rejected*** and the condition is annunciated. The remaining two signals are checked for validity to see if they are within 3 C of each other.

Moderator Outlet Temperature Selection....continued

- The ***highest*** of these two rational signals is selected for control sensing regardless of the validity check decision, although an alarm would be annunciated to advise the operator that the MTC Calandria outlet temperature measurement has ***not been validated***.

- Note that selecting the highest temperature is a ***conservative action*** since the reactor would be ***setback*** (i.e. initiate a forced power reduction) or tripped if the moderator becomes too warm.

- If only one of the three calandria outlet temperatures is rational, then that rational signal is selected for control sensing purposes while the other two signals are rejected and their irrational condition is annunciated.

- If none of the three calandria outlet temperatures is rational, all three signals are annunciated as irrational and the MTC program can not satisfy the conditions for continued operation and the program is ***failed-off*** (i.e. the program is stopped from running in that computer).

Assignment:

1. Prepare a ***flow chart*** to illustrate the logic needed for the calandria outlet temperature signal selection as described above.

2. Comment on the ***apparent usefulness*** of the validity checks for this control application - what is the significance of these checks to the overall control program performance.

Moderator Inlet Temperature Selection

- The calandria inlet temperature (**T_{min}**) is measured over a **0-100 C** range by two RTD's (63210-TT36/37) with one RTD located at each outlet of the two moderator heat exchangers (i.e. one RTD per HX outlet).
- If both signals are rational (i.e. within preset voltage limits), then the ***average*** of the two signals is prepared for use as the T_{min} control sensing parameter.
- If these inlet temperature signals are not within 5 C of each other, then the calandria inlet temperature signals are annunciated as ***drifted*** (note that we do not know which one is wrong, just that there is poor agreement), but the average is still used for control sensing purposes.
- If one calandria inlet temperature signal is irrational, then it is ***rejected*** from selection and annunciated as ***irrational***. The rational temperature signal is selected for ***control sensing*** as T_{min}.
- If both calandria inlet temperature signals are ***irrational***, then they are rejected and annunciated. Under these conditions, the MTC program can not satisfy the conditions for continued operation and so the program will ***fail-off*** in the master computer.
- However, if these signals are still irrational when sensed by the ***standby computer*** (i.e. perhaps the irrational problem could have been with the input subsystem for the previous master computer and so the problem may have been eliminated by transferring to the standby computer), then a ***default*** or ***expected*** calandria inlet temperature value is assigned as a function of the reactor power (i.e. 60.85 C at 0 %FP to 35 C at 100 %FP).

Moderator Inlet Temperature Selection…continued

- This ***default inlet temperature value*** will allow the MTC program to continue to operate on the previous standby computer with ***full measurement and control of the moderator outlet temperature*** (i.e. the key parameter of concern).

- The preset inlet temperature value (i.e. not live) allows continued operation at power while maintenance can be initiated on the inlet temperature sensing circuits.

- The expected calandria inlet temperature or ***Feedforward*** temperature $\mathbf{T_{FD}}$ presents an ***expected temperature rise*** of 26 C from Calandria inlet to Calandria outlet temperature when operating at full power
  $\mathbf{T_{FD}}$ is calculated as:

  DT = 0.15 + (26.0 * Plin)
  where **Plin** is the normalized linear reactor power
  and

  $TFD = SET_{Tmo} - DT$

Moderator Inlet Temperature Control Loop Features

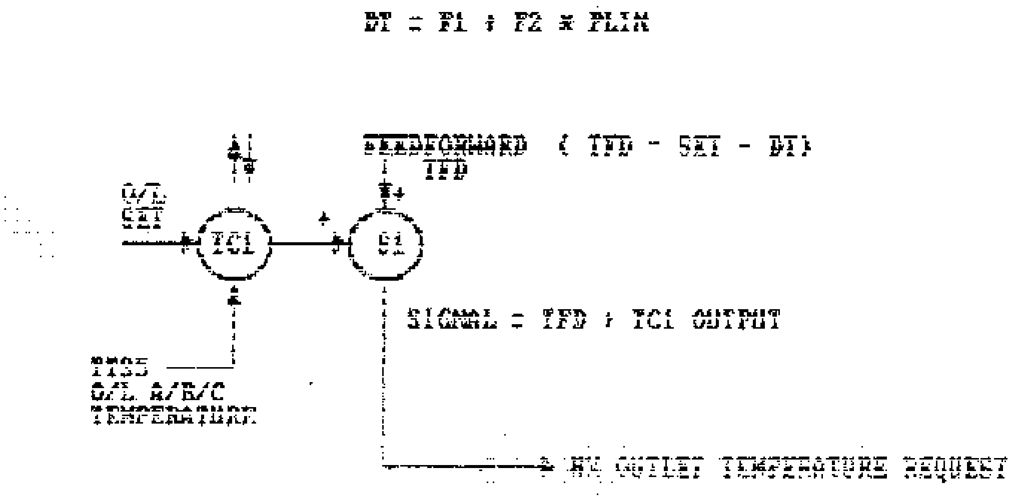


Figure #2 Moderator Inlet Temperature Setpoint Signal Conditioning

- The moderator inlet temperature loop controls the heat exchanger (***HX***) outlet temperature (or moderator inlet temperature) by manipulating the flow of the low pressure service water (***LPSW***) through the HX.

- The HX outlet temperature is sensed by ***duplicated*** temperature transmitters (i.e. TT36/37) which provide a 4-20 mA signal proportional to 0-100 C.

Moderator Inlet Temperature Control Loop Features..continued

- The LPSW flow is controlled by an air-to-close (i.e. the small TCV's will be used as the example for discussion purposes) ***fail-open*** valve (TCV13#3).

- Inlet Temperature controller TC2 (i.e. ***Secondary*** I/L Temperature Controller) compares the HX outlet temperature to the ***calculated*** setpoint $\mathbf{SET_{Tmi}}$ and develops a control signal to drive TCV13#3.

- Note that if the temperature is above the setpoint of TC2, that TCV13#3 must be requested to open more to provide more cooling. In order to open TCV13#3 the valve control signal must be decreased since TCV13#3 is an air-to-close valve. Thus TC2 must be a ***reverse acting controller*** (***increase*** in measurement, ***decrease*** in control signal).

- Calandria Inlet Temperature Controller TC2 will throttle TCV13#3 as required to manipulate the LPSW flow in an attempt to maintain or restore the HX outlet temperature to the setpoint value.

Moderator Inlet Temperature Control Loop Features…continued

- The temperature error should be calculated in the following manner:

  $T_{err} = SET_{Tmi} - T_{min}$

  To give the ***correct error sign*** (the error is ***negative*** once the temperature rises above the setpoint). Note that SET_{Tmi} is obtained from the control signal developed by the primary controller TC1.

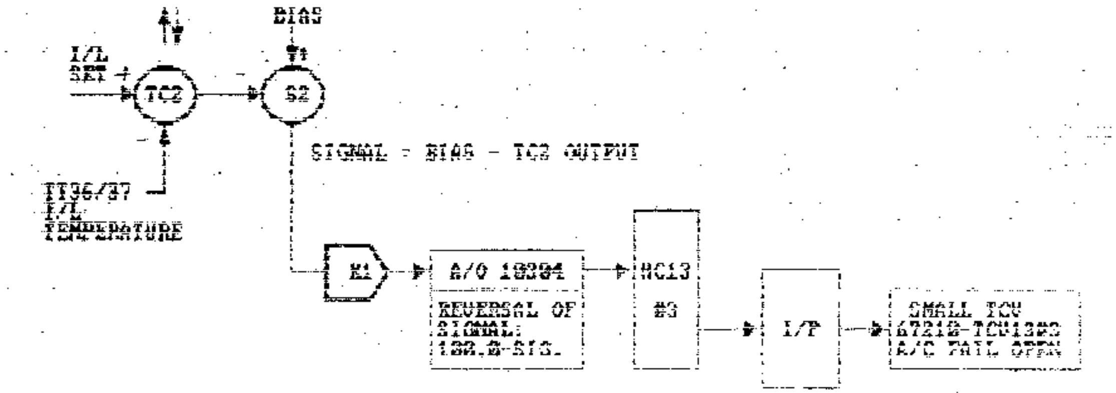


Figure #3 Moderator Inlet Temperature Control Loop Logic

Moderator Outlet Temperature Control Loop

- The moderator outlet temperature is sensed by ***triplicated*** temperature transmitters (TT35 A/B/C).
- The Moderator outlet temperature loop (TC1 - the ***primary*** control loop) controls the moderator outlet temperature by requesting colder or hotter inlet temperature setpoint values for TC2 (i.e. the ***control signal*** from TC1 becomes the ***setpoint*** SET_{Tmi} value for TC2) .
- The moderator outlet temperature controller (TC1) senses the moderator outlet temperature with respect to the TC1 setpoint of 61 C. If the moderator temperature is above the setpoint, TC1 must respond by asking for a lower inlet temperature. Therefore, TC1 must be a reverse acting controller (***increasing*** measurement, ***decreasing*** control signal).
- For example, if the moderator temperature is above the moderator outlet temperature setpoint ($\mathbf{SET_{Tmo}}$) of 61 C, then the moderator outlet loop controller will request a colder inlet temperature in an attempt to drive moderator outlet temperature back down toward the setpoint.
- This type of control is called ***cascade control*** with the ***major lag*** process (i.e. moderator outlet temperature) dictating the ***setpoint*** for the ***minor lag*** process (i.e. moderator inlet temperature).
- TC1 is the ***primary*** (or Major Lag) controller while TC2 is the ***secondary*** (or Minor Lag) controller
- If a moderator outlet temperature change occurred, TC1 will sense this temperature error with respect to the 61 C setpoint and will develop a control signal change which is the setpoint for TC2. TC2 will respond to the new error that had been created by changing the setpoint for the moderator inlet temperature loop. TCV13#3 will be driven by the TC2 control signal to try to match the HX inlet temperature to the new setpoint for TC2.

Moderator Outlet Temperature Control Loop…continued

- Note also that if the moderator outlet temperature was stable at the setpoint when a disturbance occurred at the heat exchanger outlet temperature (i.e. the moderator inlet temperature), then loop TC2 can act to correct this disturbance ***before the moderator outlet temperature is significantly disturbed*** so as to minimize any moderator outlet temperature changes.

Moderator Outlet Temperature Loop Operation

- Assume that the moderator outlet temperature was at the setpoint with the small TCV steady at 40% open position when some disturbance occurs which slightly increases the moderator outlet temperature.
- The temperature indicated by TT35 A/B/C will increase above the setpoint for TC1 which will cause a corresponding decrease in control signal which lowers the setpoint for TC2 so that a lower HX outlet temperature is requested.
- The control signal from TC2 will decrease so that the control valve is driven more open increasing the cooling water flow to the HX.
- The cooler HX outlet flow which is the inlet to the moderator should lower the moderator outlet temperature back toward the setpoint.
- As well, a ***summing function*** is provided with the outlet signal from TC1 to alter the setpoint request to TC2. This node allows a ***feedforward term*** to be introduced by subtracting the differential temperature value (i.e. DT) from the 0-100.0 Moderator Outlet Temperature Setpoint (i.e. to obtain desired inlet temperature) and then adding this value to the control signal value (i.e. Requested setpoint) developed by TC1.
- This feedforward term is DT = F1 + F2 * Plin. With F1 = 0.15 and F2 = 25.85 so that at 100%FP (i.e. Plin =1.0), with DT = 26.0 and so $TFD=Set_{TMO} - DT$ will be equal to 61.0-26.0= 35.0.

Moderator Temperature Rise Characterization

- This feature provides a factor which attempts to ***predict the temperature rise*** in the moderator from moderator inlet (HX outlet temperature) to moderator outlet.

- Note that there is expected to be very little temperature rise at ***zero power*** (0.15 C) but at ***full power*** the moderator inventory temperature will rise 26 C (i.e. inlet temperature of 35 C gives an outlet temperature of 61 C).

- So now consider the loop response to a moderator outlet temperature ***decrease*** while the reactor is held at a constant power level (i.e. Plin does not change). Signal values from TT35A/B/C will drop below the setpoint for TC1.

- Reverse acting TC1 output signal will increase which now adds the ***unchanged TFD*** value so that the requested setpoint signal for TC2 has ***increased***.

- The ***increase in setpoint*** to TC2 ***looks like a decrease in temperature*** and so the reverse acting TC2 will ***increase the control signal*** output.

- Increasing the control signal will drive the TCV more closed and so will ***decrease the coolant flow*** to the heat exchanger which in-turn will result in a ***higher calandria inlet temperature***.

- The ***warmer inlet flow*** will tend to raise the moderator outlet temperature back toward the setpoint to ***correct the original negative temperature error*** condition.

Calandria Inlet Temperature Loop Operation - Bias & Signal Reversal, small TCV

- Assume that the temperature was steady at the setpoint with the small TCV about 50% open when some disturbance is applied to slightly increase the HX outlet temperature.
- Then the TT36 and TT37 temperature will increase above that for the setpoint for TC2.
- TC2 responds by decreasing the control signal output which is subtracted from a ***bias*** value.
- The bias is an immediate ***estimate of necessary final valve position*** as a function of reactor power to act in a ***feedforward*** manner to quickly position the TCV independent of previous control decision values. Then proportional plus reset modes can act to bring the valve to a more correct final position.
- The (Bias - TC2) signal is a ***larger number*** (since TC2 signal was ***decreased***). A separate gain value (i.e. 2.5) is applied to this control signal to drive the small valve fully open with a 40% change in signal.
- The amplified signal value is now ***reversed*** by the function (Nsig = 100.0-Sig) so that the final signal output will decrease so the signal to the valve is reduced.
- The ***reduced signal*** to the air-to-close valve allows the ***valve to open more*** so the LPSW flow to the HX is increased to provide more cooling effect. Note that if the instrument ***air supply is lost***, that TCV13#3 will fail open (i.e. it is an air-to-close valve)

TCV Interfacing from the Inlet Temperature Control Loop

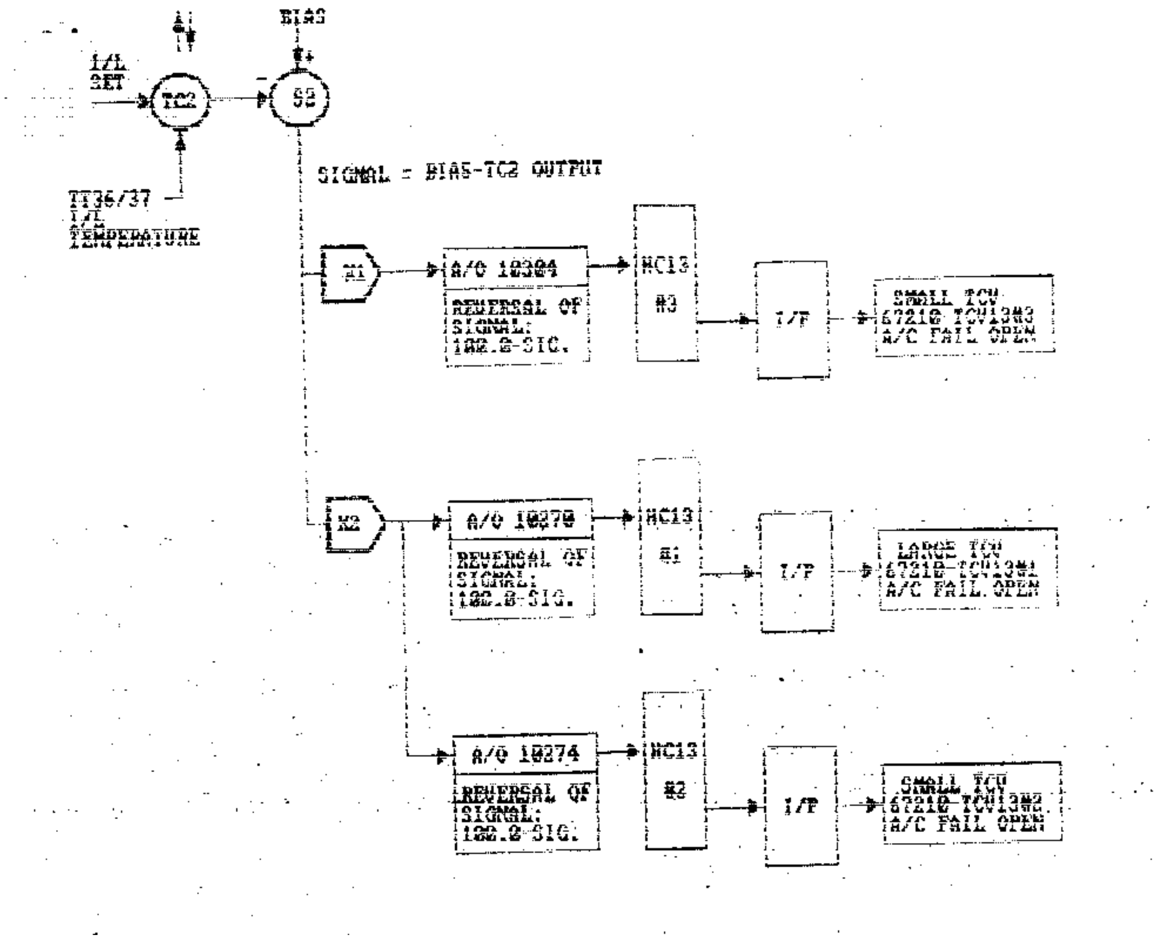


Figure #4 Moderator Inlet Temperature Control Loop – Final Valve Interfacing

Calandria Inlet Temperature Loop Operation - All TCV's

- The complete loop logic now involves the moderator inlet temperature TC2 which compares the temperatures from TT36 & TT37 against the ***computed setpoint*** which is cascaded from TC1.

- The output signal from TC2 is subtracted from a ***feedforward bias*** which attempts to set the valves roughly as a function of reactor power.

- This signal now has a gain of 2.5 applied to it for the small TCV or a combined gain which begins to stroke the large valve open as the lift changes from approximately 30% (i.e. when the small valve reaches 75% open).

- The large TCV's have a function applied which is ((LIFT - K2)/K3) so that the large valves start to open with a 30% signal lift (i.e. K2 = 0.3 and K3 = 0.7) and drive completely open with a 100% lift signal.

- The signal is ***reversed*** (i.e. 100.0-Sig) before being output to drive the air-to-close valves in the correct direction and the valves will fail open for a loss in electrical signal or a loss in pneumatic signal.

Moderator Temperature Control Assignment

1. Sketch a typical moderator heat exchanger temperature control circuit to show the relation between the calandria inlet temperature and calandria outlet temperature control loops as a cascaded control example. Show and label the key components of the physical system.

2. What are the desired operational restrictions or limitations placed on the moderator temperature that the control system should strive to achieve?

3. What is the planned function or range for the calandria inlet temperature as reactor power is increased from 0% to 100%FP? What is the designed value for calandria outlet temperature over this same power range change?

4. Briefly explain the difference between a software rationality check and a validity check.

5. Briefly explain how the temperature control valve lift signal as a function of reactor power provides an immediate valve correction based on an inferred parameter that is able to quickly place the control valves in the approximately correct energy balance position.

Lesson #5: STEAM GENERATOR LEVEL CONTROL Program

Module 2: (SGLC) NOTES

This information is intended to supplement the IAEA instrumentation & controls lectures with additional information on the CANDU control computer application for Boiler Level Controls with implementation details.

Lecture Topics

1. General Boiler Background & Interfacing
2. Drum Level Control Measurements and Control Devices
3. Boiler Level Swell and Shrink Effects
4. Ramped Boiler Level Control Setpoint
5. Feedwater Temperature Effects
6. Rangeability of Control
7. Basic Control Strategy
8. Single Element Drum Level Control
9. Three Element Drum Level Control
10. Single Element Default Control for Power Levels above 16%FP
11. SGLC Manual Mode
12. Dual SGLC or DCC loss
13. SGLC Program Rejection
14. Avoid a Poison Outage
15. Return SGLC to Full Automatic Operation
16. A Maintenance Induced Plant Outage

General Boiler Background and Interfacing

- The boilers provide the key station ***heat sink*** during normal unit operations, accepting the fission, decay and pump heat from the heat transport system and using this energy ***to create steam*** by heating and boiling light water.

- At power, the demineralized light feedwater supply is admitted to the boiler feedwater inlet at about **172 C** at a feedwater flow rate of approximately **310 Kg/sec**. This feedwater supply then becomes part of the boiler drum inventory, circulating perhaps 5 to 6 times before warming to 265 C and changing to steam and then exiting the drum as steam flow.

- A ***mass balance*** is achieved between the ***inflow*** to the drum (feedwater supply plus reheater drains flows) and the steam flow from the drum (i.e. ***outflow***) to the main steam header.

- At the balance condition, we need only match the ***total steam outflow*** from the drum with the total ***inflow*** to the drum (feed plus drains flows) in order to maintain the drum level relatively constant.

- At the same time, we must maintain an ***energy balance*** for the boilers so that the same amount of heat energy is passed on to the main steam header as is extracted from the heat transport system.

- If this energy balance is not maintained, the ***imbalance*** will show up ***as heat transport pressure*** or ***main steam pressure disturbances***.

Boiler Energy Balance Considerations

- For example, if we ***extract too much energy*** from the heat transport system (HTS) , we will ***cool down*** the HTS (causing a volumetric contraction of the HTS fluid) causing an HTS pressure decrease.

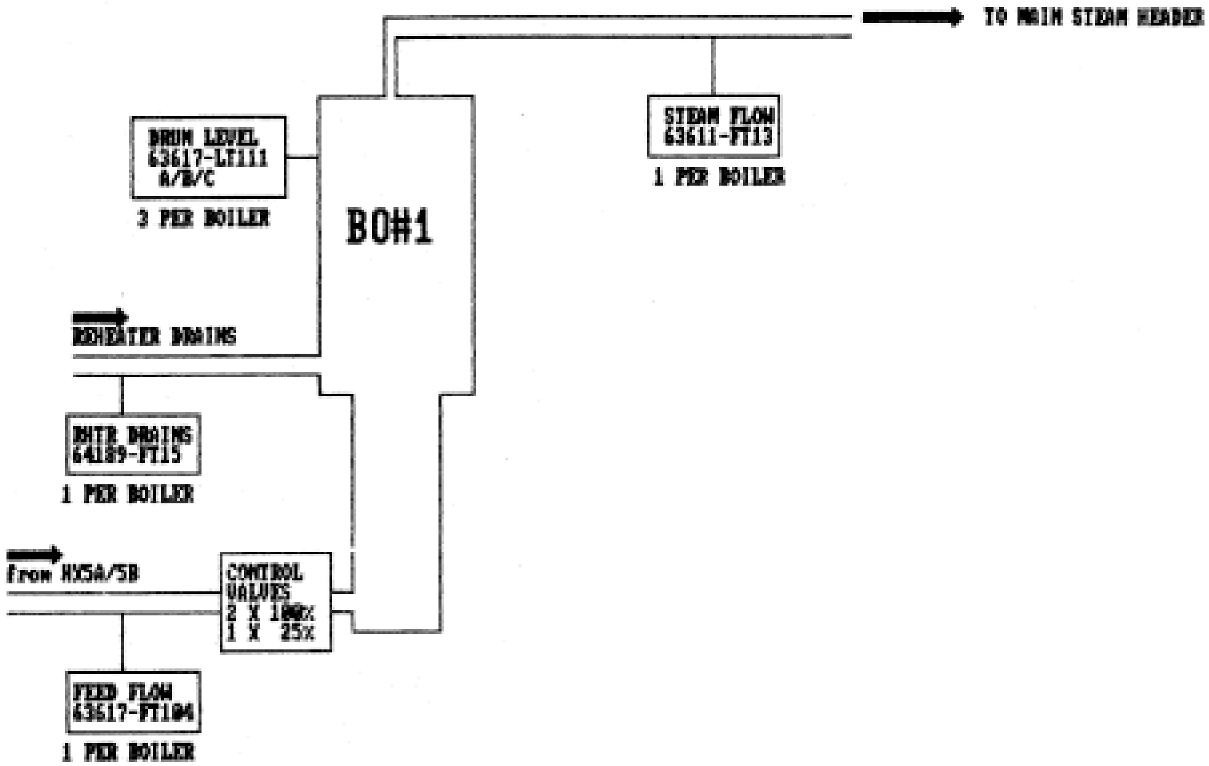
- We speak of this decrease in pressure as a ***shrink effect*** in that the fluid volume has decreased (or shrunk) with an attendent pressure drop. At the same time, the additional steam flow supplied to the main steam header (due to the increase in energy extracted) may cause a steam pressure increase (or just maintain the steam header pressure) - depending upon the steam demand (turbine GSV's, CSDVs, ASDVs) conditions.

- On the other hand, if we ***do not extract enough energy*** from the HTS, we will ***heat up the HTS*** (causing a volumetric expansion) resulting in an HTS pressure increase.

- We speak of this as a HTS ***swell effect*** in that the volumetric expansion or volume swell has caused a positive going pressure transient. At the same time, the lower steam flow supplied to the main steam header (due to the lower energy extraction) may cause a steam pressure decrease (or pressure rise) - depending on the steam demand conditions.

- So it is very important for ***steady*** and ***stable*** plant operations to maintain the ***energy balance*** and ***mass flow balance*** between the Turbine steam loads and the HTS via correct boiler control application.

Figure #1. Key CANDU Boiler Level Control Instrumentation



- Notice from Figure 1 that instrumentation is provided to measure drum level, feed flow (and drains flows) and steam flow to allow three element control.
- The ***boiler level*** for each boiler is measured directly by ***triplicated*** narrow range (i.e. 10-16 meters) level transmitters (LT-111A/B/C).

- Providing three level transmitter signals allows the control program to recognize that all signals are ***rational*** (within defined limits) and ***valid*** (within certain agreement) or not, and to then chose the ***most appropriate*** signal for control sensing purposes.

Boiler Level Control Instrumentation

- The ***demand*** or ***outflow*** applied to the boiler is indicated by one steam flow transmitter (FT-13) on the steam line supplied by each boiler.

- This flow indication is in Kg/s and this ***demand parameter*** provides the control program with the calculation ***capability to apply a feedforward control strategy*** to correct the feedwater flow to the demand value before the drum level is disturbed.

- The ***supply or inflow*** to each boiler is indicated by a feedwater flow transmitter (FT-104) on the feed line to each boiler.

- This flow is also indicated in Kg/s and this ***supply parameter*** will allow the control program to determine if a ***mass balance*** (inflow equalling outflow) has been achieved.

- In addition, ***the reheater drains flows*** (FT-15) which come into operation above 75% FP are also indicated so that the true ***total inflow*** to the boiler is known. The reheater drains flow is quite low and only amounts to about 15 Kg/s at full power operation.

Boiler Level Control Instrumentation

- The ***control valve position*** is also indicated for each boiler so that a ***gradual difference*** in the ***control valve position*** and the ***flow rate*** can be recognized to indicate the need for some corrective maintenance.

- There are three control valves for each boiler - one small valve (20% FP size) and two large valves (100%FP size each).

- The small valve is sized to supply feedwater flows up to about 20%FP although higher flows can be achieved depending upon the feed pump configuration selected.

- As well, two 100%FP capacity large control valves are provided with one selected for ***in-service*** use for power levels above 20%FP and the second large valve selected to ***standby***.

- ***Both large valves*** could be selected for service (as a duty cycle exercise) and adequate control would be maintained with both valves stroking to a much more closed position (due to the higher flow capability) than would be required with just one large valve in service.

<u>Boiler Drum Level Control Measurements and Control Devices</u>

- The ***drum level*** for each boiler should be measured by ***triplicated*** narrow range level level transmitters that provide usable level signals from zero power hot (ZPH) to full power conditions.

- The triplicated channels are allocated tags 'A', 'B' and 'C' for control purposes. In this manner, the ***median*** level signal can be selected (i.e. reject the highest and the lowest level signals from the three rational signals) for control sensing purposes.

- It should always be possible for the operator to see all three narrow range signals ***upon demand*** as well as to identify ***which signal has been selected*** automatically for control sensing purposes (i.e. the median signal is Channel C).

- Should one of the level signals be irrational, then that channel is ***declared irrational and annunciated*** as such. The ***highest*** of the remaining two level signals is selected for control sensing.

- If two channels are irrational, they both will be annunciated as irrational and ***the remaining rational signal*** is selected as the control measurement allowing continued operation of the automatic mode.

- If all three level measurement signals are irrational, then that program must ***fail-off*** (i.e. the program can no longer satisfy the conditions for continued automatic operation) and the control program would switch to ***manual mode***.

Boiler Drum Level Control Measurements and Control Devices

- An alternate source of drum level indication is the ***wide range level transmitters.*** There are only two wide range level level transmitters provided per drum and these are only calibrated correct under hot drum inventory conditions.
- This means that the wide range transmitters will slowly indicate a larger and larger error as the drum inventory is cooled down. The indication will be for more inventory (higher level) than actually exists due to the increasing specific density as the inventory cools.
- It would be quite easy to provide ***automatic compensation*** for drum inventory temperatures and hence inventory specific density to allow fairly accurate wide range drum level signals to be obtained for all operating states.
- As well, if a third wide range level transmitter was provided, then the same program rules for rationality could be applied and the wide range signals could provide an ***automatic fallback transfer*** for continued automatic control (superior to manual control with no rational narrow range indications) with appropriately scaled setpoint compensation.

Feedwater Flow Measurements

- A single feedwater flow transmitter is provided for each boiler to monitor the ***feedwater supply flow*** to that boiler.
- The single feed flow transmitter is adequate since if this flow signal is irrational, the control program can revert to automatic,***single element drum level control*** and so sustained full power operation could be maintained.
- If the feed flow transmitter fails the rationality check, then that feedflow signal is ***annunciated as irrational*** and the program rules would force the control program to ***single element*** (drum level) control.
- As well, the ***reheater drains flows*** to each boiler should be measured by a drains flow transmitter to allow the determination of the total flows into that boiler at any time.

Steam Flow Measurements

- A ***single steam flow transmitter*** is provided for each boiler to monitor the steam demand flow from that boiler.
- The single steam flow transmitter is adequate since if this flow signal is ***irrational***, the control program can also revert to ***automatic,single element drum level control*** and so sustained full power operation could be maintained.
- If the steam flow transmitter fails the rationality check, then that steam flow signal is annunciated as irrational and the program rules would force the control program to single element (drum level) control.
- Coarse indicators of the ***supply*** to, or ***demands*** on the boilers could be obtained by considering the Condensate flow, dearator level, feed valve position (***feed supply***) as well as Reactor Power and Electrical Power (***demand conditions***).
- Parameters such as these may be of use for initializing purposes when a control program is run for the first time (ie a restart) under prevailing power conditions or to confirm the validity of a control scenario.

<u>Boiler Level Swell and Shrink Effects</u>

- The principle purpose of boiler level control is to ensure an ***adequate boiler drum inventory*** to allow safe and continued economic operation of the unit over all power conditions.

- This means that we should have a ***minimum drum inventory reserve*** on hand so that if the feedwater supply is lost at power, we could continue safe operation for a set period of time.

- We usually speak of this as ***full power minutes*** of operation, so for example, if we chose to have a reserve of 3 full power minutes of drum inventory, that would mean that when the drum level reached a low level condition at which the reactor should be tripped, there would be the capability to continue at full power for an additional 3 minutes, assuming the reactor trip (shutdown) did not occur.

- Note that this is a fairly significant margin since if the reactor power was reduced to 10%, then the ***three full power minutes*** would ***now last 30 minutes*** with no additional source of feedwater supply - allowing adequate time for establishing an ***alternate feed supply source*** (say ***alternate electrical supply*** , ***auxiliary feedwater*** or ***emergency water supply*** depending upon the problems encountered).

- Now boiler drum level is a very ***dynamic*** parameter and it will behave in some unexpected ways. For example, if the boiler drum pressure is disturbed, the boiling rate equilibrium will change.

Boiler Level Swell Effects

- Imagine a stable boiling condition with a set steam pressure above the drum inventory and a certain size of steam bubbles forming along the length of the U-tube bundle in the riser.

- Let's assume that these bubbles have a diameter of 1 mm for discussion purposes over the 10 meters of the riser and that we have on average 5000 bubbles in place.

- If the steam drum pressure decreased (due to an energy balance upset - say we take more steam from the drum), then the steam bubble size could increase due to the lower pressure.

- If we allow that the steam bubble diameter increased from 1 to 1.1 mm under these conditions, then the vertical rise of 5000 mm would now cover 5500 mm - we would see an ***apparent 0***.5 meter level change due to a steam drum pressure upset.

- Again, we would call this temporary drum level increase a ***steam drum swell effect*** because the drum inventory seems to have expanded or to swell.

- Of course, once the pressure recovers, the bubbles would be compressed back in size and the apparent level increase will disappear.

- So what we have is a ***sudden, temporary steam drum level increase*** (or swell) in response to a sudden steam pressure decrease (say in response to a step increase in steam demand).

- The drum level will rise up and then as the pressure recovers, the steam bubbles will be recompressed and the level will be forced back down to near the expected value, or lower depending upon the final drum pressure and/or actual inventory changes experienced during the transient. This is called the ***swell effect***. A CANDU boiler can experience a swell effect of approximately 1.8 meters over a 0-100% power change condition.

Boiler Level Shrink Effects

- Similarly, a steam drum pressure increase can cause a compression of the steam drum bubbles in the riser section of the boiler so that the apparent ***drum inventory decreases*** or shrinks.

- This is called the ***shrink effect*** and is a temporary condition following a sudden steam demand decrease resulting in a steam pressure increase, during which the drum level decreases until the steam pressure recovers.

- Once the steam pressure returns toward pre-upset conditions, then the steam bubbles in the riser section are re-established and the drum level rises back up toward the expected level dependent upon the drum pressure and/or actual inventory changes experienced during the transient.

Ramped Boiler Level Control Setpoint

- For boiler level control of a relatively large commercial boiler, it is not desirable to maintain the drum level too high ***during low power operation*** since the boiler could be subjected to an unexpectedly large step increase in steam demand causing a large swell effect (for example if we were operating at 10% FP, we could, theoretically, see a 90% increase (or more) if some related malfunctions or failures occurred).

- If we ***maintained the drum level relatively low at low power***, then we could accommodate such large swell effect level changes without any danger of inventory carryover to the turbine.

- Similarly, it is not desirable to maintain the drum level too low ***during high power operations*** since the boiler could be subjected to an unexpectedly large step decrease in steam demand causing a large shrink effect which may be able to uncover the HTS U-tube heat exchangers.

- Consequently, if we maintain the ***steam drum level relatively high at high power***, then we can accommodate such large shrink effect level changes without any danger of uncovering our U-tube heat exchangers (i.e. maintain the principle heat sink and as well maintain the designated full power minutes of inventory).

Ramped Drum Level Setpoint

- As a result it is very common to ***ramp the boiler inventory*** as a function of the unit operating power.

- This ramping of boiler level accomplishes several things. First it makes the control system relatively immune to negative consequences arising from large shrink or swell effects while being able to maintain the necessary safety reserve inventory.

- The ramp setpoint strategy allows the boiler level control system to react ***in the same direction of the change*** - for example, if we had ***a fixed drum level setpoint*** and power was increased suddenly, then the drum level would ***rise*** due to ***swell*** effect. In a fixed setpoint system. this level rise would be opposed by a feedwater supply decrease in an attempt to lower the drum level back to the fixed setpoint. Now when the temporary swell effect subsided, the collapse of the steam bubbles and the decrease in inventory supply would result in the drum level dropping ***below*** the fixed setpoint and so the control decision would have to be ***reversed*** to supply more feedwater at the increased load in an attempt to maintain the desired inventory. Note that we have introduced an unnecessary control cycle here by trying to maintain the fixed setpoint inventory level.

- On the other hand, if we allow the drum level to be controlled ***in the direction of the applied change***, we will have less contradictory inputs to the system.

- The original steam demand increase will cause a swell effect but at the same time, the increase in power level would be recognized to ***request a higher drum level*** operating setpoint. As a result, the swell effect (***level increase***) can be matched by the ***level setpoint increase*** so that no change (or very little change) in control signal is initiated at the onset of the disturbance.

<u>**Ramped Drum Level Setpoint ….continued**</u>

- However, as the swell effect begins to subside (from the now higher level setpoint), the control valve would be opened more, admitting more feedwater to the drum.

- Likely the level drop would be arrested well before the ***previous or original*** operating point was reached so that the true level did not drop below the starting setpoint and the control valve moved progressively from the initial equilibrium condition to the new equilibrium condition without having to introduce a complete control cycle (or reversal of control decision) into the loop resulting in a more stable control condition.

- Boiler level setpoint calculations are usually done as a ***function of steam load*** or steam flow from steam flows of 15% FP or higher (since 10% flow is only 1% differential pressure).

- Traditionally, the measurement of steam flow below say 10% is not so repeatable (by differential flow metering techniques) and so ***reactor power*** is often used to calculate the drum level setpoint from 0-15% FP.

- Such a strategy requires a smooth, bumpless transition ***from the setpoint calculation based*** on ***reactor power*** to the setpoint based on ***steam flow***.

- As well, an adequate ***transfer band with deadband*** (or tolerance) must be provided to ensure that the setpoint calculation method does not cycle back and forth.

<u>**Feedwater Temperature Effects**</u>

- One further consideration we could make for the drum inventory level is the effect that the supply of ***colder feedwater*** can have on the ***apparent*** drum level.

- This can be a particular problem at lower power conditions when ***drum boiling is not well established*** and ***feedwater heating is not very effective***.

- Assume the unit is at approximately 10% power and the power level is increased to say 15% FP. Depending upon the rate of power increase, some swell effect can occur and the drum level can begin to rise (the ***temporary swell effect***) - logically, we should decrease the feedwater supplied at this time as the level seems to be above the desired setpoint.

- However, the swell effect will subside and then the ***level will begin to drop away*** below the setpoint requiring an ***increase*** in the supply of feedwater to the drum - and here is where we must be careful.

- If we supply too much ***cold feedwater*** to the drum at low power, the cold feedwater can have a ***boiling quenching*** effect so that even though more feedwater was admitted, the drum level seems to drop as the cold inventory reduces boiling in the riser - the apparent effect here is that ***not enough inventory has been supplied*** to the drum since the level is dropping.

- But we must be careful, because the inventory supplied will ***eventually expand*** and swell significantly as it is warmed up toward the boiling conditions.

- The control and operation under these conditions should be ***relatively slow*** and well thought out (to keep track of true inventory conditions in the drum).

<u>Feedwater Temperature Effects…continued</u>

- The admission of cold feedwater will also reduce the drum steaming rate as riser boiling is quenced and could lead to an imbalanced operation condition with ***drum level falling***, ***steam rate reduced*** and ***inreased feedwater supply*** - these conditions can lead to excessive boiler level increases once the ***drum inventory warms*** and ***boiling is re-established***.

- Then the ***opposite condition*** can be experienced with the drum level cycling high and feedwater supply being cut right back - if the wrong control decisions are made under these conditions, ***progressively worse*** (larger and prolonged) drum cycling can occur.

- The solution is to ***not make excessive corrections*** under these conditions and as well to ***keep track of true inventory balance conditions needed*** to match the prevailing steam demand and boiling state.

Rangeability of Control

- Usually, the flow range for the boiler feedwater covers two distinct regions - ***low power*** (say below 20% FP) and ***high power*** (say 20% to 100% FP).
- It is very difficult to obtain a control valve that can provide the necessary full power ***flow capacity*** and still be able to provide ***sensitive control*** for low power, low flow conditions.
- As a result, usually two control valves are specified for boiler level feedwater control applications. A small capacity, low flow Cv valve is specified for the under 20%FP load conditions so as to be able to provide reliable and repeatable control of the low flow feedwater conditions.
- This small level control valve would usually be selected to ***fail-open*** so that an assurred flow path can be guaranteed as a heat sink supply under failure conditions.
- A large capacity, high flow Cv valve is specified for the 20% to 100%FP load conditions so as to provide the 100% feed flow conditions at full power with the large valve approximately 70% open.
- Full power feed flow at 70% large Cv opening will allow additional feedflow to be supplied, if necesssary, to make up for possible low drum level conditions at full power (***reserve feed flow capability*** by opening the feed valve from 70% to 100% full open).

Small to Large Valve Transfer Strategy

- A transfer scheme is required to change the operation from the ***small valve to the large valve*** in a ***smooth and continuous*** fashion.

- A superior performance method of transferring is to begin to open the large valve (on increasing power demand or lift demand signal) as the small valve reaches approximately 75% of its flow capacity).

- This coordination can be done simply on the common control signal demand value being applied to each valve transducer with different positioner calibrations. For example, as the control valve lift (control signal demand) changes from 0-20%, the small valve can be stroked from 0-100% open, while the large valve can be calibrated to operate, say, from 15% - 100% lift signal to stroke 0-100% open.

- The most important point to note is that the large valve will ***not be very effective*** until it is open a few percent and so by overlapping the small and large valve, a smooth feedflow can be supplied with a minimum of complexity.

- Note that the ***small valve*** is ***usually very effective*** at maintaining the feed flow as it approaches the fully open position since supply pressure from the feed pumps is usually quite high under these conditions in preparation for the impending higher power operating conditions. Since the small and large valves are in parallel, the gradual opening of one in parallel with the other will not cause abrupt flow changes since the new incoming valve is only working on the existing pressure drop across the already open valve.

- Once the large valve has been brought into operation, the small valve could be driven closed (say for example on a signal conditioned by reactor power above 35%FP with manual override capability to allow manual restoration of flow path for testing or establishment of an alternate flow source).

- The operating transition from low power to say 25%FP (from small valve to large valve) should be ***obvious*** and ***understandable*** for the operator with a ***minimum of complexity***.

- As well, any transition points (we have so far talked about ***small valve to large*** valve and about ***setpoint calculation based on reactor power or steam power***) should be ***suitably staggered*** to ensure that several control ***strategy changes*** are ***not*** implemented or ***initiated simultaneously*** (this ensures ***smoothness of operation*** as well as ***facilitating diagnosis*** should some problem arise).

- Additionaly, there is a redundant large feedwater control valve provided in the CANDU boiler level control scheme to provide an alternate or ***standby control valve*** at power, should there be a problem with the original valve selected for in-service.

- The transfer from the in-service large valve to the standby large valve should be a simple procedure that can be implemented ***automatically or manually***.

- If a steam drum level problem exists such that a transfer to the standby valve is warranted automatically, then ***both*** valves should be selected to operate with the option for the operator to remove from service (or restore to service) the ***valve of choice*** with a ***minimum of interlock restrictions***.

- In this manner, the large feedwater control valves can be selected to service on a duty cycle schedule to allow routine maintenance and testing to confirm availability for service.

- It is also important to periodically confirm the operational availability of the small control valve when at power (when the small valve is not needed) to ensure its functionality when called upon to work at the lower power conditions (when the small valve is needed).

<u>Basic Boiler Level Control Strategy</u>

- The control strategy for boiler level control should ensure safe and reliable economic operation of the unit.

- Any incidents of outage due to control system failures should be very low and those outages should be as a result of more than one failure occurring (ie a ***single control system failure*** event should not cause lost production).

- Adequate diversity and independence of monitoring instrumentation should be provided to ensure that the computer and/or the operator can quickly and correctly ***cross-check*** the indication to confirm the validity of a particular measurement.

- Of course, ***direct reading*** and immediate cross-correlation of parametric values is preferred, but ***inferential values*** (i.e. like using valve position as an implied cross check for flow) should not be ignored.

- ***Consistency*** in manner of control strategy implementation should be applied. For example, if the manual control back-up means is provided by an analog, hardwired control module, then the ***associated control indications*** and ***alarms*** should also be provided by the same qualification class of hardwired analog equipment to ensure ***operability success*** with the ***necessary information*** set.

- Indications should be provided to show the operator the ***present operating status*** within the context of the planned operation (ie present operating point on a 0-100% FP curve) along with associated curves such as level alarms, valve transfers, reactor setback or stepbacks and reactor or turbine trips.

- As well, the ***status of related equipment*** should be available in an integrated fashion to facilitate ***rapid assessment*** of system conditions and the opportunity (if needed) to provide an alternate operating configuration.

Annunciation Considerations

- ***Annunciations*** should also be provided to give the operator ***early warning*** of impending trouble far enough in advance to allow remedial action to be taken.

- For example, the ***first warning*** may indicate a ***slight variance*** or ***slow rate of change*** from expected operations, ***second warning*** could be a ***larger magnitude or rate*** change, ***third warning*** could be ***setback*** or ***stepback imminent*** with ***fourth warning*** that a ***trip*** has occurred.

- The alarms used should be ***recognizeable*** for their relative importance, they should immediately convey the ***system*** and ***status*** condition and be ***unit condition sensitive*** (filtered according to the operating status of the plant to minimize unnecessary alarms).

- A structured ***hierarchy of complex control*** (such as feedforward, cascaded three element control), reverting to a ***simpler automatic control*** (such as ***single element***, drum level control) with a complete ***manual intervention*** control option should be provided.

- The ***transition from one control mode*** (i.e. three element) ***to another*** (i.e. single element) should be clearly indicated and annunciated.

- As well, the ability to ***transfer smoothly*** from one mode to another should be provided in an obvious and user friendly manner (i.e. that is to say, do not make a trap for the operator so that he is unable to revert control back to some previous automatic configuration).

Single Element Drum Level Control

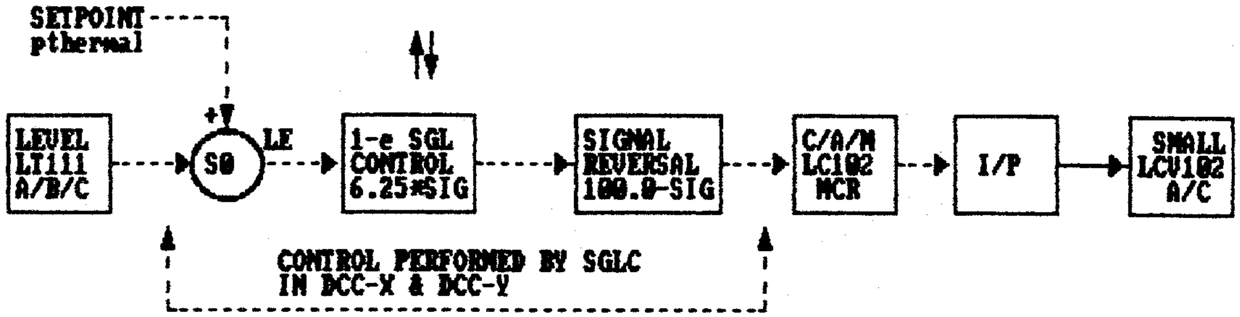


Figure #2. SGLC Single Element (1-e) CONTROL Less Than 11% FP

- The control program for power operation below 11%FP operates the small level control valve which can provide flows up to 25%FP capacity (depending upon the feed pump configuration).

- The small valve is an ***air-to-close***, fail open control valve which upon failure will ***ensure a low magnitude cooling supply*** to each boiler (assuming feedwater pump power is maintained). This flow could be regulated in a coarse on-off fashion by operating the motorized isolating valve in-line with the small level control valve.

- The drum level ***setpoint*** is calculated as a function of the ***reactor power*** below 11%FP and so the level error (LE) can be calculated by comparing the selected median level signal against the setpoint.

- Note that ***if the level is above the setpoint***, that the control valve must be closed-in to reduce the feed flow to that boiler and so the control signal must be increased as the valve is an air-to-close style - this requires an ***increasing, increasing*** control action. However, the designer chose to have all of the level control functions as reverse acting controllers (as you will see later) and so a *signal reversal function* is required to provide the correct control response.

Single Element Feedwater Control …continued

- A standard ***proportional plus integral*** control function should be invoked here. An additional gain of 6.25 (i.e. 100/16) is applied to the resultant control signal to provide a 100% small valve travel from a 16% control lift signal (which is applied commonly to the small and large valves).

- The ***single element drum level*** control routine measure drum level and developes a control signal by comparison of the selected level measurement signal with the setpoint.

- If the CAM station is selected to computer mode (‘C’), then the computer control signal is passed through the CAM station to the small LCV. Otherwise, if the CAM station is set to automatic (‘A’) or manual (‘M’), then the CAM station determines the contol signal and the ***computer tracks*** the analog control action.

<u>Boiler Level Performance for a power Increase</u>

- Assume the boiler levels were controlled ***steady at the setpoint*** with the large valves closed and the small valves approximately **<u>40% open</u>** with the power constant at 5%FP.

- If power is now increased slowly from 5% to 10% FP, the setpoint calculation (as a ***function of reactor power***) will request a higher drum setpoint and the increased boiling will tend to swell the level upward.

- At the same time, the gradually ***increased steam demand*** will tend to cause the drum level to drop below the new setpoint.

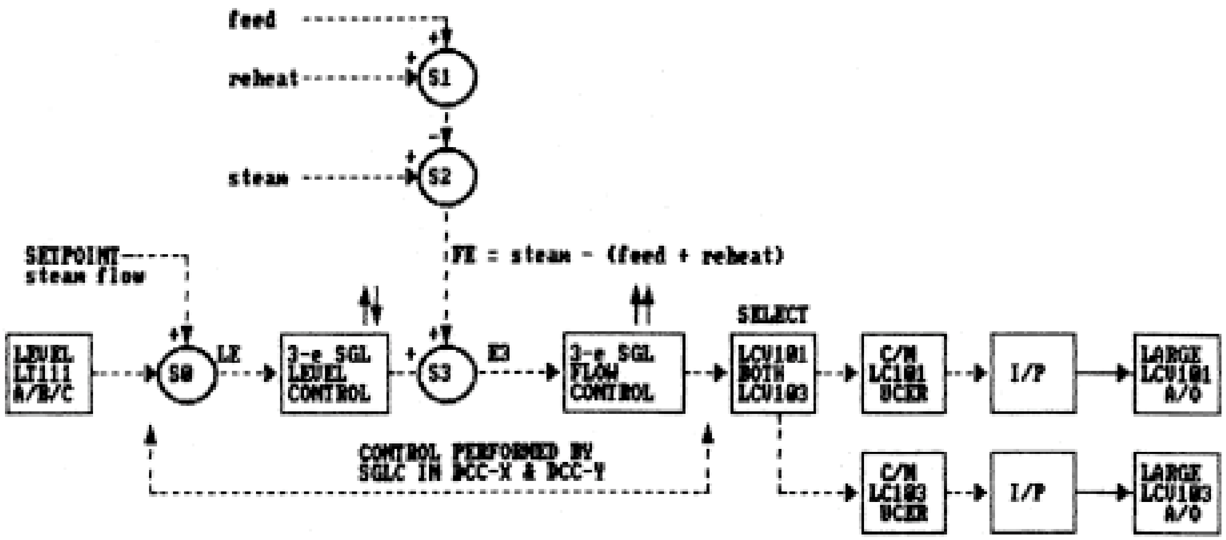
- SGLC single element will recognize the larger level error and develop a change in control signal to drive the small valve ***more open*** (but not enough yet to start to open the large valve).

- The increase in feedwater flow should be enough to restore the drum level to the new setpoint at 10%FP load condiitons. Once stabilized, the drum levels should recover at the setpoint with the small valve approximately **<u>50% open</u>**.

- As the power level increases and the steam flow signal becomes more reliable and repeatable (say ***greater than 16% Reactor FP***), then the control system can switch over to ***three element control***. The control can then remain under three element control until the power is reduced below 11%Reactor FP.

- As the power is raised from 10%FP to 20%FP, the ***setpoint*** will be calculated on ***reactor thermal power*** until power is increased above 15%FP at which time the setpoint will be calculated as a function of ***steam flow*** until the reactor power drops below 12%FP.
- In this region as well, the control mode will ***remain single element*** until the reactor power rises above 16% FP and will then remain three element until the power is reduced below 10%FP. The lift signal can drive ***both small and large*** valves.
- However,if the rate of power increase is not too great, the small valves should be adequate until the power level is above 15%FP at which time the large valves should start to stroke open (but not really have any flow contribution until about 18%FP).
- The large valve will assume more significant control above 20%FP with the small valves fully open.

<u>Three Element Drum Level Control</u>



<u>Figure #3 SGLC 3-e CONTROL Greater Than 16% FP</u>

- The level control logic is generally as described previously with the level error being determined by a comparison of the ***median rational drum level*** signal against the ***drum level setpoint*** which is calculated as a function of the ***steam flow***.

- The control signal calculation result from the reverse acting level controller is applied as the setpoint for the the feedforward term to force a further mass imbalance ***(if required due to a level error***) beyond that imbalance recognized by the ***steam flow*** and ***feed/reheater flow difference***.

- This error signal then is applied as the error parameter for the feedwater flow control which is a ***direct acting controller***. Note here that the measurement signal applied to the flow controller is:

  Flow Measurement = steam flow - feed flow - reheater drains flow

- It is important to note the ***negative*** signal applied to the feed flow parameter within the control program. In this fashion, if the actual ***feed flow increases***, the ***measurement value for E3 will decrease*** (since we are subtracting a larger number).

- This will lower the measurement for the flow controller which is direct acting and so the ***control signal will decrease***. The decrease in control signal ***will close-in the feedwater control valve*** and so the feed flow should be decreased, causing E3 to increase (since we are subtracting a smaller number) and the measurement for the flow control algorithm should reapproach the setpoint.

<u>Boiler Level Control Performance ffrom 10% to 25% FP</u>

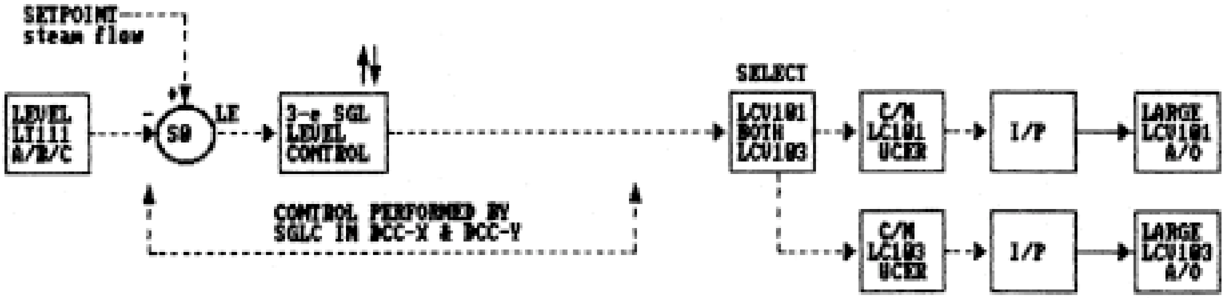
- Once the reactor power has been increased above 16%FP, then the control logic will ***switch to three element control***.
- There may be a slight rebalancing or correction as the ***steam flow measurement*** and ***feedflow control*** are brought into action for the first time.
- The ***setpoint*** should already have shifted to being calculated as a function of ***steam flow*** and so there should be little discernable change in system conditions.
- Now as the power is increased, the control response should be much tighter (i.e. closer control) as control is responding in a ***feedforward/cascade*** manner to drum level, steam flow and feed flow conditions.
- The large valves will now start to open more dependent upon the magnitude of the lift request from the control program. Depending on the status of the demand, the valves can drive open and closed as needed to maintain the drum levels to the computed setpoint.
- However, this is a transition region (transition for ***setpoint calculation*** method, ***small valve to large valve***, control mode ***1-e to 3-e***) and it is also good practice to increase reactor power ***smoothly and steadily*** from 15% to 20%FP to allow the setpoint computation, valve transfer and control mode logic to be completed.

Boiler Level Control Operation above 50%FP

- Assume now that the reactor is at 50% FP and that the boiler levels are steady at the setpoint with the selected large valve about **35% open**.
- The small level control valves can be closed and out of service under these conditions.
- At this time, the operator would check that ***adequate feed supply*** (i.e. are enough feed pumps running to supply the necessary feed flow at the required static pressure?) is ensured for the impending power increase. An additional feedpump may have already been started and left running in ***full recirculation mode***.
- If the reactor power is now increased slowly from 50% to 60%, the setpoint calculation will request a higher drum level setpoint as the steaming rate increases.
- The increased boiling will tend to swell the drum level upward while the increased steaming rate will tend to cause the drum level to drop below the setpoint so initially there may be very little level error present following the power increase change.
- SGLC ***three element control*** will recognize the increase in steam flow immediately and request additional feedwater flow to correct for the slight steam flow/feed flow imbalance.
- If the drum level had dropped below the setpoint slightly, the level control signal will also drive the feed valve more open (than would be required by the feedforward balance signal) and so the inflow will exceed the outflow allowing the drum level to begin to increase and the level will approach the new setpoint.
- Once the drum level reaches the setpoint, the level control signal will be reduced so that the mass balance is ***just re-achieved*** with the feed flow just matching the steam flow with the level at the setpoint.

- With the reactor at 60%FP, the drum level should be recovered at the setpoint with the level stable, feed flow matching steam flow and the large valve approximately **<u>40% open</u>**.

<u>SGLC 1-e Default Control for Power Levels above 16% FP</u>



<u>Figure #4 Default 1-e Control fo SGLC at power levels above 16% FP</u>

- If the SGLC is operating at power levels above 16%FP, and the control mode had transferred succesfully to three element control (3-e), then three element control can only be maintained as long as the feedwater flow transmitter for that boiler is rational and one of the four steam flow transmitter signals is rational.

- If these conditions are not satisfied, the control mode will transfer from three element (i.e. **3-e**) control to single element (i.e. **1-e**) control and the ***mode change will be annunciated***.

Default 1-e Control

- The boiler level control at power under **1-e** control will be adequate provided that ***no unit upsets*** are applied.
- The control strategy is identical to that described for single element control below 16%FP except that since the large valves are a fail-closed style (i.e. to prevent ***carry-over*** to the main steam line and turbine), the controller action must be ***reverse*** (increasing, decreasing action) and so ***no signal reversing function*** is required as was needed for the small valve.
- The control signal is routed via the LCV select handswitch to either or both large valves (depending upon the HS selection).
- If the selected hand controller (HC) is set to computer mode ('C') then the SGLC signal will position the large LCV.
- If the selected HC is set to manual ('M'), then the SGLC program for that boiler will switch to ***manual mode*** and this mode change will be annunciated.
- The control signal from the selected HC will be output to the large LCV and ***SGLC will track the manual signal*** in order to provide a ***bumpless transfer*** upon return to automatic mode.
- Once the selected HC is switched back to Computer mode ('C'), then the SGLC will assume control of the large valve in automatic mode (still 1-e if the feedwater flow transmitter signal has not been restored.).
- Control will revert to 3-e mode automatically, once the feedflow signal for that boiler and at least one steam flow signal for all boilers has been restored.

<u>**SGLC Manual Mode**</u>

- SGLC for each boiler will switch to ***manual mode*** under any of the following conditons:
  a. The selected large LCV C/M station is set to ***manual*** ('M') by the operator
  b. Any ***A/O failure*** on the ***selected large LCV*** (independent of auto transfer)
  c. ***All three level transmitters irrational for that boiler*** – the reactor will be setback to 2%FP when all level transmitters for one boiler are irrational.

- When SGLC switches to ***manual mode***, the large LCV C/M stations for that boiler ***will hold the last DCC control signal*** and the ***small LCV CAM station switches to Automatic ('A') mode***.

- It is important that the small LCV CAM station automatic setpoint be set to the ***expected level position***. When in manual mode, the SGLC control program will now ***track*** the individual signals for each valve to facilitate the return to computer control in a bumpless fashion..

Dual SGLC or DCC Loss

- First, it is important to distinguish the difference between a ***control program failure*** (i.e. one program such as SGLC) and a ***computer failure*** (the entire DCC so that all programs are effected).

- A program can fail, for example, due to a watchdog timer countdown - the strategy would be to relinquish control from the ***former master*** computer control program to the ***standby computer control*** program (i.e. program fail over from DCC-X to DCC-Y).

- If the same program stall condition exists for the standby control program, then that program will also fail-off resulting in ***no computer control for that system*** (note that other systems, such as HTS, could continue to operate as the DCC is available for other programs).

- In the case of ***SGLC program failure***, the large LCV's are ***closed*** (the AO's drive to zero signal) and the small LCVs will be under automatic control from the CAM stations.

- Note that this is not an adequate strategy to continue to operate at power as the CAM stations can only operate the small LCVs which are limited to about 25%FP flow capacity.

- As a result, the ***dual loss of the SGLC programs*** will require the reactor power to be reduced below 20%FP. If this action is not initiated by the operator manually, then the reactor will automatically be ***setback*** (***forced gradual power reduction***) on the receipt of a low drum level signal..

- The ***dual loss of DCCs*** will initiate the same response for SGLC (large valves closed, small valves operated by the CAM stations under automatic mode) but now all the other programs will also have failed off and so the reactor will be forced to a ***low power state*** (say less than 5% FP thermal power) and so the small LCVs for the boilers will easily be able to control the boiler level.

<u>SGLC Program Rejection</u>

- Assume the unit is operating at full power when all of the boiler level transmitters for the controlling DCC go irrational for Boiler #2 and so SGLC for Boiler #2 (only) switches to ***manual*** mode.

- The three ***irrational*** level transmitter signals are ***annunciated*** and the switching of SGLC for Boiler #2 to Manual mode will also be annunciated.

- SGLC switching to manual mode will hold the selected large LCV in ***the last control position*** and the associated small LCV CAM station will switch to analog control and will control to the manual set level setpoint.

- Since the three level transmitters are irrational - then the level transmitter connected to the CAM station (LT-211A) is ***also irrational*** and so there is a high or low measurement signal input to the CAM station. Since the CAM station is ***direct*** acting, the output will be high (small LCV will be driven closed) if the signal is irrational high or the output will be low (small LCV will be driven fully open) if the signal is irrational low.

- Since the reactor will be setback automatically on the irrational level signals for Boiler #2, the small LCV for Boiler #2 could be set (manually by operator intervention) to about **<u>10% opening</u>** in readiness for the end steady state power operation level (rather than leave the valve fully open or fully closed).
- Also - as the reactor setback comes into effect, the large LCV's must be manually closed-in as power is reduced to prevent over supply of feedwater to the drum.
- The drum ***wide range level*** meters on the control panel can be consulted in order to monitor the approximate level of Boiler #2.
- As well, the approximate small valve opening on the other boilers can be observed to confirm the relative correct opening for Boiler #2.
- Control Maintenance staff should be dispatched immediately to determine the cause of the irrational signals and to correct the situation.

Avoid a Poison Outage

- Assume we have had a dual SGLC program loss and the reactor power is being held at 15% FP with ***feedwater supply via the small LCVs*** under CAM automatic control (i.e. not under SGLC)

- If it is recognized that the restorative work is going to take say 45 minutes, then the unit must be taken to 60% FP in order to prevent a Xenon-135 build-up poison outage from occurring.

- The reactor power can be gradually increased while ***slowly opening the large LCV's under manual control.*** We know that the large valve must be about 25% open for 20%FP (from past operating experience).

- So if we raise power to 20%FP and then drive open each large valve to 20% opening - ***the remainder of the flow will have to come from the small LCV's***. All we need to do is ramp up the setpoint for the small LCV's CAM stations as we raise reactor power.

- Once we reach 20%FP, allow the system to stabilize and the small valve will throttle to correct the level for each boiler as the large valve supplies a ***base flow*** to each boiler.
- Now if the reactor power is raised to 60%FP, the large valves must be opened an additional 10% stroke for the 40% increase in power (so the operator must open the large LCVs about 2-3% for each 10% reactor power increase.
- Again as the reactor power is increased, the setpoint for the CAM station should be raised up so that the ***CAM station will throttle the small valve*** while the large valve supplies a base flow rate.
- Once the reactor power reaches 60%FP, allow the system to stabilize and make small changes as needed for the large valves to maintain steady levels in each boiler automatically trimmed by the smal LCV in automatic control.
- Now, control maintenance can proceed with the restoration work on the irrational transmitter signals for Boiler #2 and the unit will not poison out.

Return to Automatic SGLC Operation

- Once the irrational drum level transmitter signals for Boiler #2 have been restored, the SGLC program can be returned to service.

- It is important to do this in an orderly manner to avoid large bumps or disturbances for the feedwater supply. First, make sure that each CAM station (for the small LCVs) and each C/M station (for the selected large LCVs) are hard selected (by pushbutton) for automatic or manual control respectively (this ensures that SGLC ***can not*** assume immediate control of those valves).

- Start the SGLC program in the Master computer and check key indications (level, control signals, power, etc).

- Confirm that manual control of the LCV's is undisturbed. Next, start the SGLC program in the standby computer and as well confirm the key indications for that program.

- Next confirm the SGLC drum level setpoint - if necessary, switch SGLC setpoint mode to ***manual*** and enter in the current level as the automatic setpoint value (so that the level will be at the setpoint).

<u>Return to Automatic SGLC Operation……continued</u>

- Set the large LCV for Boiler #1 to Computer ('C') and confirm that SGLC for Boiler #1 has switched from Manual Mode to full computer control (the Manual annunciation should clear).

- As well confirm that the SGLC has assumed control of the large LCV - this can be done by gradually ***lowering*** the setpoint for Boiler #1 CAM station to 12.6 meters (as required) and confirming that the large LCV opens slightly to compensate for the closing of the small LCV. Once the small LCV is completely closed, set the CAM station for Boiler #1 to Computer mode (Boiler #1is now under full SGLC control).

- Repeat these steps for Boilers #2 - #4 to sequentially restore each boiler to full automatic control.

- Check the SGLC display to determine the computed automatic drum level setpoint. Enter this value in small increment values via the manual SGLC level setpoint entry until the drum level is at the computed SGLC setpoint value. Switch SGLC setpoint mode to full automatic.

- Check current ***alarms*** and ***alarm history*** for the boilers GSI to ensure that all expected alarms have cleared and that no unexpected alarms have appeared.

- Confirm key system inputs and outputs and that valve positions and flows are near the expected values for 60%FP operation.

- At this point, boiler level control is available for resumed full automatic control and reactor power can be raised as required.

A Maintenance Induced Plant Outage

Correct Method of Disconnecting the Feed Flow Signals

- If the feedwater flow transmitters interfaced to the boiler level control routine must be recalibrated at power, then significant care must be exercised.
- The feed flow signal should be ***shorted*** (i.e. zero signal) at the CDF WIBA's connected to the SGLC input subsystem. This will immediately force the feed signal to be irrational and so it would be rejected from selection and so will not be used by the SGLC program rules (i.e. control will switch from 3-e to 1-e)
- The WIBA (isolating disconnect switch in each connector) would now be ***opened*** to physically disconnect the field from the computer.
- SGLC would continue to operate – but in 1-e mode now due to the irrational feed flow signal.

Calibration of FeedFlow Transmitters Leading to Turbine Trip & Reactor Trip

- If the feed signal is not shorted out and the WIBA's are opened, then the ***slow capacitive discharge*** across the high impedance of the open circuit will allow the feed flow signal to slowly decay.

- This will appear to the program that the feed flow is gradually, but rationally decreasing and it would appear as if there was not enough feed supply provided to that boiler. The control program can execute perhaps two or three more passes before the flow signal is determined to be irrational.

- During this time, the SGLC program will be ***trying to drive the control valve more open*** in an attempt to correct for the apparent drop in feed flow.

- At this point in time the ***feed flow will be much greater than the steam flow*** and so the drum level will begin to rapidly rise up under 3-e control.

- When the feed flow signal is seen to be irrational, then the control mode will switch to **1-e** mode. But now, the 1-e control will start with an initialized integral term so that the control valves are assumed from their last position. In this way, the 1-e control will take over control with the large valve quite open (more open than needed for the desired steam/feed flow rate).

- Now single element control tuning is much slower (i.e. ***lower gain***) than 3-e and so even though the level is rising, the control response or control gain is quite low so that the valve closes in too slowly to prevent a high boiler level condition from occurring and the ***turbine is tripped on actual high boiler level*** condition.

- The turbine trip will drive the isolating MV's for the drum level control valves closed so there is ***no feedflow***. But SGLC will continue to try to act to correct for the high level condition. As a result the high level condition will force 1-e control to gradually integrate the level control valve closed.

- Once the turbine trip condition is ***reset*** (since the boiler levels begin to drop back down with no feed supply), the MV's will be re-opened and the drum level control ***valve will start acting from the closed*** or just about closed position (in 1-e response to the previous high drum level condition).

- The reactor would have been stepped back to 60%FP on the turbine trip and so as the normal steaming rate at 60%FP is established, the ***feedwater must be increased*** to match this demand (i.e. 60%FP condition) or the drum level will fall.

1-e Drum Response following Turbine Trip.

- Again, the 1-e controller is beginning live execution with the control valves likely closed or quite closed at 60%FP and so the drum level drops rapidly.

- As the drum level drops below the setpoint, 1-e control ***begins to open the level valves*** but quite slowly due to the relatively low gain and slow reset times.

- At this time, there is ***no feedheating***, so the introduction of colder feedwater introduces a ***drum shrink effect*** to make the levels appear to drop even more due to the quenching effect of the cold feedwater – the drum level drop continues.

- The single element response is not fast enough to be able to establish the mass balance condition to stop the level drop before the low drum level reactor setback (which causes further level shrink) and the low drum level reactor trip occurs.

- Note that in this scenario – we are trying to continue to operate following a turbine trip by only using 1-e control which was really designed for stable, low power and slow change conditions.

- So for this event, the unit has been subjected to ***a high drum level turbine trip*** followed by a ***low drum level reactor trip*** both unnecessarily since the incorrect maintenance practice initiated the event.

Possible Improvements to Prevent this Situation from occurring Again

- ***Revise the Maintenance Procedures*** to ensure that the WIBA's connecting field signals to a control program are shorted before being opened

- Implement ***better coordination between Operators and Maintenance staff*** – for example the WIBA's on the standby DCC should have been shorted & opened first by control maintenance with the operator monitoring the resulting indications – once standby indications were seen to be ***as expected and acceptable*** the feedflow could be disconnected for the Master program with known results.

- Provide better ***Work Plan 'Back Out' Conditions*** strategy with full reference to the necessary operating conditions – as soon as the drum level started to rise the operator should have been prepared to intervene or restore the channel signal prior to a turbine trip occurring.

- Review 3-e to 1-e transfers (and other transfers) to ensure that controlability is a higher goal than bumplessness (i.e. perhaps allow a bump but assume correct control).

- Review SGLC logic to see if the logic is initialized following opening of the MV's after a turbine trip sequence to ensure that 1-e control begins from a known condition (i.e. – look to steam flow, or reactor power, etc to get first approximation) so that the valves are not almost closed (this would prevent the reactor trip on low drum level).

SGLC Lecture Summary

Lecture Topics

1. General Boiler Background & Interfacing
2. Drum Level Control Measurements and Control Devices
3. Boiler Level Swell and Shrink Effects
4. Ramped Boiler Level Control Setpoint
5. Feedwater Temperature Effects
6. Rangeability of Control
7. Basic Control Strategy
8. Single Element Drum Level Control
9. Three Element Drum Level Control
10. Single Element Default Control for Power Levels above 16%FP
11. SGLC Manual Mode
12. Dual SGLC or DCC loss
13. SGLC Program Rejection
14. Avoid a Poison Outage
15. Return SGLC to Full Automatic Operation
16. A Maintenance Induced Plant Outage

Lesson 5: STEAM GENERATOR CONTROL

MODULE 3: PRESSURE CONTROL

MODULE OBJECTIVES:

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

1. Sketch a graph of the turbine setpoint vs. reactor power for the Boiler Pressure Control (BPC) routine for a station which does not have a pressurizer.

2. Sketch a simple line diagram representing the main steam supply system from the boilers to the H.P. turbine (include safety valves, SRVs, GSVs, and the BPC logic blocks). State the purpose of each device indicated on the sketch.

3. Describe the negative feedback and the feedforward components of the turbine control section of BPC.

4. Sketch a graph of the SRV setpoint ramp vs. reactor power for the BPC routine (include the turbine setpoint ramp).

5. Describe the negative feedback and the feedforward components of the steam reject valve control section of the BPC.

6. State the general function and operation of the BPC system in the "at-power" mode. Include a block diagram to show the measurements and the manipulated variables.

7. Describe the purpose of a fast boiler pressure control routine.

8. Describe the control room indications available which can be used to verify that steam demand is matching the reactor power and that BPC is operating as expected.

Overall Unit Control

The following equipment is of particular importance to boiler pressure control:

- **Boilers**
- **Governor valves**
- **Speeder motor**
- **Reject valves**
- **Boiler pressure trans.**
- **First Stage Pressure trans.**

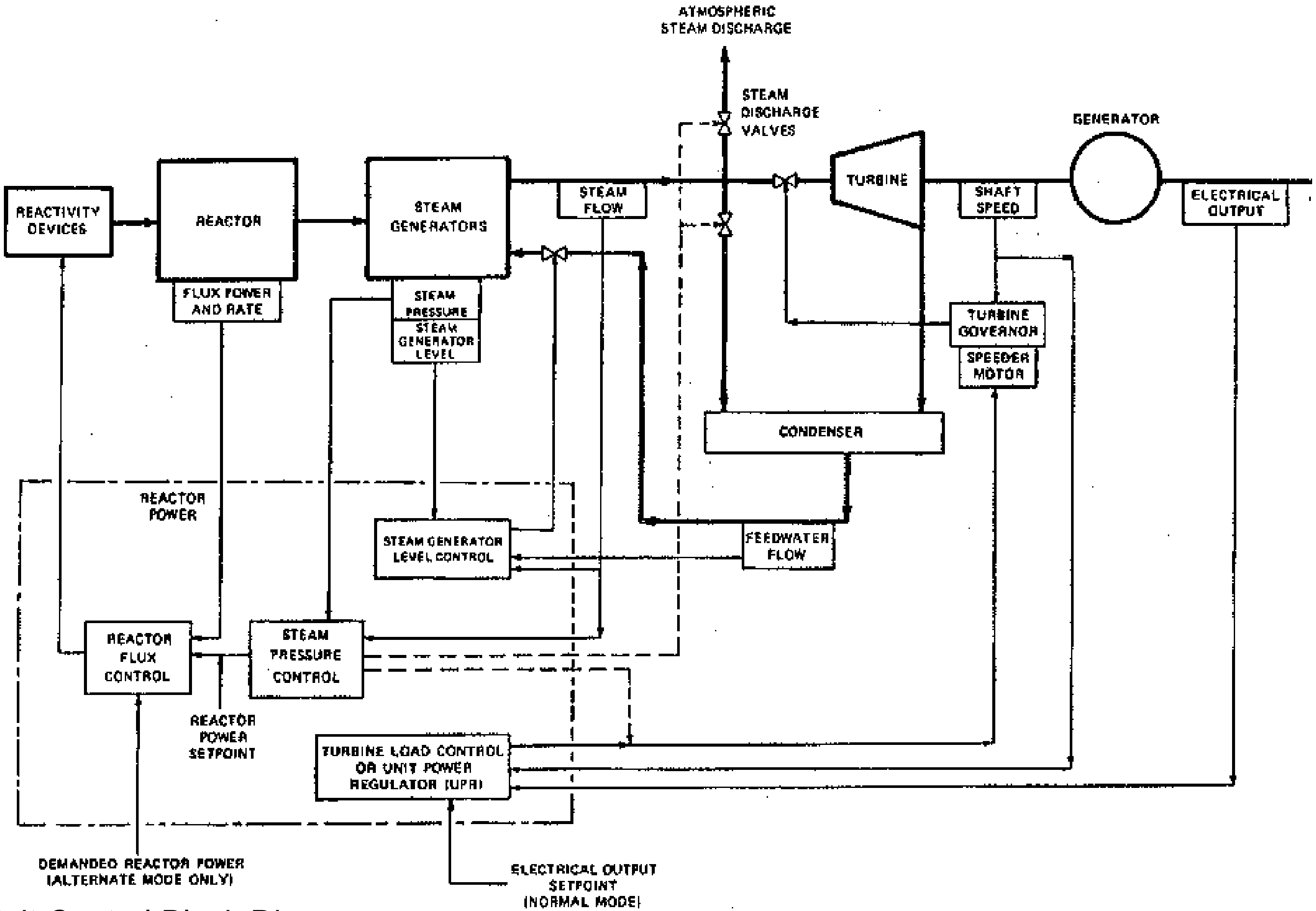


Figure 1: Overall Unit Control Block Diagram.

- **The** ________ ***boiler pressure control system*** **is designed to continually balance the *source energy* supplied (from the heat transport system) with the *sink energy* taken up by either the turbine or the reject valves.**

Ramped Boiler Pressure

- The boiler pressure setpoint is only ramped as a function of reactor power for those plants which do not have a pressurizer - otherwise the boiler pressure is constant.

- With no pressurizer, the power is ramped negatively (Figure 2) to provide a more constant HTS average temperature - i.e. less swell load for HTS control.

- For the example provided here, the pressure ramp is from approximately 5 MPa (at 0% FP) to approximately 4 MPa (at 100% FP) so the RIH temperature (as set by the boiler heat sink) is cooler at 100%FP than at 0%FP to offset the corresponding rise in ROH temperatures.

- This *ramped boiler pressure* (and corresponding temperature) minimizes the heat transport inventory swell and shrink (as the reactor power is changed) by maintaining a relatively constant average heat transport temperature.

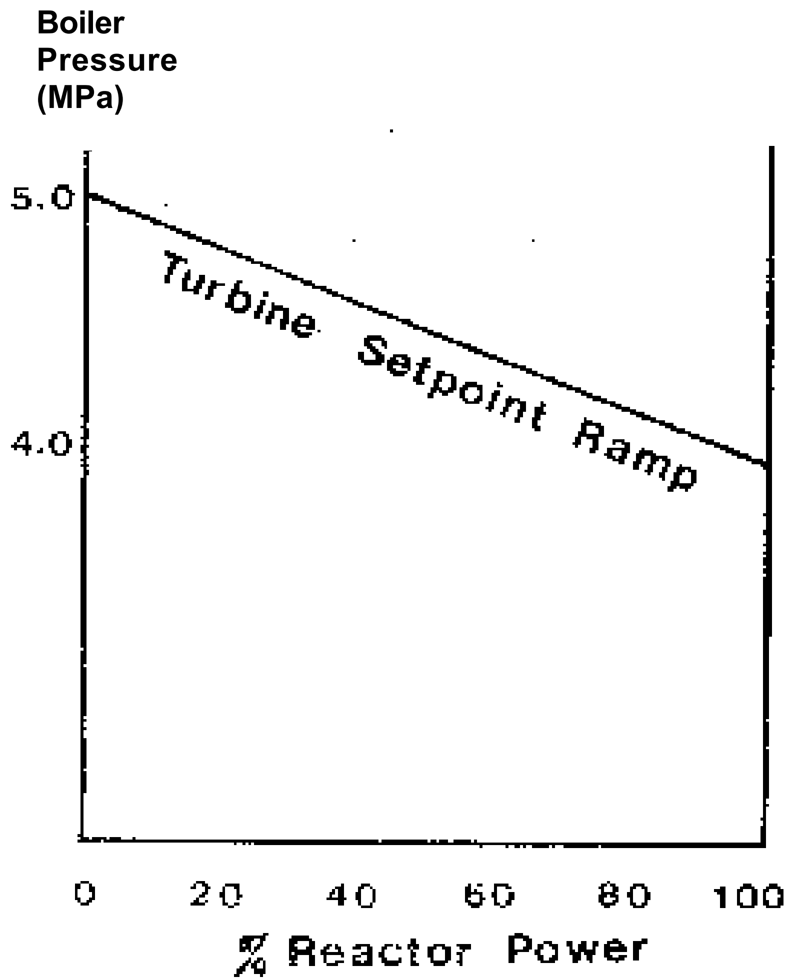


Figure 2: Ramped Boiler Pressure.

BOILER PRESSURE CONTROL MANIPULATIONS

- **For a station having a *reactor-leading-turbine* overall plant control scheme, the boiler pressure control provides the means for the unit power output to follow the reactor.**

- **As the reactor power is increased, the *energy* supplied to the boilers is first raised. Then, a *lower boiler pressure setpoint* is calculated to satisfy the ramp of Fig 2.**

- **This higher energy input with lower pressure setpoint *results in a larger magnitude positive boiler pressure error.***

- **The *higher boiler pressure* is reduced by *increasing the steam flow from the boilers* (i.e. run-up the speeder gear to open the governor valves more)**

- **Depending upon the Plant configuration, the increased boiler steam flow can be admitted *to the turbine (preferred path)* or discharged *via the steam reject valves (alternate heat sink).***

- **The following Diagram (Figure 3.) shows the key Boiler Pressure System components for the Pickering A 550 MWe station for illustrative purposes.**

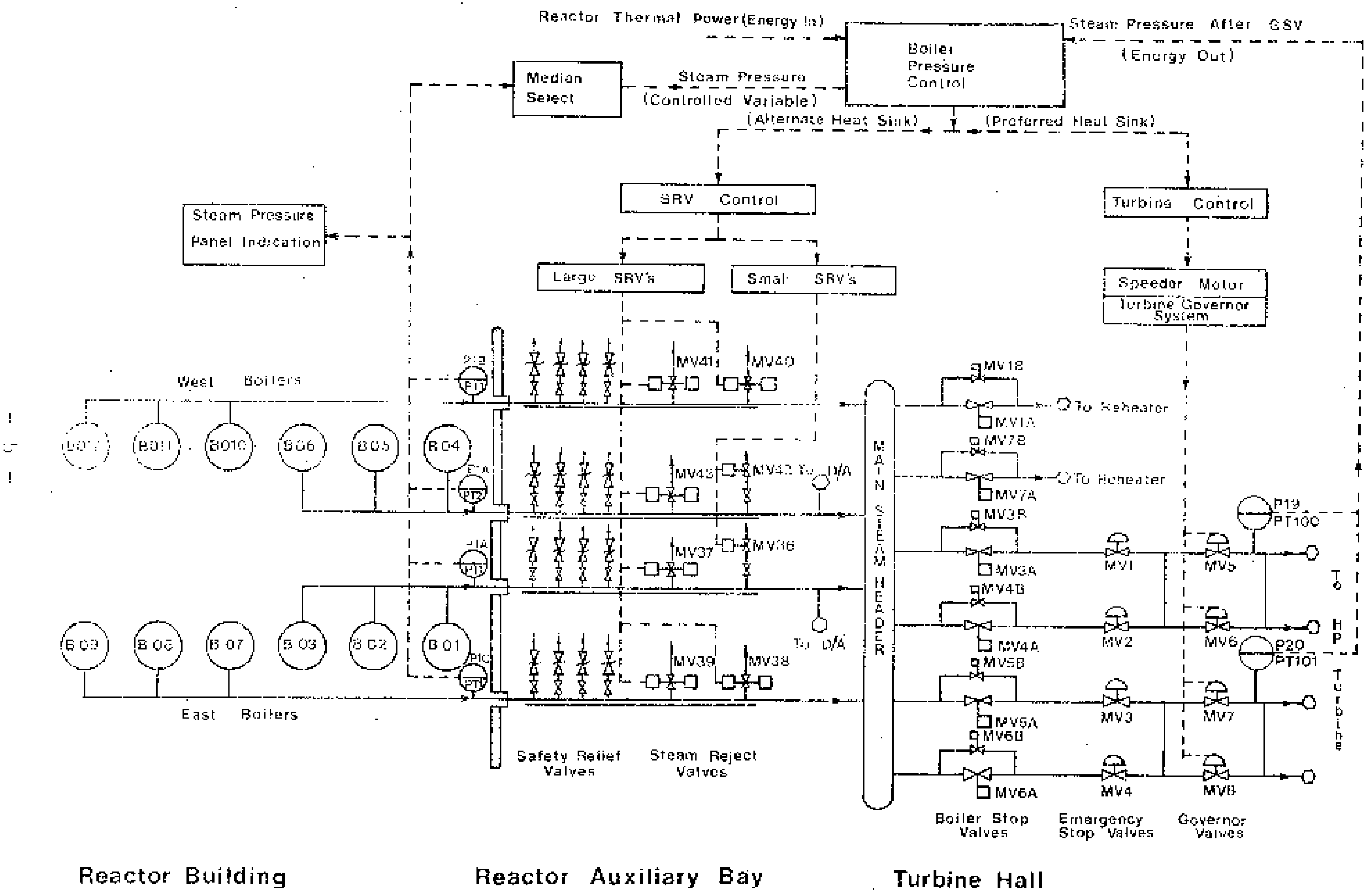


Figure 3: Boiler Pressure Control System.

Boiler Pressure Control (BPC) System

The main components of the boiler pressure control system are outlined in Figure 3.

- **The steam pressure is sensed by electronic *pressure transmitters* which develop the measurement signal for the boiler pressure control routine.**
- **The BPC setpoint is computed as a function of the reactor power.**
- **The difference between the steam pressure and the steam pressure setpoint is the boiler *pressure error*:**

Boiler Pressure Error = Steam Pressure - Steam Pressure Set Point

Note: This is one example where the sign of the control error was choosen so that the error would be positive when the pressure is above the setpoint (more obvious to the operator)

- **The boiler pressure error is used to develop a proportional feedback control signal used to manipulate the boiler heat sinks.**
- **If the *boiler pressure error is positive* - more steam is admitted to the turbine or the reject valves.**
- **The boiler pressure control has *two control output routines*:**
  1. ***turbine governor* control - preferred sink**
  2. ***steam reject valve* control - alternate sink**

Turbine Governor Control - Preferred Heat Sink

- **In the "*at power*" mode, the turbine is used as the principle *heat sink* for controlling the boiler pressure.**

- **The expected boiler pressure resulting from the turbine heat sink is provided as a ramp.**

- **If the boiler pressure should *rise above* the turbine setpoint ramp (+ve error), the steam flow to the turbine is increased (in this case the heat sink had not been effective enough)**

- **Turbine steam inflow control is referred to as *speeder gear* control which manipulates the *governor valve position*. If the boiler pressure is too high, the speeder gear is *run-up* which admits more steam to the turbine.**

- **When the boiler pressure *drops below* the setpoint ramp (-ve error), the pressure error drives the speeder gear back (*run-back*) down to decrease the steam flow via the governor valves to the turbine. (in this case the heat sink had been too effective)**

- **On speeder gear run-back, the *steam flow* to the turbine is *reduced* and the boiler pressure should recover (rise) back to the setpoint ramp.**

- **BPC will manipulate the speeder gear in a negative feedback control fashion to attempt to maintain the boiler pressure at the turbine setpoint ramp.**

Turbine Governor Control (continued)

- **Remember that the boilers, heat transport and reactor will all be operating at the same time as the turbine demand changes are occurring and that the *total energy balance* must be maintained.**

- **If the turbine extracted too much energy from the boilers, the boiler pressure would drop presenting a colder heat sink to the heat transport system, in-turn causing the heat transport pressure to drop. The reactor power would have to be increased (if operating in the reactor-leading-turbine mode) to restore both the heat transport and boiler pressures.**

- **If the BPC system was functioning normally and the reactor was *setback* (an automatic power reduction for some reason not associated with the turbine), then a *feedforward* turbine control signal would be developed.**

- **If the reactor is *not setback*, the feedforward term is set to zero.**

- **The feedforward term is proportional to the *difference* in the computed *reactor power now (say 86%) ,* and what the *reactor power was two seconds previously (say 90%)*.**
  Feedforward Signal (-ve) = %RP(now) - %RP (-2 seconds)

- **This negative signal will *run-back* the speeder (decreasing steam flow) *anticipating* that the boiler pressure will begin to drop due to the lower reactor power.**

Steam Reject Valve Control - Alternate Sink

- **The steam reject valve control ramp setpoint is offset from that of the turbine *by +100 kPa* as shown in Figure 4.**
- **Should the steam pressure rise more than approximately *+100 kPa above the turbine steam pressure setpoint*, the SRV setpoint ramp is engaged.**
- **If the boiler pressure exceeds the SRV ramp, the reject valves (Figure 3) will *begin to stroke open*.**
- **The SRV's are an *effective, alternate heat sink* which supplement the heat sink capability of the turbine.**
- **The reject valve (Figure 3) control scheme will *throttle the SRVs proportional to the boiler pressure error*.**
- **If the SRV control signal is *5% or lower*, the *small SRVs are stroked open* while the large SRV's remain closed.**

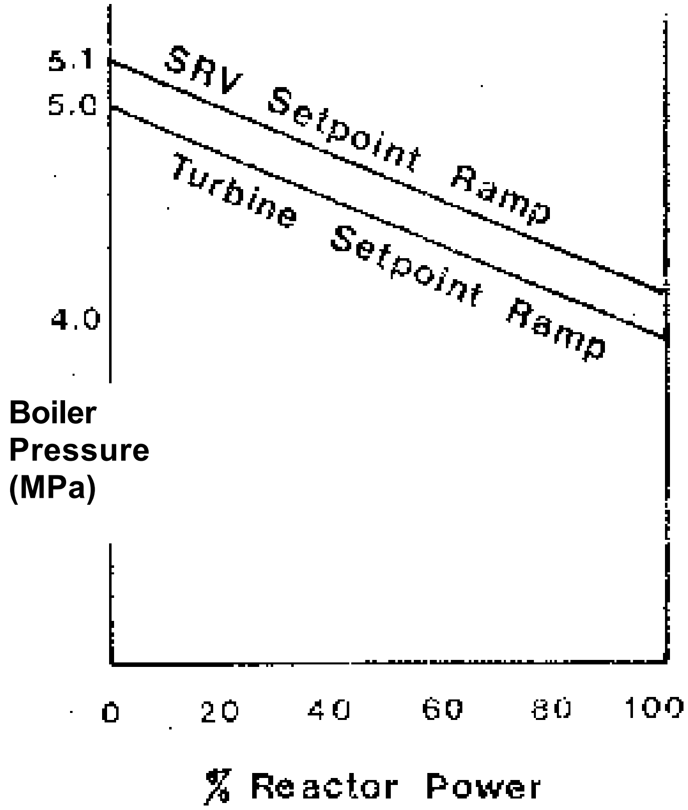


Figure 4: Turbine and SRV Setpoint Ramps

- **If the SRV control signal is *greater than 5%,* the *small SRVs are set fully open* while the *large SRV's begin to be stroked* proportional to the SRV signal**
- **A *reactor setback* will be initiated by the large reject valves driving open .**

Steam Reject Valve Control (continued)

- **Note that when the large SRV's open, there is a *more effective heat sink* provided plus the *heat source is reduced* by the reactor setback action (*two diverse actions* to ensure pressure reduction and recovery).**

- **If the turbine is *off-steam pressure control* and the *reactor is not tripped*, the SRVs control routine will also develop a *feedforward* term.**

- **The average steam pressure after the governor valves (Figure 3 - PT100, PT101) is used to compute the *reactor power* as a *function of the steam pressure*.**

- **The difference between the *actual reactor power* (energy source) and this *steam pressure computed power* (turbine energy sink) is used to *predict the energy mismatch* between reactor output and the energy sink available at the turbine.**

- **This positive feedforward signal anticipates that the *boiler pressure is going to rise* and begins to drive the SRVs open to prevent the pressure excursion.**

Fast Boiler Pressure Control (mini-computer example)

- **The boiler pressure control routine is executed every two seconds which is usually adequate to maintain stable boiler pressure control.**
- **This control sampling time frame may be too slow if the turbine is subjected to disturbances such as turbine runback or a loss of load**
- **To avoid such problems, a core resident routine similar to the SRV control program can be run every 0.5 seconds.**
- **This program is called the Fast Boiler Pressure Control (FBPC) routine.**
- **The FBPC routine is activated by a priority interrupt that is enabled from the logic circuits of either the fast or the slow *turbine runbacks* (if the reactor is not tripped).**
- **In this fashion, the normal BPC program execution will be temporarily interrupted and a fast SRV routine will be run to ensure that the SRV control scheme is serviced frequently enough to maintain pressure control.**

INTEGRATED BOILER PRESSURE CONTROL

- **The boiler steam pressure operating diagram is illustrated in Figure 5.**
- **The pressure should be controlled to the turbine pressure control ramp with the turbine as the heat sink.**
- **BPC attempts to manipulate the steam flow via the governor valves or SRVs in order to balance the reactor power output.**
- **The success of the BPC performance can be determined by examining the *boiler pressure* panel indicators or by calling up the *boiler pressure error* on the computer display.**
- **If the +100 kPa SRV pressure offset *above the turbine pressure ramp* is exceeded, the SRVs would begin to operate.**

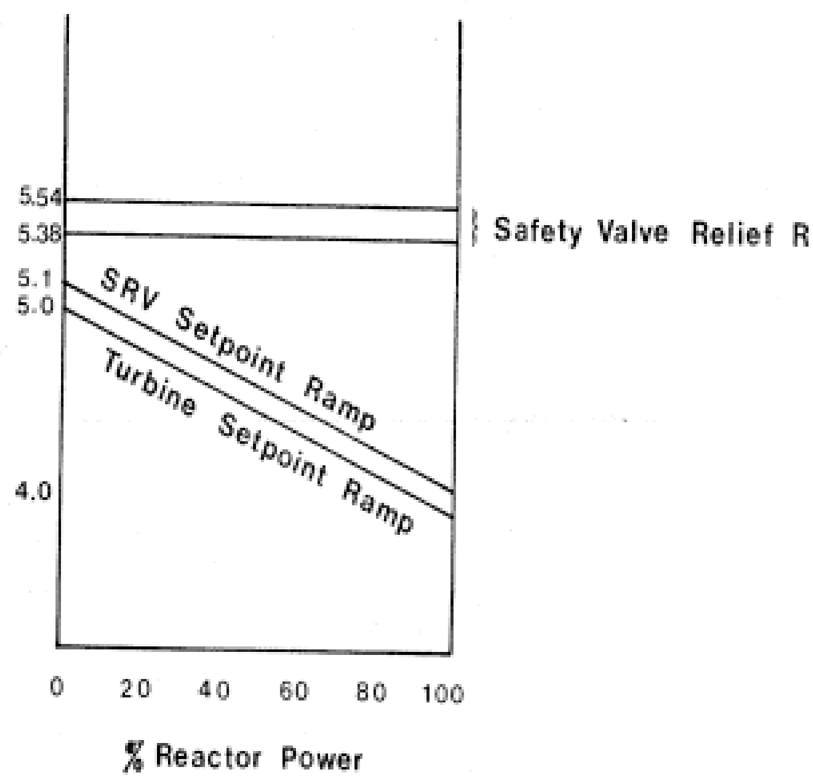


Figure 5: Steam Pressure Operating Diagram.

- **If the turbine *and* the SRV's are not able to control the boiler pressure, then separate *overpressure protection* is required.**
- **Steam system overpressure protection is provided by the *sixteen safety valves* (Figure 3).**
- **These valves are set to relieve at pressures ranging from 5.38 to 5.54 MPa(g) and can each release approximately 6% of the full power steam flow.**

BOILER PRESSURE CONTROL MODULE ASSIGNMENT

1. **Sketch a graph of the turbine setpoint vs. reactor power for the Boiler Pressure Control (BPC) routine for a station which does not have a pressurizer.**
2. **Sketch a simple line diagram representing the main steam supply system from the boilers to the H.P. turbine (include safety valves, SRVs, GSVs, and the BPC logic blocks). State the purpose of each device indicated on the sketch.**
3. **Describe the negative feedback and the feedforward components of the turbine control section of BPC.**
4. **Sketch a graph of the SRV setpoint ramp vs. reactor power for the BPC routine (include the turbine setpoint ramp).**
5. **Describe the negative feedback and the feedforward components of the steam reject valve control section of the BPC.**
6. **State the general function and operation of the BPC system in the "at-power" mode. Include a block diagram to show the measurements and the manipulated variables.**
7. **Describe the general purpose of a fast boiler pressure control routine.**
8. **Describe the control room indications available which can be used to verify that steam demand is matching the reactor power and that BPC is operating as expected.**