IAE CANDU Controls Lectures
Darlington Boiler Level Control Program Review

STEAM GENERATOR LEVEL CONTROL Program (SGLC) NOTES

These notes are based on DNGS-A station information - but dated back to 1991 (so may not be current)

This information is intended to supplement the IAE controls lectures with additional information on the digital control computer application to Boiler Level Controls with implementation details and some considerations for control improvement or innovation.

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. Possible Improvements to the SGLC design
15. Avoid a Poison Outage
16. Return SGLC to Full Automatic Operation

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) in order to maintain the drum level 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***.

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 may cause a steam pressure increase (or just maintain the steam header pressure) - depending upon the steam demand (turbine, 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 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.

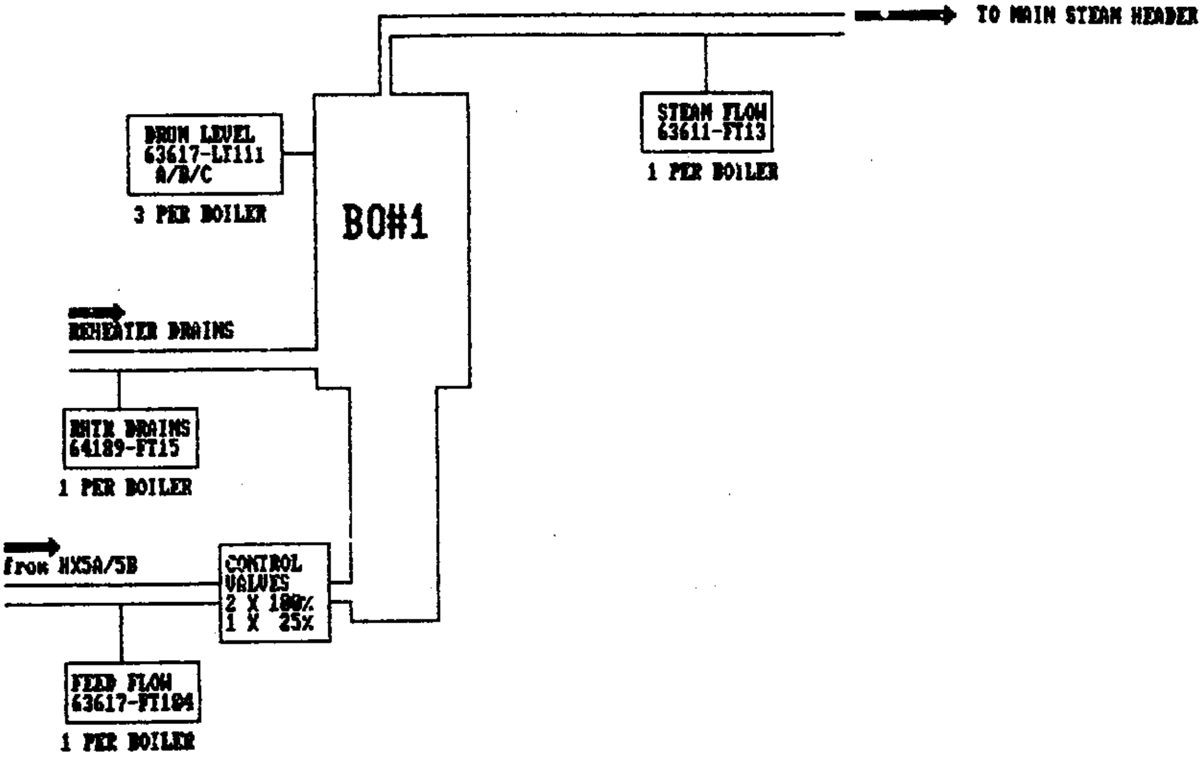

Figure #1. Key CANDU Boiler Level Control Instrumentation

From Figure 1. it can be seen that 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.

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 parameter provides the control program with the calculation ***capability to apply a feedforward control strategy*** to correct the feedwater flow before the 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 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 amounts to about 15 Kg/s at full power operation.

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 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 valve in service.

Drum Level Control Measurements and Control Devices

The ***drum level*** for each boiler should be measured by ***triplicated*** narrow range level level transmitters that provide usable level signals from 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 (ie 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 purposes. 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. 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*** and the control program would revert to ***manual mode***.

An alternate source of drum level indication is the ***wide range level transmitters***, currently there are only two wide range level level transmitters provided per drum and these are usually only calibrated correct under hot conditions. It would be quite easy to provide ***automatic compensation*** for drum inventory temperatures and hence 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.

IAE CANDU Controls Lectures
Darlington Boiler Level Control Program Review

A single feedwater flow transmitter is provided for each boiler to monitor the ***feedwater 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. As well, the ***reheater drains flows*** to each boiler should be measured by a drains flow transmitter to allow the determination of all flows into that boiler at any time. 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.

A ***single steam flow transmitter*** is provided for each boiler to monitor the steam 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.

Note that a very simple ***inventory accounting routine*** could be prepared for each boiler by computing the ***starting inventory*** in the boiler, adding the total inflow (feedwater plus reheater drains) and subtracting the total steam flow removed. In this way, the ***true resident inventory*** for that drum would be known and this could be used to 'trim' questionable control decisions (say under cold feedwater corrections, etc) to avoid long term cyclic responses.

As well,this information could be immediately available for the operator following a postulated ***loss of feedwater*** event to assist with mission time definitions. The apparent drum level could also be determined by considering such factors as steam drum pressure and feedwater temperatures to better assist operators with understanding dynamic condiitons. Such data could be used to present an updated '***margins***' display to show the existing ***Reactor power minutes inventory*** available at any time , scaled by the ***present*** reactor power level.

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.

Boiler Level Swell and Shrink Effects

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 I 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 or 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. 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 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.

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, 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 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.

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. At the same time, the ramp 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. 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.

Feedwater Temperature Effects

On further consideration we should 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). 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. The ***feedwater temperature*** is a valuable control assessment parameter to assist in knowing what the consequences of a feedwater flow correction will be.

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 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. This 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).

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 it is needed).

Basic Control Strategy

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*** (ie like using valve position as a 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.

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*** from expected operations, ***second warning*** could be a ***larger magnitude*** 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

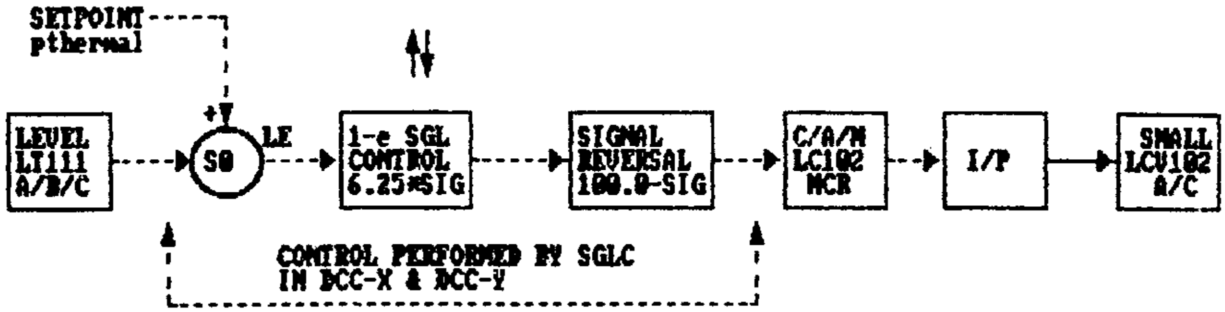

Figure #2. SGLC Single Element (1-e) CONTROL Less Than 11% FP

The control program for power operation below 11%FP operates the small level control valve which can provide flows up to 25%FP capacity. 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.

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.

IAE CANDU Controls Lectures
Darlington Boiler Level Control Program Review

Assume the boiler levels were controlled ***steady at the setpoint*** with the large valves closed and the small valves approximately **40% open** 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 ***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 **50% open**.

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.

Three Element Drum Level Control

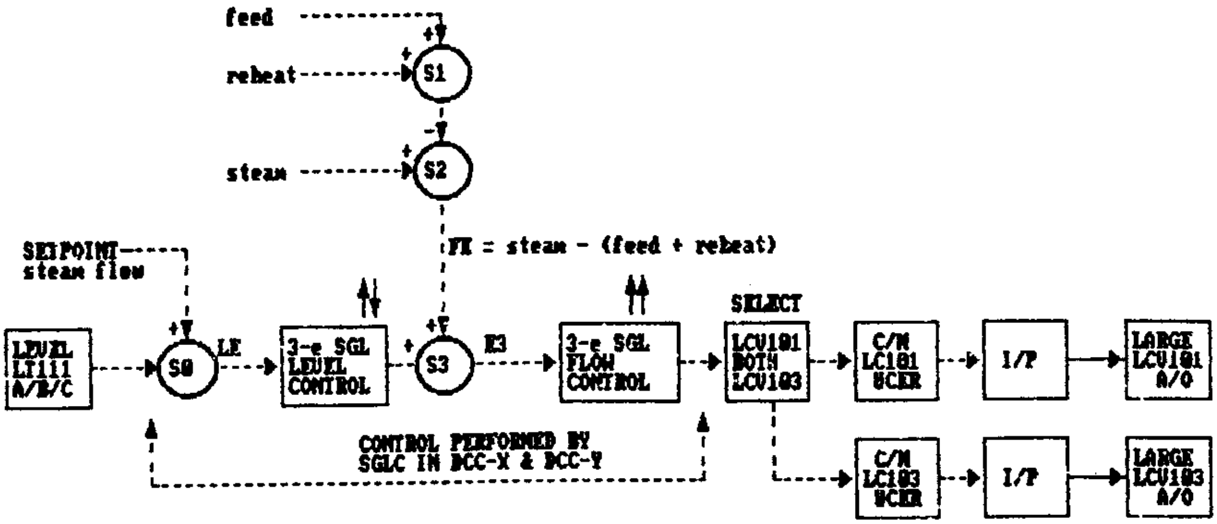

Figure #3 SGLC 3-e CONTROL Greater Than 16% FP

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.

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 as the computed setpoint.

However, this is a transition region and it is more logical to move (i.e increase reactor power) ***smoothly and steadily*** from 15% to 20%FP to allow the setpoint computation, control mode logic and valve transfer logic to be completed.

Assume now that the reactor is at 50% FP and that the boiler levels are steady at the setpoint with the selected large valve **35% open**. The small 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?) is ensured for the impending power increase. An additional feedpump may have already been started and left running in full recirculation mode. If the 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. SGLC ***three element control*** will recognize the increase in steam flow immediately and request additional feedwater flow to correct for the steam flow/feed flow imbalance. If the drum level had dropped below the setpoint slightly, the level control signal will drive the feed valve more open (than required by the feedforward balance signal) and so the inflow will exceed the outflow allowing the level to increase and the level will approach the new setpoint. Once the level reaches the setpoint, the level control signal will be reduced so that the mass balance is ***just reachieved*** 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 and the large valve approximately **40% open**.

SGLC 1-e Default Control for Power Levels above 16% FP

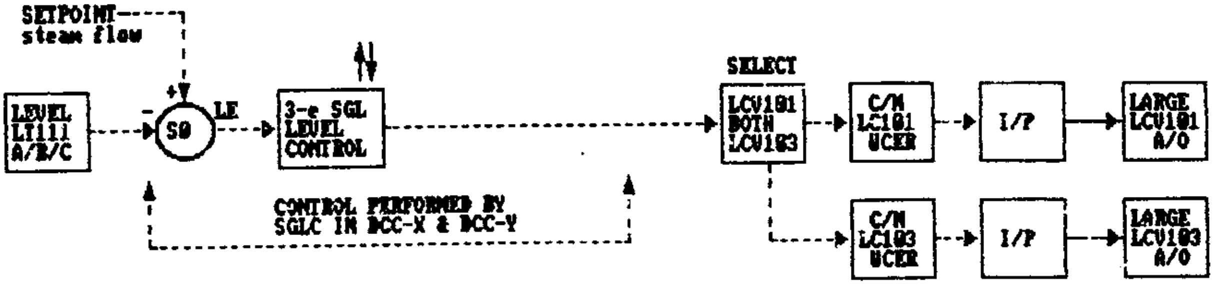

Figure #4 Default 1-e Control fo SGLC at power levels above 16% FP

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 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***. 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.

SGLC Manual Mode

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*** - 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. The SGLC control program will now ***track*** the individual signaals 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*** (such as SGLC) and a ***computer failure*** (the entire DCC). A program can fail, for example, due to irrational input signals - 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 irrational signals 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 this case, 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 20%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 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.

SGLC Program Rejection

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. 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) to about **10% opening** 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 closed manually 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 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.

It is worth considering some of the design features here to see if ***possible improvement*** could be achieved. The initial problems was three irrational level transmitter signals for Boiler #2 for one DCC and the response was to setback the reactor effecting all boilers and systems. Perhaps it would be prudent to attempt to read those signals from the standby computer - that is, invoke a control program transfer from master to standby. If the signals can not be read then the alternate follow up plans can be initiated. However, if the signals can be read on the standby DCC, then SGLC control under full automatic control can be resumed and the unit outage would be avoided.

Could We Do It Better?

As a ***training exercise***, let's consider if we could improve the situation by a different design strategy. However, we must recognize that there are many constraints to making such changes in an operating plant such as computer memory limist, costs, resource availability, risk, etc. However, it is still worth considering in order to have some strategy for use with future applications.

Now let's assume that none of the signals can be read by the standy computer - then the SGLC program must fail off and the reactor setback will be initiated on irrational boiler level signals. Because this is now a dual SGLC program loss, the large LCVs will close and control will switch to CAM automatic mode for the small valve only (the operator does not need to manually close the large LCV via the C/M stations in the unit control equipment room).

The CAM station for Boiler #2 will still be irrational and so this is perhaps a candidate for one additional and independent transmitter signal or to provide the capability to switch in (via scaled interfacing) the ***wide range level transmitter*** signal. It does not seem to be good practice to remove both the automatic control means and the backup control capability by one failure mechanism. If such a diverse or alternate signal was provided, then the operator need only switch the CAM station for Boiler #2 to select the alternate signal source and boiler level control for Boiler #2 can be resumed automatically in the same manner as the other boilers, much reducing the work load on the operator for this event.

Note also that the boiler level control for that boiler could have been rejected (as opposed to all boilers) as the signals for all other boilers were rational. This means that these three boilers could have remained at full power with full confidence and the problem only resided with boiler #2. Now usually, the four boilers act very similarly and very often, two boiler act in a near identical manner (heat transfer, boiling rate, in flows, etc). This means that (***with suitable tracking of past performance***), that the operating characteristics for that boiler would be known (ie the large LCV should be 62% open when at 100%FP but only open 58% if the power was reduced to 95%FP). We would also know cross correlation information such that if the large LCV for Boiler #4 was 64% open that the large LCV for Boiler #2 would be open 2% less, etc.etc.

As well, we could monitor the ***wide range level signals*** for each boiler so we could have a rational fallback signal for each boiler available at all times. In this way, we could continue automatic operation with full confidence by either accepting the wide range signal as the backup and placing validity checks on the final control decision by assessing the performance of known 'good' boilers. Should the wide range signal also not be available (highly unlikely) then a fuzzy logic implementation could be attemped to consider all inflows to and all outflows from the troubled boiler along with cross-correlation relational parameters to allow continued full power operation with high priority annunciation to initiate control maintenance recovery work on the original irrational signals.

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. 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 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. 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, 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). 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 (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 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.