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## **7 FEEDWATER CONTROL SYSTEM**

### **Learning Objectives:**

1. State the function of the Feedwater Control System (FWCS).
2. List the inputs used to control steam generator water level and describe how each input is used.
3. List the override signal associated with the FWCS.
4. Explain the two modes of automatic control for the FWCS.
5. Explain the difference between actual and indicated steam generator level following a plant cooldown.

### **7.1 Introduction**

Each steam generator is equipped with independent three element and single element controllers. The elements used are steam flow, feed flow, and level. These elements will be used to control feedwater flow to each steam generator to maintain proper steam generator level during normal plant operation. The FWCS will automatically control steam generator level above 15% power using the three element mode of control. During startups and shutdowns, when below 15% power, a single element (level only) control is selected, and the feed water bypass valves will be controlled to maintain steam generator level.

The FWCS is designed to perform the following functions:

1. Automatically maintain steam generator water level at the designed normal water level using a three element control system above 15% power and a single element control system below 15% power,
2. Provide reduced feedwater flow after a turbine trip by shutting the main Feedwater Regulating Valve (FRV) and positioning the bypass FRV to supply five percent (5%) of main feedwater flow to each steam generator and
3. Allow the operator to manually control the main and bypass FRV's to control feedwater flow to each steam generator.

The main feedwater line to each steam generator is provided with a feed water regulating valve and a bypass valve. The bypass valve may be used to manually control feed water flow at no load or low load operations. An additional control function of the FWCS is to adjust the speed of the turbine driven main feed pumps. This signal is varied between minimum and maximum as a function of the differential pressure ( $\Delta P$ ) across the FRV.

### **7.2 FWCS Inputs**

#### **7.2.1 Steam Generator Level**

Two level detectors per steam generator measure the  $\Delta P$  between the upper and lower taps in the downcomer area of the steam generator. One is used for high/low steam generator level alarms and for the operation of the feedwater regulating bypass valve (through the single element controller). The remaining transmitter is used for level indication and control of the FRV (through the three element controller). Steam

generator alarms, penetrations, and operating limits referenced to the low level tap (0% indicating) are listed in Table 7-1.

<b>Table 7-1 Steam Generator Level (Narrow Range)</b>	
High level tap	100%
High level turbine trip	92.5%
High level alarm	81%
Bottom of steam separators	78%
Normal level	65%
Surface blowdown ring	61%
Low level alarm	51%
Low level pre-trip	47%
Feed ring	39%
Low level reactor trip	37%
Top of Steam Generator tubes	32%
Low level tap	0%

Differential pressure (D/P) cells are used to produce a signal proportional to steam generator downcomer level by measuring the difference in pressure between a reference leg and a variable leg. The reference leg (high level tap) has a constant level maintained by a condensate pot. The condensate pot and reference leg are unlagged and located external to the steam generator. Steam (525°F) is condensed in the condensate pot where the ambient temperature is relatively low (120°F). The variable leg (low level tap) has a variable level due to the changing downcomer level. Electronic force balance transmitters

convert the  $\Delta P$  to a 4-20 ma current signal. The maximum signal output occurs at maximum level (which corresponds to a minimum  $\Delta P$ ). The detectors are narrow range instruments measuring 183 inches of level in the normal operating range. The level indicators display level as zero (0) to one-hundred percent (100%).

Since density compensation is not incorporated in the level detection circuitry, manual level correction is required for reduced steam generator pressure (temperature). Transmitters are calibrated for a generator pressure of 850 psia. Since the reference leg is external, its temperature is constant (120°F ambient). As steam generator temperature is reduced (during a cooldown), the reference leg density is constant, but the density of the steam generator water increases. If indicated level is maintained at 65% then the actual level will decrease as the steam generator temperature is reduced. At 850 psia, indicated level equals actual level (65%). At 14.7 psia, indicated level equals 65%, but actual level equals 47.5%.

### 7.2.2 Steam Flow

An elbow tap (inside containment) at the outlet of each steam generator measures steam flow. The steam flow is forced to the outer radius of the elbow causing a measurable  $\Delta P$  to be developed. A D/P transmitter produces a 4-20 ma electrical signal that's proportional to  $\Delta P$ . The signal is biased to always have a minimum output of approximately 10% due to the inaccuracies of sensing such a small  $\Delta P$ . The steam flow system is calibrated for operation at 850 psia.

### 7.2.3 Feed Flow

A venturi flow nozzle, downstream of the FRV, is used to sense main feedwater flow. The venturi nozzle has a restriction which causes a measurable  $\Delta P$  proportional to flow rate. An electronic transmitter and square root extractor are used for producing the feed flow signal. As with steam flow, the feed flow signal is biased at 10% due to the

existence of similar inaccuracies at small  $\Delta P$  signals. Like steam flow system, feed flow is calibrated for its normal operating range

### 7.3 FWCS Normal Operations

#### 7.3.1 Below 15% Power

##### BYPASS FEEDWATER REGULATING VALVE CONTROL

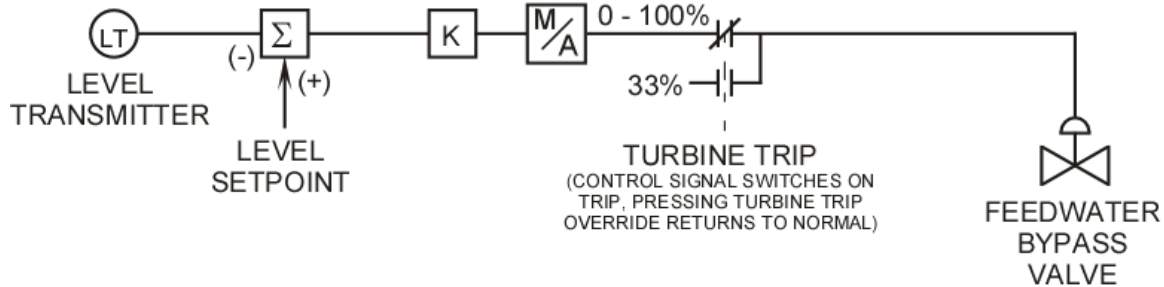


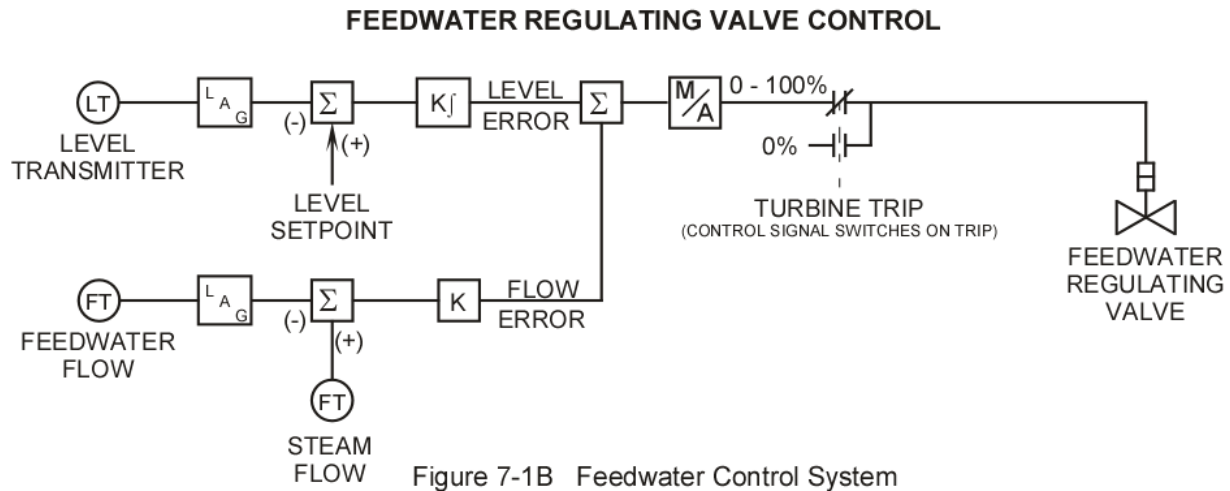
Figure 7-1A Feedwater Control System

During plant startup (< 5% power) the auxiliary feedwater system may be used to feed the steam generators until a main feedwater pump is operating. Since the auxiliary feed pump turbine exhausts to the atmosphere and there is no automatic level control associated with this system, this is not a desirable method for level control. A main feedwater pump is normally placed in service between three and five percent (5%) power to minimize the use of the auxiliary feedwater system.

With power less than 15%, steam generator level is controlled by a single element controller. Actual steam generator downcomer level is compared to a manually adjusted level setpoint signal (normally 65%). The deviation from setpoint (level error) is amplified by a proportional controller with the resulting signal used to adjust bypass FRV position such that the deviation is zero. The controller gain is set to allow a proportional band of 22% level (the bypass valve will be fully open when actual level is 22% below setpoint). Valve capacity is 15% of 100% feed water flow or 2150 gpm.

When controlling steam generator level with the bypass FRV, the manual isolation valves upstream of the main FRV are normally closed. Although the main FRV's are closed, feedwater leakage past them may exceed the rate of steam generation within the steam generator leading to high water levels.

### 7.3.2 Above 15% Power



When power is approximately 15%, level is controlled by a three element controller. Feed water flow is compared with steam flow to determine the flow error. Actual steam generator level is compared with a level setpoint (65%) to determine the level error. The two error signals are combined to position the main FRV. The main FRV capacity is 14,310 gpm.

The lag circuits act to anticipate changes. The faster the input changes (with respect to time), the greater the magnitude of the output signal. For example, a level decrease of 10% in 20 seconds will produce a larger error signal than a level decrease of 10% in 40 seconds. The proportional plus reset (integral) controller can have an output when no input deviation exists. The reset action allows actual level to equal the level setpoint. This action is necessary since the main FRV must be continuously opened as power increases, hence the total valve signal must increase even though feed flow equals steam flow and steam generator level equals setpoint.

The gain of the flow error circuit is twice the gain of the level error circuit. This arrangement compensates for the effects of shrink and swell which occur during transients. The three element system is unstable at low power levels, since feed and steam flow signals are inaccurate at low flow conditions, and small changes in valve position result in large flow changes. To minimize this unstable characteristic, the main FRV controller is usually operated in manual with the FRV closed during low steaming conditions.

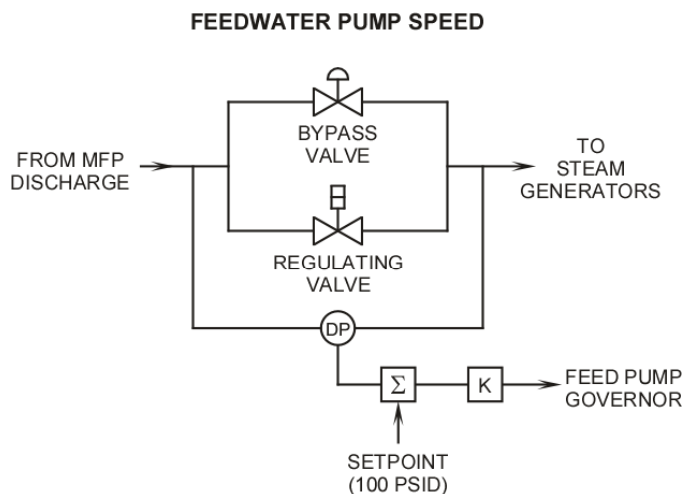


Figure 7-1C Feedwater Control System

In addition to bypass and FRV positioning, the FWCS adjusts turbine feedwater pump speed. Consider the example of the FWCS sensing an increase in steam generator level, which will reduce the opening on the main feed water valves, due to level error. The reduced opening restricts flow and causes an increase in differential pressure across the FRV for the same feedwater turbine speed. The differential pressure controller senses the increased  $\Delta P$ , transmits a

signal to the speed changer calling for a reduction in turbine speed. Reducing the turbine speed decreases pump discharge pressure which reduces the FRV  $\Delta P$ . The end result will be a new turbine speed and valve position, for the same  $\Delta P$ , to maintain the new steam generator condition.

## 7.4 FWCS Transient Operation

### 7.4.1 Step Change in Power

Assume the plant is operating at 50% power and steam generator level is at setpoint with steam flow and feed flow matched. A negative step change (-10%) in steam flow results in a rapid water level decrease (shrink). Initially the control system receives two opposing signals. The decreasing water level (shrink) demands an opening of the main FRV to restore level to setpoint (65%). The large flow error requires the main FRV to be shut so that feedwater flow will equal steam flow. During the initial part of the transient, the flow error signal is dominant due to the larger gain of the flow error circuit. If the valves were allowed to open on the transient as a result of level error (due to shrink), then a large flow error would exist (feed flow > steam flow) and a large overshoot in level would occur.

As the transient progresses, the flow error is reduced and the water level error becomes dominant during the remaining part of the transient in order to restore level to setpoint. The overshoot in level is characteristic of the response of any complex controller. The gains, reset time, and lag times are adjusted such that these overshoots and oscillations are minimized. At the end of the transient new steady-state conditions are reached with feedwater flow matching steam flow and the steam generator water level at setpoint.

### 7.4.2 Turbine Trip

In order to prevent overcooling following a turbine trip, (remember that the reactor trips if power is greater than 15%) feedwater flow is automatically ramped down to five percent (5%) of its 100% value. This is accomplished by closing the main FRV regardless of its mode of control and positioning the bypass valves to 33% open. This bypass valve position corresponds to five percent (5%) feedwater flow. Manual

push buttons are installed to allow the operator to remove the ramp down signal.

A turbine trip results in a ramp down in feed water flow to five percent (5%) of full flow within 60 seconds. The electrical signal to the FRV is grounded resulting in the valve shutting within 60 seconds regardless of its mode (manual or auto). A trip override is provided to restore manual control to the bypass valve (FRV remains closed). The feed water bypass valve receives a signal of 33% of total such that it provides five percent (5% of rated feed flow. A ramp down will provide a better regulation of cooldown after a trip.

### **7.4.3 Level Transmitter Failures**

A leak or rupture in the reference leg will reduce pressure on the high side of the D/P cell. A minimum  $\Delta P$  will be sensed by the D/P cell which gives a high level output. A leak or rupture in the diaphragm which separates high pressure and low pressure fluids will cause a minimum  $\Delta P$  and give a high level output.

Each steam generator has two level transmitters that are used for control by the FWCS. The two transmitters are connected to the FWCS via a selector switch. During normal operation, the output of one transmitter is sent to the three element control system and a level recorder. The output of the second transmitter is sent to level alarms, level indicators, and the single (1) element control system. During a transmitter failure, the selector switch is used to select the remaining operating transmitter and allow it to drive both the three element and the single (1) element control systems and therefore no control functions will be permanently lost.

Failure of the level transmitter associated with the bypass FRV will give high/low level alarms and a high/low indicated level on the main control board regardless of power level or mode of control. The level recorder will continue to indicate normal level. If power is below 15% and level is being maintained automatically, then the bypass FRV will fully open or fully shut. In either case, the operator should put the controller in manual and bring level back to setpoint. The problem can then be diagnosed and the non-failed level transmitter selected. If power is above 15%, there will be no effect on feedwater control. The level transmitter should still be repositioned since this action could be forgotten after a trip or shutdown.

Failure of the level transmitter associated with the main FRV will give high/low indications on the level recorders. The high/low level alarms would not come in until actual level, as sensed by the other transmitter, reached the alarm setpoint. Additionally, the level indicators would indicate normally. If power is above 15% and FRV control is in automatic when the level transmitter fails low, the FRV would receive a signal to fully open. This would cause a feed flow mismatch which would over feed the steam generators causing actual level to increase. This condition would continue until the operator takes corrective action. The immediate action would be to shift the control station to manual and restore steam generator level to setpoint. If left unchecked, a high steam generator level (92.5%) will be exceeded, causing a turbine trip, and a reactor trip will result.



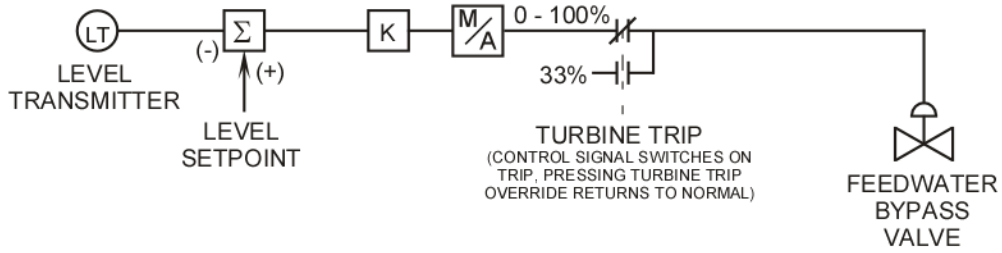
## **7.5 Summary**

The FWCS functions to control steam generator level during plant startups, normal operation, and plant shutdowns. Two different control schemes are employed. When the plant is operating at power levels less than 15%, a single (1) element (steam generator level) control is used. When the plant is operating at power levels greater than 15%, a three element control system (steam flow, feed flow, and steam generator level) is used.

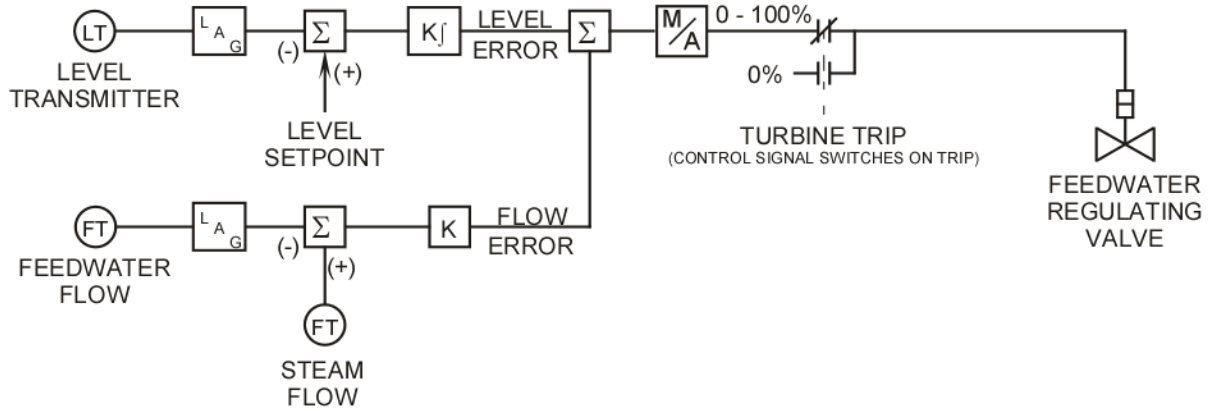
The FWCS provides an override feature when the turbine is tripped. The override feature consists of closing the FRV and positioning the bypass valve to thirty three percent (33%) open.



### BYPASS FEEDWATER REGULATING VALVE CONTROL



### FEEDWATER REGULATING VALVE CONTROL



### FEEDWATER PUMP SPEED

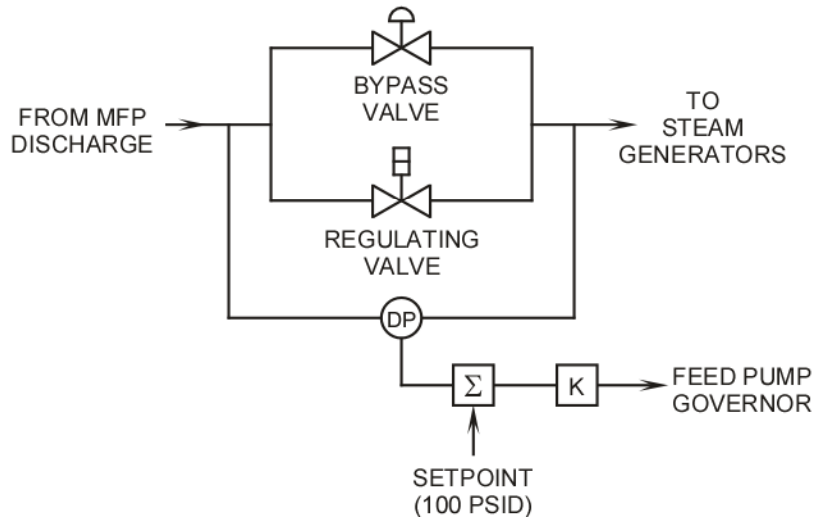


Figure 7-1 Feedwater Control System