7.10 FEEDWATER CONTROL SYSTEM

7.10.1 Power Generation Objective

The objective of the Feedwater Control System is to maintain a pre-established water level in the reactor vessel during planned operation.

7.10.2 Power Generation Design Basis

The Feedwater Control System shall regulate the feedwater flow so that the proper water level in the reactor vessel is maintained according to the requirements for steam quality over the entire operating range of the reactor.

The feedwater flow shall also provide sufficient subcooled water to the reactor vessel during power operation to maintain normal operating temperatures.

7.10.3 Description (Figures 7.10-2 through 7.10-7)

The Feedwater Control System, during normal operation, automatically regulates feedwater flow into the reactor vessel. The system is capable of being manually operated.

The feedwater flow control instrumentation measures the water level in the reactor vessel, the feedwater flow rate into the reactor vessel, and the steam flow rate from the reactor vessel. The system also measures final feedwater temperature (Units 2 and 3 only). During automatic operation, the level, steam flow, and feed flow measurements are used for controlling feedwater flow.

The optimum reactor vessel water level is determined by the operation of the steam separators, which limit the water carryover with the steam going to the turbines, and which limit the steam carryunder with the water returning to the core. The water level in the reactor vessel is maintained within 2 inches of the desired level. This control capability is achieved during plant load changes by balancing the mass flow rate of feedwater to the reactor vessel with the steam flow from the reactor vessel. The feedwater flow regulation is achieved by adjusting the speed of the turbine-driven feedwater pumps to deliver the required feedwater flow to the reactor vessel.

7.10.3.1 Reactor Vessel Water Level Measurement

Reactor vessel water level is measured by four identical independent sensing systems. A differential pressure transmitter (dPT) senses the difference between the pressure due to a constant reference column of water and the pressure due to the variable height of water in the reactor vessel. These differential pressure transmitters are installed on pipelines that serve other systems (see Subsection 7.8, "Reactor Vessel Instrumentation"). Each of the four dPTs supply signals to the Reactor Feedwater Control System (RFWCS). The average of the four dPTs is used to develop a controlling level signal.

Three wide range pressure transmitters supply reactor pressure signals to the RFWCS. The pressure signals are averaged and the average reactor pressure signal is then applied to each dP signal and the average dP signal to produce a pressure compensated level signal.

The four compensated level signals and three pressure signals are indicated in the control room. Both level and pressure loops have manual bypass switches installed above their respective indicators to allow an operator to take that particular loop out-of-service. The RFWCS level and pressure loop bypass status is indicated in the MCR.

Average water level is used by the RFWCS as the controlling water level. Controlling water level and average reactor pressure are continually recorded in the control room.

7.10.3.2 Steam Flow Measurement

Units 2 and 3

The steam flow is measured across each main steam line flow restrictor by a differential pressure transmitter. The differential pressure due to steam flow is sent to the RFWCS indicating mass flow rate.

The steam flow signals are compensated for adiabatic expansion of steam through the Main Steam flow nozzles and for temperature/density effects. The RFWCS sums all four main steam line flow signals to produce a total steam flow signal used in the control algorithm. Total steam flow is recorded in the control room.

Unit 1

The steam flow is measured across each main steam line flow restrictor by a differential pressure transmitter. The steam flow signal is then linearized by a square root converter to output a mass flow rate.

The corrected steam flow rate from each main steam line is indicated in the control room. The steam flow signals are added by a summer to produce a total steam flow signal for indication and feedwater flow control. The total steam flow is recorded in the control room.

7.10.3.3 Feedwater Flow Measurement

Units 2 and 3

Feedwater flow is measured in each feedwater line on the reactor side of the high pressure heaters. A flow element in each feedwater line is provided for flow measurement. The pressure difference across the flow element is sensed by a differential pressure transmitter. The differential pressure due to feedwater flow is sent to the RFWCS indicating mass flow rate. Four RFW temperature signals are used to provide density compensation for feedwater line flow. The feedwater inlet lines' flow elements are calibrated for incompressible flow at 380.1°F. A correction factor is applied to compensate for temperatures different from the calibrated density.

The feedwater flow signals are summed to provide a total feedwater flow signal used in the control algorithm. Total feedwater flow is recorded in the control room.

Unit 1

Feedwater flow is measured in each feedwater line on the reactor side of the high pressure heaters. A flow element in each feedwater line is provided for flow measurement. The pressure difference across the flow element is sensed by a differential pressure transmitter. The feedwater signal is then linearized by a square root converter to output a mass flow rate.

A summer is used to add the flow signals from the feedwater lines. The output from the summer is the total feedwater mass flow rate signal. This signal is used for indication and feedwater flow control. The total feedwater flow is recorded in the control room.

7.10.3.4 Feedwater Control Signal

Units 2 and 3

The RFWCS generates a control signal which is sent to each Reactor Feedwater Pump Turbine (RFPT) governor. The governor is designed to maintain normal operation in the event of a single loss of power and at worst may cause the loss of a single RFPT in the event of a loss of two power supplies to the three governors. The RFWCS is designed to be a fault tolerant system which can maintain normal operation in the event of any single component failure, including loss of a single power feed.

Different modes of operation are available between the RFWCS and the RFPT governors: Governor Manual, Local, RFWCS Individual Manual, Master Manual, Single Element, and Three Element.

The RFWCS is designed to maintain the water level in the reactor vessel within the designated range during all modes of plant operation.

Level Control (Units 2 and 3)

The basic RFWCS control algorithm implements a proportional-integral (PI) control scheme.

The system also has a programmed response to mitigate reactor vessel overfill following a reactor scram. The transient level overshoot will be limited by controlling flow from a single RFW pump.

Indication is provided by the RFWCS that the scram response logic is active. The operator may bypass this logic using a handswitch provided in the Control Room. Indication of scram logic bypass is also provided to ensure the operator can determine system status. The programmed scram response logic will be a lock in signal which will only clear when either the Scram Response Inhibit handswitch is used or the Master Level Controller is taken to manual, the measured level increases above the level setpoint, or a pre-set time limit expires.

Governor Manual and Local Operating Modes (Units 2 and 3)

Each RFPT is controlled by a governor which adjusts the speed of the RFPT as determined by demand from the Control Room operator. The governor obtains speed feedback from either of two magnetic speed pickups. When first starting the turbine, the turbine will automatically ramp to its low speed stop of approximately 600 RPM. Speed can then be adjusted by using the speed control handswitch in the Control Room.

Local control of each turbine may be enabled from the Control Room provided the turbine is already in Governor Manual control. Full control of the turbine is then available for testing in each Reactor Feedwater Pump Room. Local control is similar to Governor Manual control except for the location of the controls.

RFWCS Individual Manual and Master Manual Operating Modes (Units 2 and 3)

In RFWCS Individual Manual mode, the reactor water level is controlled in an open-loop manner through operator adjustment of each feed pump speed (or startup valve demand) from its Control Station located in the Main Control Room. The Control Stations are similar to controllers, but only provide input and output display and do not actually perform any control function. All control functions are implemented in the RFWCS located in the Auxiliary Instrument Room.

In RFWCS Individual Manual mode, signal conditioning is performed on the demand signal by the RFWCS, but no control functions are implemented. The only limits on operational demand are the Control Station maximum ramp rate, and minimum and maximum system output range limits.

The RFWCS is designed to operate in a Master Manual mode. In this mode, the available RFW pump Control Stations are placed in auto and the master level Control Station is in manual. Reactor water level is controlled in an open-loop manner through operator adjustment of the output demand signal from the master level Control Station located in the Main Control Room.

Unit 1

The feedwater control signal adjusts the speed of the turbine-driven feedwater pumps. The components which are manually operated, or which automatically function to produce the feedwater control signal, are the following.

Level Controller (Unit 1)

The level controller has two options, one- and three-element control. The one-element control has an input to the level controller which is the corrected level. The level controller is a reverse-acting controller with a reasonable proportional band with reset control. The gain of the reset control is set to a small value for the purpose of eliminating the offset during steady-state operation. The reset control has little or no effect during a transient. One element control (water level) is the preferred process input to the controller when the reactor is operating at relatively low power levels. The water level is measured by two independent sensing systems, each consisting of a differential pressure transmitter connected to a reference condensing chamber leg located within the drywell. Each level signal is independently corrected for water density and indicated, and if selected as a control input, is recorded in the control room. When the mode selector switch is placed in the "one element" position, it routes the water level signal directly to the level controller. If this corrected water level signal decreases, the level controller output increases, which will restore the water inventory to the correct level. The three-element control is similar to the one-element control. The difference between the three- and one-element controls is the signal to the controller, which is the correct level signal verniered (plus or minus) by a water inventory signal. To obtain this inventory sense, feedwater flow is fed (minus) into number 2 input of a proportional amplifier and steam flow is fed (plus) into the number 1 input. The output is biased in such a way that, with no inventory (steam flow equals feedwater flow), the output is 50 percent. With inventory in the reactor (feedwater greater than steam), the output is less than fifty percent; and with inventory in the hot well (feedwater less than steam), the output is greater than 50 percent. This inventory signal is added inversely to the corrected level signal in a second proportional amplifier whose output is fed to the level controller. Thus, an anticipatory signal is obtained, correcting for projected changes in level due to process flow changes, which will correct feedwater to lessen the effect of changes on reactor level. The deviation meter compares the true, sensed level with the controller setpoint.

Bias Manual/Automatic Transfer Station (One for each turbine driven feedwater pump) (Unit 1)

The bias manual/automatic transfer station is a manual station with a transfer switch. While the turbine-driven feedwater pumps are being controlled by the level controller, the transfer switch is positioned so that the manual controller is bypassed and the level controller signal goes through the manual/automatic transfer station to a turbine-driven feedwater pump. During startup or when manual control is desirable, the level controller signal is blocked by the transfer switch and the feedwater control signal is transmitted and controlled at the manual/automatic transfer station by the operator.

7.10.3.4.1 Automatic Operation

Single Element Mode (Units 2 and 3)

Single element mode applies to both the feedwater pumps and the startup valve.

When in single element mode, the operator adjusted level setpoint on the master level Control Station (or startup level Control Station) is compared to the average reactor level to generate an error signal which is used to drive a PI algorithm to generate the control signal to the control element (either the feedwater pump(s) or startup valve).

Three Element Mode (Units 2 and 3)

Three element mode applies only to the feedwater pumps. When in three element mode, the operator adjusted level setpoint on the master Control Station is compared to the average reactor level and the steam flow-feedwater flow mismatch to generate an error signal which drives a PI algorithm to generate the control signal to the feedwater pumps.

The main steam/feed flow mismatch and level error signals are input into the master controller PI algorithms.

Variable Tuning (Units 2 and 3)

Control system gains may vary based on plant operating conditions. A validated total steam flow signal is used to determine power level, and thereby vary the control system tuning parameters. This power variable tuning will prevent too rapid a response at low power levels and too sluggish a response at higher power levels.

The desired response from the PI control algorithm will be achieved by changing the gain and/or reset on the input error signal. This signal represents level error and steam flow/feed flow mismatch in three element control and level error in single element control.

Unit 1

The level controller setpoint is set for optimum reactor vessel water level for efficient steam separator operation (this includes limiting carryover and carryunder, which affects recirculation pump operation and turbine performance and longevity) and the need to maintain adequate reactor core cooling.

The ability of the Feedwater Control System to maintain reactor vessel water level within a small margin of optimum water level during plant load changes is accomplished by the three-element control signal. The three-element control signal consists of reactor vessel water level, total steam flow, and feedwater flow signals.

The three-element control signal is obtained as follows. The total steam flow signal and the total feedwater flow signal are fed into a proportional amplifier. The output from this amplifier reflects the mismatch between its input signals and is designated as the steam-flow/feedwater-flow error signal. If steam flow is greater than feedwater flow, the amplifier output is increased from its normal value when steam and feedwater flows are equal. The reverse is also true. This amplifier output is fed to a second proportional amplifier (3 element error summer) which also receives the reactor vessel water level signal. The addition of the reactor vessel water level signal to the steam-flow/feedwater-flow error signal results in the three-element control signal which is fed through the dynamic compensator to the level controller.

The feedwater control signal is adjusted by the level controller according to the requirements of the three-element control signal so that the required reactor vessel water level is maintained.

7.10.3.4.2 Optional Operating Modes

Units 2 and 3

At power, three-element control is the preferred method of operation, but single-element control is always available provided there is at least one valid level signal available. With no valid level signals, the system reverts to RFWCS Master Manual mode.

Governor manual control is normally used only during the transition from feedwater pump startup to Individual manual control. Local control is also available, but is provided mainly for testing and is not normally used at power. The RFPTs can also be controlled from their respective Woodward Governors located in the Auxiliary Instrument Room.

Unit 1

Optional methods of Feedwater Control System operation are available, but not normally used during power operation of the reactor. A one-element signal (reactor vessel water level) can be used to replace the three-element control signal to the level controller. The manual/automatic transfer stations can be individually operated to control each of the turbine-driven feedwater pumps.

Units 1, 2, and 3

During startup (MODE 2), feedwater can be supplied by the condensate booster pumps through the reactor feedwater pump low-flow-bypass control valve. This valve can be remotely controlled from the Main Control Room, either manually or automatically.

7.10.3.5 Turbine Driven Feedwater Pump Control

Units 2 and 3

Feedwater is delivered to the reactor vessel through three turbine-driven feedwater pumps, which are arranged in parallel. The turbines are driven by steam from the reactor vessel. During normal operation, the speed demand signal from the RFWCS is supplied to the governor and a signal is sent to a final driver. The final driver controls a servo valve to vary the oil supply to operate the Reactor Feedwater Pump Turbine Control valves. If the signal from the RFWCS to the governor is out of range (nominal 4-20 mA), the governor will "fail-as-is" and initiate an alarm in the control room.

Unit 1

Feedwater is delivered to the reactor vessel through three turbine-driven feedwater pumps, which are arranged in parallel. The turbines are driven by steam from the reactor vessel. During normal operation, the flow demand signal from the level controller is fed to a function generator which linearizes the flow-versus-speed characteristics of the feed pump turbine. The output from the function generator is a speed demand signal which is used by the feed-pump turbine-speed governor to adjust speed to the desired value. Each turbine can be controlled by its manual/automatic transfer station. If the feedwater control signal to a turbine is lost, an alarm unit in the feedwater control circuit causes the turbine speed to lock "as is" and initiates an alarm in the control room.

7.10.4 Inspection and Testing

Units 2 and 3

Feedwater flow-control-system components are tested and inspected based on manufacturer's recommendations and sound maintenance practices. This can be done prior to plant operation and during scheduled shutdowns. Reactor vessel water level indications from the four water level channels can be compared during operation (and are compared automatically by the RFWCS) to detect instrument malfunctions. Steam mass flow rate and feedwater mass flow rate can be compared during constant load operation to detect inconsistencies in their signals. The RFWCS continually performs diagnostic tests while operating and will provide operators with alarm(s) of system abnormalities.

Unit 1

Feedwater flow-control-system components are tested and inspected based on manufacturers' recommendations and sound maintenance practices. This can be done prior to plant operation and during scheduled shutdowns. Reactor vessel water level indications from the three water-level-sensing systems can be compared during normal operation to detect instrument malfunctions. Steam mass flow rate and feedwater mass flow rate can be compared during constant load operation to detect inconsistencies in their signals. The level controller can be tested while the Feedwater Control System is being controlled by the manual/automatic transfer stations.