7.11 PRESSURE REGULATOR AND TURBINE-GENERATOR CONTROL

7.11.1 Power Generation Objective

The pressure regulator is a function of the turbine control system. The power generation objective of the pressure regulator and the turbine-generator control system is to provide an energy control system that, in conjunction with the Nuclear Steam Supply System controls, maintains essentially constant reactor pressure and limits transients during load variations.

7.11.2 Power Generation Design Basis

1. The pressure regulation function of the turbine control system is designed to manipulate turbine control valves and turbine bypass valves, individually or in parallel, to maintain reactor pressure within a narrow range of the pressure setpoint as reactor power varies from 0 percent to 100 percent nuclear boiler rated flow.

2. The turbine control system is designed to maintain a specified turbine load and speed.

7.11.3 Deleted

7.11.4 System Description (Figure 7.11-2)

The turbine control system encompasses the functions of controlling reactor pressure, turbine load, and turbine speed. The turbine control system is an electro-hydraulic control (EHC) system that combines digital process controls and data acquisition with high-pressure hydraulic actuators. The control system operates in one of five control modes: speed control, load control, pressure control, valve position limit and maximum combined flow limit control (see Figure 7.11-2). The control valve flow demand signals from the individual mode calculations combine at a low select bus. Of these signals, the one which calls for the least steam flow to the turbine determines the control valve position. The system is said to be in a particular mode when the control valve flow demand from that mode determines the control valve position. Indication of the control mode is available as part of the EHC system controls and displays.

Steam flow is controlled by valve position. The positioning controls are similar for the various servo controlled valves. Each positioning control acts upon a hydraulic valve actuator, a servo valve to control the valve actuator, an electronic position feedback signal which gives the actual valve position, and the valve position demand signal which provides the desired valve position. The demand signal is combined with the position feedback signal to produce the position error signal. The position error signal controls the servo valve to admit more hydraulic fluid to the hydraulic

actuator to open the steam valve or to bleed-off fluid from the hydraulic actuator to close the steam valve. When the demand signal equals the position feedback signal, the position error signal is zero resulting in no steam valve movement.

Each of the four turbine control valves has its own positioning servo. Each servo receives the control valve position demand signal. All four valves operate in parallel to control turbine steam flow.

Three of the six turbine intercept valves use positioning servos as described above. Each positional valve receives the intercept valve flow. The positional valves operate in unison. The other three intercept valves positions are controlled by solenoid valves which are operated by the position of the positional valves. These valves are either fully open or fully closed. During normal operation, all six intercept valves are fully open.

Each of nine bypass valves uses a positioning control similar to those described above. The bypass valves are operated sequentially. A sequential bias signal is combined with the flow signal and position feedback signals to produce the position error signal. Each bypass valve positioning control receives the bypass valve flow signal. The bias signal is different for each bypass valve and provides the offset necessary for sequential operation.

7.11.4.1 Speed Control Mode

In the speed control mode, the EHC system produces control signals used to control turbine speed and acceleration. The speed input signal is derived from active proximity probes and passive magnetic speed pickups. The speed inputs and the resultant rates of change are compared to reference signals for control of both turbine speed and acceleration. The steam flow signal thus produced is processed via the low select bus to effect changes in control valve position and consequently steam admission into the turbine. If more steam is available than is demanded by speed control, the excess steam is routed to the condenser via the bypass valves to control pressure. This mode is only active until the generator breaker is closed, at which time its control valve flow demand signal is switched off the low select bus. However, speed will always affect the control valves during an overspeed through the control valve and intercept valve logic.

7.11.4.2 Load Control Mode

In load control mode, the EHC system produces control signals necessary to maintain a specific turbine load. Turbine load is derived from a generator load sensor and a real power sensor. The operator can manually set the load reference signal which corresponds to the desired turbine load. The load reference signal is compared with the actual sensed generator load to produce a steam flow demand signal. This signal is processed via the low select bus to effect changes in control

valve position and consequently steam admission into the turbine. If more steam is available than is demanded by load control, the excess steam is routed to the condenser via the bypass valves to control pressure.

7.11.4.3 Pressure Control Mode

In the pressure control mode the EHC system produces control signals necessary to maintain a specific system pressure. The system pressure controlled is operator selectable for either reactor pressure control or steam line header pressure control. A total steam flow signal is generated which corresponds to the total steam flow through both the turbine control valves and turbine bypass valves necessary to maintain a specific system pressure at a given reactor power level. Reactor pressure is sensed from the reference leg for the reactor water level instruments, providing a direct reading of reactor vessel pressure. Four individual reactor pressure inputs are processed to produce a reactor pressure demand signal. Steam line header pressure is sensed upstream from the turbine stop valves in one of the main steam lines. Two individual header pressure inputs are processed to produce a header pressure demand signal, which is translated into a flow demand.

For either pressure control mode, the pressure demand signal is combined with the pressure reference signal, which is set by the operator, to produce the steam pressure error signal. This signal is processed via the low select bus to effect changes in control valve position and consequently steam admission into the turbine. If more steam is available than is demanded by pressure control, the excess steam is routed to the condenser via the bypass valves.

7.11.4.4 Valve Position Limit Mode

In control valve position limit mode, the EHC system uses operator input to limit the positioning of the steam control valves by lowering the control valve position limit until it requests less steam than the other control modes, the operator may directly position the control valves. The control valve position limit signal, which is set by the operator, produces the control valve steam demand signal. This signal is processed via the low select bus to effect changes in control valve position and consequently steam admission into the turbine. If more steam is available than is demanded by the control valve position limit, the excess steam is routed to the condenser via the bypass valves to control pressure.

7.11.4.5 Maximum Combined Flow Limit Mode

In the maximum combined flow limit mode, the EHC system compares the total steam flow in both the control valves and bypass valves with an operator controlled limit between 50 and 150 percent of rated steam flow. This limit is placed on the low select bus with the other control signals above and is only made active when steam

demand exceeds the setpoint, at which point it clamps the position of the control valves and/or the bypass valves to restrict total flow to its setpoint.

7.11.5 Deleted

7.11.6 Normal Operation

7.11.6.1 Initial Reactor Pressurization and Pressure Control

During plant startup, pressure in the reactor is initially less than the specified reactor pressure setpoint and the turbine is shutdown. Both the control valve flow and bypass valve flow signals are zero causing the turbine control valves and bypass valves to be fully closed.

As power in the reactor is increased, initially, no steam flows from the reactor, but reactor pressure increases. When pressure begins to exceed the pressure setpoint, steam must be released from the reactor to maintain reactor pressure at the setpoint. Assuming that the control valve position limit, load setpoint and combined maximum flow limit are adjusted high enough that they do not affect control, and "All Valves Closed" is selected which produces a control valve signal of zero, the following will occur:

1. As pressure increases and then exceeds the pressure setpoint, pressure error becomes greater than zero.

2. The control valve flow signal equals the smallest of the inputs to the low select bus. At this time, the signal is zero because the demand based on "All Valves Closed" is zero. This holds the control valves closed.

3. The difference between the control valve demand and the pressure demand is the bypass demand. With the control valve flow signal equal to zero, the bypass demand equals the pressure demand.

4. Since the combined maximum flow limit is set high enough that it has no effect, the bypass demand will open the bypass valves.

5. For each bypass valve, the bypass demand is combined with the individual bypass valve position signal and the individual bypass valve bias signal to produce each bypass valve's position error signal. With the small pressure demand which occurs during reactor startup, the sequential bias is great enough that the position error signal is less than zero for all bypass valves except the first one, holding all valves except the first one closed. For the first bypass valve, the position error signal will be greater than zero. This position error signal will operate the servo valve admitting hydraulic fluid to the hydraulic actuator to open the first bypass valve. As the valve opens, the position feedback signal

increases, the valve will continue to open until the position feedback signal equals the bypass demand producing a zero position error signal. The bypass valve remains positioned partly open.

As reactor power is increased, the amount of steam which must be released from the reactor to maintain the specified pressure increases. This produces an increased pressure demand which is processed as described above. The net effect is an increase in the bypass demand. This signal causes enough bypass valves to open to permit sufficient steam flow to maintain the specified reactor pressure.

7.11.6.2 Turbine Startup

The turbine is normally started with the reactor at normal operating pressure and about 15-percent power. This amount of power produces sufficient steam for turbine acceleration and to meet the turbine vendor’s minimum turbine load requirements. Turbine startup is initiated by operator selection of the desired speed and acceleration rates which set the speed reference and acceleration reference signals. The zero speed signal from the speed sensor is combined with the speed reference signal to produce a speed error signal much greater than zero and the acceleration signal is combined with the acceleration reference signal to produce an acceleration error signal slightly greater than zero. The speed and acceleration error signals are applied to the low select bus.

During turbine startup the control valve demand equals the acceleration error signal since it is the smallest signal on the low select bus. For each control valve, the position feedback signal is combined with the control valve demand to produce the position error signal which is slightly positive when the control valve is fully closed. This causes the servo valve to operate to admit hydraulic fluid to the hydraulic actuator opening the control valve. The valve will continue to open until the position feedback signal equals the control valve demand producing a zero position error signal which causes the servo valve to stop admitting hydraulic fluid to the hydraulic actuator. Each control valve unit receives the control valve demand causing all four control valves to operate in parallel. At this time, all four control valves will be slightly open admitting steam to the turbine causing it to accelerate. The acceleration signal is combined with the acceleration reference signal as described above and will cause slight changes in the control valve demand to position the control valves to produce a steady turbine acceleration rate. As actual turbine speed approaches selected turbine speed, the speed error signal decreases until the speed error signal is less than the acceleration error signal. The output from the low select bus will now be the speed error signal. This causes the control valve demand to decrease resulting in a slight decrease in control valve position and slightly reduces turbine steam flow. When the turbine speed equals the selected speed, the control valves will be open only enough to admit sufficient steam to the turbine to maintain the selected speed.

Simultaneous with operation of the control valves, the intercept valve demand ramps to 100 percent. The intercept valve demand is combined with each positionable intercept valve's position feedback signal to produce individual intercept valve position error signals. The servo valves operate to admit hydraulic fluid to the hydraulic actuators to open these valves. They will continue to open until each valve position feedback signal equals the intercept valve demand. Each positionable intercept valve position feedback is compared to an almost fully open setpoint which controls an electrical solenoid valve which will operate to admit hydraulic fluid to one of the nonpositionable intercept valve's hydraulic actuator causing the nonpositionable intercept valve to fully open. The six intercept valves operate to control steam flow between the high and low pressure turbines. Normally, all six valves are fully open.

While the turbine is accelerating and after it reaches the selected speed, it is still necessary to maintain steady pressure. This is accomplished by releasing steam from the reactor. Part of the steam is released through the turbine; the remainder must be released through the bypass valves. The pressure demand generated in the pressure control is proportional to the total steam which must be released through the control and bypass valves as described above. The control valve demand equals the speed/acceleration demand. The bypass demand is the difference between the pressure demand and the control valve demand. Generally, reactor power, pressure, and required pressure demand do not change during turbine startup. The bypass demand signal will be reduced by an amount equal to the control valve demand. The reduced bypass demand will reduce the amount of steam flowing through the bypass valves. At this time, the bypass valves are controlling pressure and will fluctuate as necessary to maintain the pressure at the specified setpoint.

7.11.6.3 Turbine Loading and Normal Plant Operation

After the turbine achieves rated speed, the generator is synchronized with, and connected to, the power transmission system. This results in steady turbine speed, with speed control removed from the low select bus and speed only affecting control valve demand through the control valve and intercept valve overspeed regulation logic. As the operator increases the desired turbine load, the load reference signal increases. Assuming the load demand is still the smallest of the low select bus inputs, the control valve demand will increase by a corresponding amount. This causes the control valves to open further, admitting more steam to the turbine, and increasing the power produced in the turbine. As the control valve demand increases, there is a corresponding decrease in the bypass demand resulting in a decrease in steam flow through the bypass valves.

As turbine load is increased, a point occurs where the control valve demand equals the pressure demand. This produces a zero bypass demand resulting in no flow through the bypass valves.

Pressure corrections are controlled by either the control valves or the bypass valves depending on whether slight flow decreases or increases are required.

For normal plant operation, the load setpoint is adjusted higher than actual turbine load. All available steam is sent to the turbine. The control valves are regulating turbine load and controlling pressure including making minor control valve position changes to maintain pressure at the specified setpoint.