Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 9.0

Integrated Control System

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9.0 INTEGRATED CONTROL SYSTEM

Learning Objectives:

1. Explain the function of the following Integrated Control System (ICS) subassemblies:
    a. Unit load demand (ULD)
    b. Integrated master (IM)
    c. Feedwater demand
    d. Reactor demand

2. Define the following terms:
    a. Track
    b. Runback
    c. Cross limits

3. With the use of a block diagram of the ICS, discuss the following:
    a. Normal power increase and decrease
    b. Runbacks
    c. Cross limits
    d. Placing an ICS hand/auto station in hand (manual)
    e. Turbine trip

9.1 Introduction

The integrated control system (ICS) has as its basic requirement the matching of generated electrical megawatts with demanded electrical megawatts. As shown in Figure 9-1, the ICS accomplishes this requirement through four subassemblies: the unit load demand, the integrated master, the feedwater demand, and the reactor demand. The unit load demand functions as a megawatt electric setpoint generator for the ICS. The integrated master receives the megawatt setpoint from the unit load demand to control the electrical output of the turbine generator. In addition, the integrated master translates the megawatt demand into signals for feedwater and reactor control. In the feedwater demand subassembly, the megawatt demand signal, converted to a feedwater demand in the integrated master, controls the amount of feedwater supplied to the once-through steam generators. The reactor demand subassembly moves the reactor's control rods in or out in response to the megawatt demand signal, and also controls the average reactor coolant system temperature. Section 9.2 discusses the four subassemblies; Section 9.3 discusses ICS operations.

9.2 General Description

The basic integrated control system is shown in Figure 9-2. The following terms used in this chapter are defined below.

1. Track : Track is defined as a condition during which actual generated megawatts are substituted for the megawatt demand signal. This is shown in Figure 9-2 by transfer relay T_1. During normal operation, T_1 supplies the megawatt demand signal from the ULD hand/automatic (H/A) station to the other ULD subassembly components. In TRACK, T_1 substitutes actual generated megawatts (Mwe) for the megawatt demand signal. Additionally, in TRACK the rate is automatically changed to 20% per minute. TRACK is initiated when the ICS senses that fully automatic control has somehow been inhibited. The following conditions place the unit in TRACK :

   a. Reactor trip
   b. Generator output breakers open
   c. Any major ICS hand/automatic station in hand (manual):
      (1) Reactor demand
      (2) SG/RX master
      (3) both loop feedwater demands
   d. Diamond rod control in manual
   e. Turbine electro-hydraulic control in manual (turbine tripped or turbine not controlled by ICS)
   f. Feedwater flow greater than feedwater demand by 5%
   g. Reactor or Feedwater cross limits

2. Runback: A runback is an automatic reduction in unit load and occurs when necessary power generation equipment is lost or its capacity is reduced. The runback condition reduces load at a rate proportional to the severity of the loss of generation equipment and also sets a maximum allowable load limit into the ULD. Once a runback condition is sensed, unit load is reduced at the predetermined rate until load is below the maximum allowed value for the runback rate. Conditions that cause a runback are given in Table 9-1. If an asymmetric rod condition is assumed, then a runback rate of 30% per minute will be transferred to the remainder of the ICS, and unit load will be reduced to less than 60% (i.e., 60% of the 100% generated megawatt value). If an attempt to exceed 60% should occur, then another runback condition would exist with load being reduced to less than 60% at 30% per minute.

9.2.1 Unit Load Demand

The unit load demand (ULD) provides the ICS with the ability to sense both the desired amount of electrical generation and the desired rate of change of electrical generation. These variables are placed into the system by the plant operator and are transmitted to the remainder of the system, resulting in the generation of the desired amount of electrical load. The operator inputs the megawatt demand from 0 to 1350 MW electrical (MWe) by changing the setpoint (SP) adjustment associated with the unit load demand hand/automatic (H/A) station shown in Figure 9-2. After this input is made, the operator must also input the desired rate of load change. The operator determines unit electrical output rate of change from 0.5% per minute to 5% per minute by changing the setpoint supplied to the rate limiter. (Below 15% power a maximum rate of change of 0.75% per minute is imposed.) Other required operator inputs into the ULD are the high- and low-load limits. These two limits allow the maneuvering of the unit between their setpoints.

Generally, the low-load limit is set to approximately 15% of unit generation capability, and the high-load limit is set at the 100% load value; however, the operator may input any value between 0 and 100% as a setpoint into either load limit. An example of a setpoint that could be input into the high-load limit is the power restriction associated with only one operable main feedwater pump. The maximum amount of feedwater flow that one pump can deliver is 60%; therefore, this value can be placed into the high-load limit as a setpoint to prevent inadvertent load requests that are greater than 60%. Demands greater than the high-load limit are automatically reduced to the high-load limit at the operator selected rate of load change. As previously stated, the low-load limit is usually set at 15%. Below 15% load, unit stability is reduced (the turbine may not be loaded, and input signal magnitude is very small), and fully automatic operation may be prohibited. If the demanded load is less than the low-load limit, it will be increased automatically to the low-load value at the operator selected rate of load change. During runback or tracking conditions, the low-load limit is ignored by the system.

9.2.1.1 Frequency Corrected Load Demand

Frequency correction is the increase or decrease in demanded generated megawatts based on grid frequency. A decrease in grid frequency is indicative of a grid load greater than grid generation. The turbine electro-hydraulic control system senses this condition and opens the turbine control valves, increasing steam flow to the turbine. The increase in steam flow causes the turbine to pick up load. When a particular load value is placed into the ICS, the ICS will try to reduce the load back to setpoint as unit load is increased on a decrease in grid frequency. This reduction in load is the opposite of the desired action; therefore, a frequency correction is applied to the ICS to add to the load demand. With frequency correction, any decrease in grid frequency will increase megawatt demand from the ULD. However, the high-load limit prevents the frequency-corrected load demand from exceeding the high-load setpoint.

9.2.1.2 Unit Load Demand Operations

Unit load demand operations can be illustrated by the following example. Assume that the unit is at 675 Mwe (50%), and it is desired to increase the unit load to 1013 Mwe (75%) at 5% per minute. At the rate-of-change station, the operator selects a rate of 5% per minute. The 75% load value is placed into the ULD H/A station. The output of the rate unit is an increasing signal changing at a rate of 5% per minute. Using this example, the output of the rate unit will reach the desired 75% load demand 5 min after the load change is initiated. From the rate unit, the signal passes to the summing amplifier (∑), where frequency correction is added. The output of the summing amplifier is compared to the high- and low-load limits and the runback load limits. Since the load demand is greater than 15% and less than 100%; and no runback condition exists; the ULD subassembly is unaffected. The output of the frequency-correction summing amplifier is the megawatt demand for the turbine, the feedwater system, and the reactor. This demand signal causes simultaneous increases in generated megawatts, feedwater flow, and reactor power, and the unit will stabilize at 75% load.

With the unit at 75% load, the effects of placing the reactor demand subassembly hand/automatic station in hand and manually increasing its setpoint will be examined. Placing the reactor demand station in hand results in the ICS being placed in TRACK. In TRACK, actual generated megawatts are substituted as the megawatt demand signal via transfer relay T_1, and increasing the reactor demand station setpoint will result in outward rod motion, an increase in reactor power, and an increase in OTSG pressure. An increase in OTSG pressure further opens of the turbine control valves and increases generated megawatts. The output of the ULD subassembly is increased at a rate of 20% per minute, which is automatically input to the rate unit. The other ICS stations keep track of this increase in ULD output. Simultaneously, the ULD H/A station load setpoint keeps track of the actual generated megawatts. As a result, when the operator completes the power change and returns the reactor demand station to automatic, the desired load (setpoint) will agree with the actual load.

Next assume that while the unit is at 75%, a feed pump trips. The feed pump trip inserts a runback signal into the ULD. The feed pump runback calls for a maximum unit load of 60% and a load decrease rate of 50% per minute. The ULD subassembly accomplishes the decrease in load demand by adding -100% to the summing amplifier (∑) which precedes the rate unit, and by inputting a 50% per minute rate of decrease to the rate unit. Simultaneously, the ULD H/A station load setpoint tracks the decreasing output of the rate unit. When the ULD subassembly output no longer exceeds the feed pump runback load limit (60%), the runback inputs to the summing amplifier and the rate unit are removed. The ULD subassembly output is thus stabilized at the new demanded load of 60%.

The response of the ULD subassembly to a violation of the high- or low-load limit is similar to the runback response. If the high-load limit is exceeded, -100% is added to the summing amplifier upstream of the rate unit, the load demand is reduced at the operator-selected rate, and the load demand setpoint tracks the output of the rate unit. If the load demand is less than the low-load limit, the response is identical, except that +100% is added, and that the load demand is increased. In either case, the automatic inputs to the ULD subassembly are removed when the limit is no longer violated.

Finally, assume a load increase from 35% to 50% at a rate of 5%/min has been demanded by the operator. Additionally, assume that when the unit reaches 40%, a tracking condition occurs. Since the unit is in TRACK, 40% becomes the unit load demand

and the plant should stabilize at this load value. When the tracking condition clears, the load change must be reinstated by the operator.

In this section the generation of a setpoint, called a megawatt demand, by the ULD during normal operations; tracking operations; and runback conditions has been discussed. The following sections discuss the processing of the megawatt demand signal.

9.2.2 Integrated Master

The functions of the integrated master (IM) (Figure 9-2) are (1) to control the load of the turbine generator, (2) to provide a modified megawatt demand signal to the feedwater and reactor demand subassemblies, (3) to control the 22 atmospheric dump and turbine bypass valves, (4) to compensate for changes in plant efficiency in order to maintain a constant turbine load, and (5) to characterize the megawatt demand signal into feedwater and reactor demand signals. These functions, with the exception of item (5), are accomplished by controlling turbine header steam pressure. The IM receives inputs of megawatt demand from the ULD, actual turbine load, and turbine header steam pressure.

9.2.2.1 Generator Load Control

Steam header pressure is controlled at a constant value (1035 psia in the 205 FA units) in the B&W PWRs. During transient operations, the integrated master treats the turbine as a steam pressure regulator. On load increases the turbine is supplied a header pressure control setpoint lower than actual turbine header steam pressure, and on load decreases the turbine is supplied with a setpoint that is higher than actual turbine header steam pressure. This modification of setpoint is accomplished by comparing generator load with the megawatt demand from the ULD in the MW error difference unit (△) as shown in Figure 9-2. The difference between the two inputs is supplied to a summing amplifier where it is combined with the header pressure setpoint (SP), normally 1035 psia, supplied by the operator. This summing amplifier modifies the header pressure setpoint as previously described. The output of the summing unit is supplied as a modified setpoint to the pressure-error-(turbine) unit where a comparison with actual steam header pressure (PT) is made. The error that results from this comparison is supplied to the turbine electro-hydraulic control (EHC) system and is translated into a turbine control valve position demand. If the load change from 50% to 75% is examined in this portion of the integrated master, then the following actions are noted:

1. As the ULD megawatt demand is increased, an error between actual generated megawatts and megawatt demand is sensed by the Mw error difference unit (△) .

2. The megawatt error signal is combined with the header pressure setpoint in the summing amplifier (∑). The output of this amplifier is a reduced header pressure setpoint.

3. The reduced header pressure setpoint is subtracted from actual header pressure in

the pressure error (turbine) difference unit resulting in a pressure error signal.

4. The pressure error signal is supplied to the turbine. This error signal "informs" the turbine that actual steam pressure is higher than setpoint. With a high error signal, the turbine EHC system opens the turbine control valves in an effort to restore header pressure to normal.

5. As the turbine valves are opened, steam flow to the turbine increases. The increased steam flow causes an increase in generated megawatts.

Actions (1) through (5) will continue until the turbine generator is at 75% load. The actions on a load decrease signal are just the opposite. When the decreased megawatt demand signal from the ULD is sensed in the integrated master, the header pressure setpoint is increased. The turbine is informed that actual steam pressure is less than setpoint. The response of the turbine EHC system is to close the control valves in order to raise steam pressure. The closing of the turbine valves decreases steam flow, which, in turn, lowers turbine load.

Thus far the turbine's control of header pressure has been discussed only during fully automatic operations of the ICS, but the turbine also controls header pressure during tracking operations. When TRACK is initiated, transfer relay T_2 in Figure 9-2; inputs a zero modification. This transfer function prevents the header pressure setpoint from being modified by a megawatt error signal during tracking operations (see Table 9-2). Since header pressure modification is blocked, the output of the summing amplifier (∑) is the operator-supplied header pressure setpoint. Any deviation between actual header pressure and setpoint is sensed in the pressure error (turbine) unit. The turbine valves respond to pressure error. They open if pressure is high and close if pressure is low. Changes in valve position cause changes in turbine load which are tracked by the ICS stations.

The response of the turbine valves to header pressure errors, as described above, occurs only if the turbine EHC system is in automatic. When the turbine EHC system is in manual, the operator must control header pressure.

9.2.2.2 Output Signal Modification

The second function of the integrated master is to provide a modified signal to the feedwater and reactor demand subassemblies. This signal modifier consists of a difference (pressure-error- (modifier)) unit (△) that is supplied with a header pressure input from actual turbine header steam pressure (PT) and a header pressure setpoint (SP). The output of this difference unit is header pressure error and is supplied to a summing amplifier (∑) located between the variable gain unit (χ) and the steam generator/reactor master hand/automatic station shown in Figure 9-2. The purpose of the signal modification circuit is to allow rapid achievement of the desired turbine load at the desired steam pressure during load increases or load decreases. On load increases, turbine load is quickly achieved by excess energy removal from the OTSG. This excess energy removal results in a decrease in steam header pressure, which, in turn, causes a header pressure error. The error is added to the megawatt demand signal, and appropriate increases in feedwater demand and reactor demand restore header pressure to normal. On decreases in turbine generation, the turbine again reaches the required setpoint before the feedwater system or the reactor. In this maneuver header pressure rises because the reactor's heat generation exceeds the turbine's heat removal. The rise in header pressure, when compared with the setpoint, results in an error, which, when added to the megawatt demand, decreases the feedwater and reactor demands, returning header pressure to setpoint.

9.2.2.3 Turbine Bypass and Atmospheric Dump Valve Control

The third function of the integrated master is the control of the steam dump and turbine bypass valves. There are 22 steam dump and turbine bypass valves divided into five banks: six modulating turbine bypass valves with a total capacity of 18.5%, four "off-on" bank 2 atmospheric dump valves with a capacity of 19.6%, four "off-on" bank 3 atmospheric dump valves with a capacity of 19.6%, four "off-on" bank 4 atmospheric dump valves with a capacity of 19.6%, and four "off-on" bank 5 atmospheric dump valves with a capacity of 19.6%. Control of these valves is accomplished by a header pressure error signal developed by comparing actual header pressure (PT) with the header pressure setpoint (SP) in the pressure-error-(valves) unit. The error signal from this comparison is supplied to each group of steam dump valves. Three different bias values may be added to the header pressure error signal. These bias values are represented by numbers located in boxes in Figure 9-2. The transfer relay (T_3, T_4, T_5, T_6 and T_7) directly below the bias boxes selects the correct value of bias that is to be subtracted from the header pressure error signal. The value of bias selected is dependent on specific plant conditions and is explained later. From the transfer relays, the error signals are passed through hand/automatic stations for the turbine bypass valves, or directly to the valves in the case of the other four groups. An interlock prevents opening the turbine bypass valves, which admit steam to the condenser, if the condenser is not in service. (See Table 9-2.) This interlock is represented by the box labeled "Cond Intlk" (condenser interlock) and transfer relays T_8 shown in Figure 9-2.

Now that the control devices for the valves have been described, the purpose of the different bias values will be explained in the following paragraphs. Three specific plant conditions determine the amount of bias subtracted from the header pressure error signal. (See Table 9-2.) These conditions are a turbine trip, normal power operations, or a reactor trip. When the turbine is tripped, a bias value of 0 psi is selected for the turbine bypass valves, a bias value of 15 psi is selected for the bank 2 atmospheric dump valves, a bias value of 30 psi is selected for the bank 3 atmospheric dump valves, a bias value of 45 psi is selected for the bank 4 atmospheric dump valves, and a bias value of 60 psi is selected for the bank 5 atmospheric dump valves. These particular values allow the control of steam pressure at its normal value during the following conditions:

1. turbine trip
2. plant startup - dissipates reactor coolant pump and reactor heat before turbine loading
3. maintains unit at no-load T_{avg} before criticality

During normal operations, bias values of 50, 65, 85, 105, and 125 psi are selected for the turbine bypass valves, bank 2 atmospheric dump valves, bank 3 atmospheric dump valves, bank 4 atmospheric dump valves and bank 5 atmospheric dump valves, respectively. These biases are high enough to prevent valve actuation during minor perturbations yet low enough to prevent steam safety valve actuation during larger perturbations. During the power escalation, these bias values are automatically selected when the turbine bypass valves close and steam header pressure error is less than 10 psi, or unit load demand is >15%.

When the reactor trips, bias values of 165, 175, 185, and 195 psi are selected for the turbine bypass valves, bank 2 atmospheric dump valves, bank 3 and bank 4 atmospheric dump valves, and bank 5 atmospheric dump valves, respectively. The high bias values are used after a reactor trip to minimize reactor coolant system (RCS) cooldown and the effect of this cooldown on pressurizer level and pressure. Normal pressurizer level is 220 in., and normal (>15% power) T_{avg} is 601°F. For every degree change in T_{avg}, pressurizer level changes by approximately 5 in. If a cooldown to no-load T_{avg} following a reactor trip occurs, then, by using the T_{avg}/pressurizer level relationship, pressurizer level would decrease below the indicated range.

601°F − 550°F = 51F°
51F° × 5in./F° = 255 in. (contraction)
220 in. - 255 in. = −35 in. pressurizer level

The reactor trip bias values allow a cooldown to 567°F, and the resulting pressurizer level is 50 in.

601°F - 567°F = 34F°
34F° × 5 in./F° = 170 in. (contraction)
220 in. - 170 in. = 50 in. pressure level

Figure 9-3 shows the effects of the different bias values. A discussion of the steam dump valve operation during plant heatup, reactor startup, and power escalation provides a convenient method of summarizing the bias value selection and valve operation. When the reactor coolant pumps are running, energy is being added to the reactor coolant. The energy addition raises reactor coolant temperature. As heat is transferred from the reactor coolant to the OTSGs, steam pressure increases. When the pressure-error-(valves) difference unit senses that actual steam pressure is equal to or greater than 1035 psia (the normal setpoint), then a positive error signal is transmitted to the bias boxes. Since the turbine is off-line, the turbine trip values will be selected. Looking at the turbine bypass valves, a value of zero will be subtracted from the error signal, and valve actuation will occur. As the error signal increases, the turbine bypass valves will open further. The actions of the turbine bypass valves control header pressure at setpoint. If the error signal should exceed 15 psi, then atmospheric bank 2 valves will open. Similar error values of 30, 45, and 60 psi will cause actuation of the bank 3, 4, and 5 atmospheric dump valves. The turbine bypass valves stabilize the unit at hot standby (operating mode 3) and dissipate the reactor coolant pump heat and the reactor's decay heat.

The reactor is now brought to a critical condition, and power is escalated to approximately 15%. The reactor's heat is dumped to the condenser by the turbine bypass valves. At 15%, the turbine is placed in service. As the turbine starts to assume electrical load from the grid, header pressure tends to decrease. To prevent the decrease in header pressure, the turbine bypass valves close. When the valves are fully closed and header pressure error is less than 10 psi, then the "normal" values of bias will be selected. Power escalation from 15% to 100% is achieved with the turbine controlling steam pressure and the steam dump and turbine bypass valves acting as relief valves. If the reactor trips, the reactor trip bias values will be selected. The response of header pressure when the reactor trips, is shown in Figure 9-4.

9.2.2.4 Plant Efficiency Compensation

The next function of the integrated master is compensation for changes in plant efficiency to maintain a constant plant load. In Figure 9-2 an integrator senses the megawatt error (the difference between megawatt demand and actual generated megawatts) and sends this signal, via the dashed lines, to the variable gain unit (χ) and the summing amplifier (∑). This portion of the integrated master is called the calibrating integral. The operation of this calibrating integral can be illustrated by assuming an increase in circulating water temperature. With an increase in circulating water temperature, vacuum decreases. In turn, when vacuum decreases, turbine efficiency decreases. A decrease in turbine efficiency causes a decrease in generated megawatts. When megawatts drop, a megawatt error is developed. This error is integrated and applied to both the variable gain unit and summing amplifier. The megawatt demand signal from the ULD is increased to the reactor and feedwater demands by these two units. The turbine load will be returned to setpoint by the megawatt error described earlier in this section. At low loads the change in gain required to compensate for small megawatt errors is large; therefore, the output of the calibrating integral is supplied to the summing amplifier. Megawatt errors at high loads can be compensated for by small changes in gain; therefore, the calibrating integral's output to the variable gain unit is sufficient to cause the required change in the megawatt demand signal. Additionally, the calibrating integral’s output is blocked if load changes by more than 2% per minute.

The megawatt demand, after being modified by either the header pressure error or the calibrating integral, is transmitted to a hand/automatic station. This hand/automatic station is called the steam generator/reactor master and gives the operator control of the demand signal being sent to the reactor and feedwater demand subassemblies. Placing the steam generator/reactor master in hand initiates TRACK and also prevents runback signals from reaching the reactor and feedwater demand subassemblies.

9.2.2.5 Integrated Master Output

The final function of the integrated master is to characterize the megawatt demand into demand signals for the feedwater and reactor demand subassemblies. This function is accomplished by multiplying the megawatt demand signal by proportionality constants yielding demands for the feedwater system and the reactor. This characterization is represented in Figure 9-2 by the boxes labeled "Feedwater Demand Calculator" and "Reactor Demand Calculator." A low limiter, set at 15%, limits the demand signal to the reactor.

9.2.3 Feedwater Demand Subassembly

It would seem that feedwater flow could be controlled by comparing the feedwater demand with actual feedwater flow and modulating the feedwater regulating valves and feed pump turbine speed to achieve the desired amount of feedwater flow. Indeed, this is done, but the design of the OTSGs and the RCS prevents the use of a simple control system. Before the limitations placed on feedwater demand are discussed, the basic control loops will be described. The feedwater demand, after being characterized by the integrated master, is supplied from the unit load demand subassembly. The feedwater demand signal is represented in Figure 9-2 by a line from the feedwater demand calculator to the variable gain unit (χ). From the variable gain unit (χ), the signal passes through a summing amplifier (∑) and then splits into two paths. These two paths eventually become the demand signals for the feedwater supply to the A and B OTSGs. The demand signal for the A OTSG is through a variable gain unit (χ), a hand/automatic station, a difference unit, and a transfer relay. The difference unit calculates the error between actual feedwater flow, supplied by the loop A feedwater flow transmitter (FT), and feedwater demand. The error signal travels from the difference unit (△) to a high-select unit (>), and through the individual valve hand/automatic stations to the feedwater regulating valves for the A OTSG. The signal path for the B OSTG feedwater control is identical, except that a difference unit (△) is used upstream of the loop demand hand/automatic station. The signal to the feedwater regulating valves is an error signal based on the difference between loop B feedwater demand and actual loop B feedwater flow. As previously stated, the control of feedwater flow is complicated by design considerations of the OTSG and RCS. Considerations such as feedwater temperature, RCS average temperature, the difference between the RCS loop cold-leg temperatures, and the difference between reactor power demand and actual reactor power add signal modifications to the feedwater demand.

9.2.3.1 Signal Modification

Modifications to the feedwater demand signal are described below:

Average Feedwater Temperature

The first modification to the feedwater demand signal is made by average feedwater temperature. At any given load value, there is a balance of Btu exchange between the primary and secondary sides of the OTSGs. To not disturb this ratio, when feedwater temperature varies, the total feedwater demand is modified by a function of feedwater temperature. With a fixed RCS temperature and a fixed △T across the primary side of each OTSG, a fixed amount of energy is available. If colder feedwater is introduced into the secondary side of a steam generator at a fixed flow rate, more heat would be required to raise this fluid to the proper steam generator outlet conditions, i.e., superheated to the proper value. However, if the flow rate on the secondary side were reduced, the total amount of energy required to raise the colder feedwater to the proper outlet conditions would also be reduced. Therefore, by properly reducing the feedwater flow rate for a given feedwater temperature reduction, the proper OTSG steam conditions can be maintained.

A comparison between actual feedwater temperature and the desired feedwater temperature versus power is made. If feedwater temperature is lower than the desired temperature, a reduction in feedwater demand will occur. A graph of the desired feedwater temperature versus power is shown in Figure 9-5. The minimum feedwater temperature is maintained by the main steam supply to the high-pressure heaters. If feedwater loop temperature decreases to 340°F, an automatic trip of the main feedwater pump associated with that loop is initiated. In Figure 9-2, the output of the feedwater temperature limit is supplied to a variable gain amplifier (χ) . If the average temperature is greater than the desired temperature, the gain of the amplifier is unity. If the average temperature is less than the desired temperature, the gain of the amplifier is proportionally reduced. Reducing feedwater demand decreases feedwater flow. The output of the variable gain unit is supplied to the feedwater demand summer (∑).

Average Reactor Coolant Temperature

In the feedwater demand summing amplifier (∑), the second feedwater demand modification occurs. This modification of the feedwater demand allows feedwater flow to control average RCS temperature. A summing amplifier input of T_{avg} error supplied by the reactor demand subassembly is shown in Figure 9-2. Because the heat transfer characteristics of the OTSGs are not fixed, as they are in the U-tube steam generator design, the control of T_{avg} can be accomplished by varying the sizes of the heat transfer regions in the OTSGs. If T_{avg} increases, then an increase in the subcooled liquid and nucleate boiling heat transfer areas (OTSG levels) will restore the parameter. Conversely, a low T_{avg} can be returned to normal by a decrease in the subcooled liquid and nucleate boiling heat transfer areas. The amount of heat transfer area available in the subcooled liquid and nucleate boiling regions of the OTSGs is a function of feedwater supply; therefore, a high T_{avg} error requires an increase in feedwater flow, and a low T_{avg} error requires a decrease in feedwater flow. The required increases or decreases in feedwater flow are accomplished by feedwater demand additions or subtractions in the feedwater demand summing amplifier. The summing amplifier will receive the T_{avg} error input if the reactor demand is not capable of controlling temperature and feedwater is capable of accepting temperature control. The reactor demand is not capable of T_{avg} control if the reactor demand hand/automatic station is in hand or the rod control (Diamond) station is in manual. The feedwater demand subassembly will accept T_{avg} control if at least one steam generator is not on low-level limits and at least one feedwater demand station is in automatic. (See Table 9-2.) Low-level limits are discussed later in this section.

Reactor Cross Limits

The third modification to the feedwater demand signal is also made in the summing amplifier. This modification is called reactor cross limits. It is very desirable to maintain heat generation (reactor power) equal to heat removal (feedwater flow). If a large difference between reactor demand and reactor power exists (i.e., + 5%), then feedwater demand must be modified. This difference is determined in the reactor demand subassembly.

Assume that reactor demand is 50% (since the ICS is in automatic, feedwater demand is also 50%) and reactor power is 44%. In this example an error of 6%, as sensed by the comparison of reactor demand and reactor power, exists. The 6% error exceeds the allowable error of 5%; therefore, the signal sent to the feedwater demand summer will reduce feedwater demand by 1%. If a reactor demand of 50% and a reactor power of 58% are assumed, then the reactor cross limits signal that is sent to the feedwater demand summer will increase feedwater demand by 3%.

When reactor cross limits occur, feedwater demand is increased or decreased, and the ICS is placed in TRACK. In TRACK, actual generated megawatts become the demand signal for the remainder of the ICS, and the load transient will stop. Cross limits maintain the proper relationship between heat generation (reactor demand) and heat removal (feedwater demand).

After the modifications of feedwater temperature, RCS average temperature, and reactor cross limits are made, the feedwater demand signal is finally sent to the loop A and loop B feedwater demand strings.

9.2.3.2 Loop Feedwater Demand

The loop feedwater demand strings are shown in Figure 9-2. On the A side the total feedwater demand signal is routed through a variable gain amplifier (χ). The feedwater demand for the A OTSG is calculated here and is equal to the total feedwater demand times the gain of the variable gain amplifier. If the total demand is 100% and the gain of the amplifier is 0.5 (its normal value), then the feedwater demand for the A OTSG is equal to 50%. On the B side the feedwater demand for the B OTSG is calculated by a difference unit (△). The inputs to the difference unit are total feedwater demand and loop A feedwater demand; therefore, the loop B feedwater demand equals the total feedwater demand minus the loop A feedwater demand. Using the example above, total feedwater demand minus loop A feedwater demand (100% - 50%) equals a 50% demand for the B OTSG. These values are the normal 100% power conditions; however, if an asymmetric RCS flow condition or a difference between the cold leg temperatures is present, the feedwater demands to the OTSGs will change.

9.2.3.3 Asymmetric Reactor Coolant System Flow

Asymmetric flow conditions are sensed in the ICS by RCS flow transmitter inputs. RCS loop B flow is subtracted from RCS loop A flow in a difference unit (△), and the result is transmitted to a summing amplifier (∑). The RCS flow is combined with any difference between the RCS cold-leg temperatures (ΔT_c) in the summing amplifier. The output of the summing amplifier determines the gain of the variable gain amplifier (χ) that is used in the loop A feedwater demand calculations. If two reactor coolant pumps (RCPs) are operating in the A reactor coolant loop and one RCP is operating in the B loop, then the ICS will limit megawatt production to 75% by automatically reducing unit load and by setting a maximum allowable load limit into the ULD. Since only one RCP is operating in loop B, the energy available in the B OTSG is limited. The energy removal (feedwater flow) from the B OTSG must also be limited, and this is accomplished in the following manner:

1. The RCS flow difference alters the gain of the loop A feedwater demand variable gain unit from 0.5 to 0.66.

2. The feedwater demand to the A OTSG equals the reduced <u>total</u> feedwater demand (reduced to 75% in the ULD by the loss of 1 RCP) times the gain, that is, 75% x 0.66 = 49.5%.

3. The feedwater demand for the B OTSG equals the reduced <u>total</u> feedwater demand minus loop A feedwater demand, that is, 75% - 49.5% = 25.5%.

4. Feedwater demands to the OTSGs are proportional to the energy available to each steam generator.

One way to look at this is that with only 3 RCPs in operation, the plant can only safely produce about 3/4 of full power. Since RCS flow in the A loop remains about the same, the A OTSG is producing about the same amount of total steam after the loss of one B loop RCP as it was before the loss of the RCP. The reduction of B loop RCS flow to about one-half of its normal value limits the steam production in the B OTSG to about one-half of the amount prior to the loss of the RCP. Overall, at the new lower power level, the A OTSG is producing about two-thirds of the total steam and the B OTSG is producing the remaining one-third.

It should be noted that the subcooled liquid and nucleate boiling heat transfer areas (level) in the A OTSG will be greater than those in the B OTSG, because of the difference in feedwater supply rates. If the action of the RCS flow circuit does not equalize the RCS cold-leg temperatures, then the ΔT_c circuit, acting through the summing amplifier, will add the necessary corrections.

9.2.3.4 Unit ΔT_c Compensation

The Unit ΔT_c circuit consists of an input of the difference between loop A and loop B inlet temperatures (ΔT_c) and an operator-supplied setpoint (usually 0). The setpoint is compared with the ΔT_c input, and the result is supplied to the summing amplifier through a hand/automatic station. ΔT_c control is designed to equalize loop cold-leg temperatures to prevent unequal radial flux distributions in the core. The radial flux imbalance would result because of the lack of perfect mixing of vessel inlet temperatures. Operational situations that could result in ΔT_c conditions are unequal fouling of the steam generators, plugging of tubes in one steam generator, and, of course, asymmetric RCS flow conditions. The gain of the variable gain amplifier in the loop A feedwater demand is altered by ΔT_c corrections.

9.2.3.5 Feedwater Hand/Automatic Control Stations

The feedwater demand signal, after being modified by RCS flow and/or ΔT_c, is passed to the loop feedwater demand hand/automatic stations. These stations allow the operator to select manual control of the feedwater demands to the A and B OTSGs. If manual control is selected, the feedwater temperature, reactor cross limits, RCS flow and ΔT_c modifications are blocked. Manual control of both of these stations places the ICS in TRACK.

9.2.3.6 Flow Error Derivation

Whether the station is in hand or automatic, its output is sent to a difference amplifier in the associated loop feedwater demand string. In the difference unit the error between feedwater demand and actual feedwater flow is calculated. This error signal will eventually control feedwater valve position.

9.2.3.7 Feedwater Demand Reactor Trip Transfer Relays

From the output of the feedwater flow error amplifier in each loop demand string, the feedwater demand signal is sent to a transfer relay (T_{10}, T_{11}). During normal operation, the relay passes the feedwater flow error signal through to the high-select device (>) described below. Following a reactor trip, the relay substitutes the level error signal (described below) for the feedwater flow error signal to control the feedwater valves. The purpose of transferring the signal is to prevent overcooling the RCS with the addition of large amounts of feedwater following a reactor trip.

Immediately following the trip, steam generator levels are above the low-level limit setpoint and the large negative level error signal will shut the feedwater valves. (See Table 9-2.) After passing through the transfer relay, the feedwater demand signal is sent to a high-select device (>).

9.2.3.8 Level Error

The high-select device (>) is used to select either feedwater flow error or steam generator level error for the control of the feedwater valves. Level error is derived from the comparison between level setpoint and the selected startup range level input. Between 0% and 15% power OTSG level is maintained at the low-level limit (2 ft); as reactor power is increased, T_{avg} is increased by the operator from no load value to 15% load value. From 15% to 100% the level in the OTSG is increased and T_{avg} is held constant. The switchover from low-level limit to flow error control occurs automatically in the high-select (>) device when the magnitude of feedwater flow error exceeds the magnitude of level error. A 6-ft level setpoint is provided to increase generator level if all four reactor coolant pumps are lost. The increase in the subcooled liquid and nucleate boiling heat transfer areas promotes natural circulation in the OTSG. A transfer relay (T_{12}, T_{13}) will select the 6-ft setpoint if all four pumps are lost. (See Table 9-2.)

As stated above, following a reactor trip, relays T_{10} and T_{11} transfer the level error signal to the feedwater valves. Since steam generator levels are above the low-level limits setpoints, the large level error signal will shut the feedwater valves.

9.2.3.9 Feedwater Control Valve Operation

The output of the high-select device is sent to the feedwater control valves. Two feedwater control valves are installed in each OTSG feedwater supply line. These valves are the startup feedwater regulating valve, which is used to control feedwater flow between 0% and 15% power, and the main feedwater regulating valve, which controls feedwater flow between 15% and 100% power. The valves are sequenced into service by the ICS. The sequence program for these valves is shown in Figure 9-6.

In addition to sequencing the feedwater valves, the ICS opens a block valve in series with the main feedwater regulating valve when the startup regulating valve is 80% open. The ICS also closes the block valve if both main feedwater pumps are tripped or if all four RCPs are tripped.

Differential pressure transmitters piped across the feedwater regulating valves are used by the ICS in the feedwater pump turbine speed control circuit. (See section 9.2.3.10 below for additional information.)

9.2.3.10 Feedwater Pump Turbine Speed Control

The feedwater pump turbine speed is controlled to maintain a constant differential pressure across the feedwater regulating valves. A low-select device (<) selects the lowest of the valve differential pressure (ΔP) inputs and compares this value with a setpoint (SP) in a difference unit (Δ). The ΔP error signal is sent to a summing amplifier (∑). The summing amplifier adds the total feedwater demand signal to the ΔP error. The total feedwater demand signal is developed by adding the loop A and loop B demand signals in a summing unit. The addition of the total feedwater demand signal to the ΔP error signal provides an anticipatory speed demand for the turbines on rapid load changes. Otherwise, feedwater pump turbine speed is a function of valve differential pressure. As the feedwater regulating valves are opened up by the feedwater flow error signal, the ΔP across each valve tends to drop. When the valve ΔP drops, the feedwater pump turbine speed is increased to restore the valve ΔP to setpoint.

9.2.3.11 BTU Limits

The BTU limits help to ensure that the steam from each OTSG never reaches saturated conditions. This is necessary because no moisture separation equipment is installed in the steam generator. Steam leaving the OTSG with high moisture content would be detrimental to the high-pressure turbine.

The ICS indirectly checks for superheated conditions of the steam leaving the OTSGs by monitoring four parameters and calculating a BTU limit for each OTSG. The inputs into the BTU limits calculation are the reactor outlet temperature (T_h), reactor coolant flow, feedwater temperature, and OTSG pressure. The first two inputs (T_h and RC flow) are used as a measure of heat input to the OTSG, and the other two (OTSG pressure and feedwater temperature) are a measure of the heat removed from the OTSG. The BTU limits calculation produces a maximum FW demand value and compares it to the actual loop FW demand. If the calculated BTU limits exceed the actual loop FW demand signal, the steam leaving the OTSG may be $< 35\ ^{o}F$ superheat.

If BTU limits are reached, an alarm is sounded in the control room. The operator should take manual actions to ensure that the OTSGs do not operate in a saturated steam condition. Figure 9-9 shows the effect of BTU limits on the alarm setpoint calculation.

In the original design of the ICS, BTU limits reduced feedwater demand. However, with this ICS configuration, certain instrument failures can cause a reduction in feedwater (because of BTU limits) and an increase in reactor power. This large upset in heat transfer results in undesired pressure excursions in the RCS. Consequently, the BTU limits signal was removed from the ICS in the late 1980s.

9.2.3.12 Subassembly Operations

Examining the actions of the feedwater demand subassembly during a plant startup provides a method of illustrating integrated system operations. The OTSGs are on low-level limits in the first phases of the startup. The low-level limit is maintained by the level error signal created by the difference between startup range level and the level setpoint of 2 ft. The level error signal modulates the startup feedwater regulating valve to maintain level. As heat from the reactor is added to the OTSG, its boiling rate increases, and a greater opening of the startup feedwater regulating valve is required to maintain correct OTSG level.

At approximately 15% power, the feedwater flow error signal exceeds the level error signal and is used as the controlling signal. The inventory in the OTSG is controlled by feedwater flow through both the startup feedwater regulating valve and the main feedwater regulating valve. Above 15% the startup valve remains 100% open, and the main feedwater regulating valve is modulated. Valve position changes cause △P changes that result in speed changes of the main feedwater pump turbines. These actions continue until the unit is at 100% power.

If a reactor trip occurs, then the level error is selected as the control signal input to the loop feedwater flow control valves. The level setpoint is compared immediately with a large level signal, and the resultant large level error closes the feedwater regulating valves. When the feedwater regulating valves close, the large △P error, combined with the large change in flow demand, rapidly reduces feedwater pump turbine speed to its minimum value. The combination of reduced feedwater flow and steam flow through the steam dump valves reduces the OTSG inventory. As inventory drops below the low-level limit setpoint, the high- select device allows OTSG level error to control feedwater flow.

In this section, the characterized megawatt demand signal has been converted to a feedwater demand signal. The next section discusses the megawatt demand signal sent to the reactor demand subassembly.

9.2.4 Reactor Demand Subassembly

The megawatt demand signal from the unit load demand is converted to a reactor demand signal in the integrated master subassembly. When the megawatt demand signal exceeds 15%, it is sent to the reactor demand subassembly. In the reactor demand subassembly (Figure 9-2), the megawatt demand signal is combined with three other signals in a summing amplifier (∑). These signals are T_{avg} error, T_{avg} calibrating integral input, and feedwater cross limits.

9.2.4.1 T_{avg} Input

The T_{avg} error is developed by comparing an actual T_{avg} signal with a setpoint (normally 601°F) in a difference unit (△). If T_{avg} is below setpoint, the reactor demand signal will be increased. If T_{avg} is above setpoint, then reactor demand will be reduced. The T_{avg} error is also sent to a calibrating integral. The calibrating integral supplies outputs to the reactor demand summing amplifier and to a variable gain unit (χ). The variable gain unit is used to adjust for T_{avg} errors at high demands, when a small change in gain causes a large change in output. The calibrating integral output to the summing amplifier allows adjustment for T_{avg} errors at low-demand conditions. The output of the T_{avg} calibrating integral is blocked if the demand signal is changing more quickly than 2% per minute, if T_{avg} is below setpoint with the OTSGs on low-level limits, or if the reactor demand hand/ automatic station is in hand (manual).

9.2.4.2 Feedwater Cross Limits

The third input into the summing amplifier is feedwater cross limits. The feedwater cross limits reduce reactor demand when feedwater flow is less than feedwater demand by more than 5%. The reduction in reactor demand is necessary to keep heat generation (reactor power) within the limits of the heat removal (feedwater) system. The signal for the reduction of reactor demand is calculated in the feedwater demand subassembly as the difference between feedwater demand and actual feedwater flow. Assigning numbers to these signals will explain the actions of feedwater cross limits. If the feedwater demand signal is 80% and actual feedwater flow is 74%, the feedwater cross limits signal will reduce reactor demand by 1%. Values of feedwater cross limit signals may be calculated by the following formula:

(FW demand - FW flow) - 5% = reduction in reactor demand signal

Feedwater cross limits can only reduce reactor demand. Feedwater cross limits causes a TRACK condition.

After the summing unit combines reactor demand with cross limits and the T_{avg} errors, the signal is routed to the variable gain unit (χ), where the demand signal is adjusted by the T_{avg} calibrating integral. From the variable gain unit (χ), the signal is directed to the Hi-102%, Lo-10% limits box shown in Figure 12-2. The purpose of the Hi/Lo limits is to allow T_{avg} errors to increase the reactor demand to greater than 100% and decrease demand to less than 15%. A word of caution: The 102% limit is a limit on reactor demand, not reactor power. High reactor power trips can occur even though the demand signal is at the high limit. If the reactor demand signal is within limits, it is passed to the reactor demand hand/automatic station.

9.2.4.3 Reactor Demand Station

The reactor demand hand/automatic station allows manual control of reactor power by the operator. If this station is placed in hand, the ICS will go into TRACK. Several interlocks must be satisfied to place the reactor demand station in automatic:

1. Power must be available to the ICS.

2. The DIAMOND rod control station must be in automatic.

3. The difference between reactor power and reactor demand must be less than 1%.

The output from the reactor demand hand/automatic station is supplied to a difference unit (Δ). In the difference unit, actual reactor power is compared with reactor demand, and the resultant error (called neutron error) will cause rod motion. To prevent continuous rod motion, the neutron error must exceed a predetermined deadband before rod motion will be initiated. The deadband is illustrated in Figure 9-7. From the difference unit the neutron error signal is routed through the Diamond rod control station to the control rod drive control system. Three non-ICS outputs are supplied by the nuclear instrumentation input to the reactor demand subassembly: a neutron power signal to the boration control system, a RCP start interlock, and a control rod interlock to prevent rod withdrawal during asymmetric rod conditions. A block diagram of these outputs appears in Figure 9-8.

Again, operational activities can be used to summarize the actions of the reactor demand subassembly. Assume a power escalation from 60% to 80% is desired. The load change is initiated in the ULD subassembly by increasing the load setpoint. The rate limited megawatt demand signal passes from the ULD to the integrated master where it is characterized for the reactor demand subassembly. The reactor demand signal is sent through the summing amplifier (∑), the variable gain unit (χ), the HI/LO limits box, and finally to the difference unit (Δ). When the comparison between reactor demand and actual reactor power yields a difference greater than 1%, rod withdrawal will occur. When the rod withdrawal increases reactor power and the neutron error is reduced to less than 0.25%, then the rod withdrawal will stop. These actions continue until load is stabilized at 80%. If it is assumed that the main feedwater valve response is sluggish during the power escalation to 80%, feedwater cross limits can affect the reactor demand signal. The moment that the feedwater demand signal exceeds the actual feedwater flow value by 5%, feedwater cross limits are transmitted to the reactor demand subassembly. The cross limits reduce reactor power demand and place the ICS in TRACK. In TRACK the reactor demand signal is set equal to the generated megawatts and is further reduced by feedwater cross limits. The unit operator can reinitiate the power escalation by changing the ULD setpoint when cross limits are cleared. The power escalation from 60% to 80% will cause changes in the xenon concentration in the core.

Initially, the concentration is reduced by the higher neutron flux level at 80%. When the concentration is decreased, positive reactivity is added to the reactor. This reactivity addition eventually results in an increase in T_{avg}. The elevated T_{avg} is sensed, and the T_{avg} error signal reduces the reactor demand signal, causing inward rod motion. The opposite effects occur if the xenon concentration is increased.

Now that each subassembly has been described, the next section of this chapter will deal with the overall operation of the integrated control system.

9.3 Integrated Operations

The events in the ICS occur simultaneously, and it is impossible to write concurrent descriptions of subassembly actions; therefore, the discussion of a particular transient will start with unit load demand (ULD) actions and continue through the integrated master, feedwater demand, and reactor demand actions. Transients such has Loss of one RCP, Load Rejection, and Reactor Trip and selected instrument failures are described in Chapter 19.0, Transients and Instrument Failures.

9.3.1 Normal Power Increase

Initial Conditions: The plant is at a stable power level of 30% with all ICS hand/automatic stations in automatic. A load increase to 80% at a rate of 5% per minute is desired.

1. Unit Load Demand (ULD) Actions
   a. The operator must input the desired rate of load change and the new load value.
   b. In Figure 9-2, the new load value (at the desired rate of increase) is supplied to the frequency-correction summing amplifier (∑). At the end of 1 min, the output from the summing amplifier (ignoring any frequency correction) will increase from 30% to 35%.
   c. Since load is changing more quickly than 2% per minute, a signal is sent to block the outputs of the megawatt error and T_{avg} error calibrating integrals.
   d. Any required frequency correction is added to the megawatt demand signal in the frequency-correction summing amplifier.
   e. The megawatt demand signal is sent to the integrated master.
2. Integrated Master Actions
   a. The megawatt demand signal is compared with generated megawatts, and the resultant megawatt error signal is sent to a summing amplifier (∑).
   b. In the summing amplifier, the megawatt error modifies the turbine header steam pressure setpoint to a lower value.
   c. The reduced turbine header steam pressure setpoint is combined with actual turbine header steam pressure in the pressure-error-(turbine) difference unit (Δ), and the error signal causes the turbine valves to open to lower header pressure back to setpoint.
   d. In reality, the opening of the turbine valves lowers steam pressure. The decreased steam pressure is compared with an unmodified header pressure setpoint in the pressure-error-(modifier) difference unit. The resulting error signal is added to the megawatt demand in the main integrated master summing amplifier. The pressure-error-(modifier) signal increases the megawatt demand signal being sent to the feedwater and reactor demand subassemblies.

e. The megawatt demand signal is translated into the proper signals for feedwater and the reactor demands in the integrated master, and the signal is sent to the respective subassemblies.

3. Feedwater Demand Actions

   a. Since modifications from feedwater temperature, reactor cross limits, or T_{avg} error are not required, the feedwater demand signal is directed from the main summing amplifier ($\sum$) to the variable gain unit (χ) in the loop A feedwater demand and to the difference unit (Δ) in the loop B feedwater demand.

   b. Feedwater demand is compared with actual loop feedwater flows, and the resultant error signal increases the positions of the main feedwater regulating valves.

   c. The opening of the feedwater regulating valves decreases the valve ΔPs, and this signal, coupled with the increase in feedwater demand, increases main feedwater pump speed.

4. Reactor Demand Actions

   a. It will be assumed that the need for feedwater cross limits is not present; therefore, the reactor demand summing unit will receive signals from T_{avg} error and megawatt demand.

   b. Because the reactor demand is less than 102% and greater than 10%, the signal will pass through the Hi/Lo limits box directly to the difference unit (Δ).

   c. The comparison between reactor demand and reactor power creates a neutron error. The neutron error results in outward regulating rod motion.

The actions described above will continue until the unit load is at 80%. It should be noted that the pressure-error-(modifier) different unit (Δ) will continue with increases in feedwater and reactor demands until steam pressure is returned to normal.

9.3.2 Turbine EHC in Manual

Initial conditions: The unit is at 50% load, and the EHC is placed in operator auto control (i.e., not controlled by ICS). The operator initiates a load decrease to 40% by changing the load setpoint.

1. ULD Actions

   a. When the operator auto mode of control is selected, the ICS goes into TRACK. Actual generated Mwe becomes the unit load demand, which is transferred to the feedwater and reactor demand subassemblies.

b. As turbine load is reduced, the demand to the feedwater and reactor demand subassemblies will also be reduced.

2. Integrated Master Actions

   a. Since the turbine is being controlled by the EHC system, the signal from the ICS is not sensed by the turbine.

   b. Should header pressure exceed the 1035 psia setpoint plus the "normal" bias values, turbine bypass valves and/or atmospheric dump valves will open.

3. Feedwater Demand Actions

   a. As the demand signal from the ULD decreases, the feedwater demand signal decreases.

   b. Feedwater flow is reduced as the regulating valve positions and feed pump speeds are reduced by the decreased feedwater demand signal. Feedwater flow will equal 40% at the end of the transient.

4. Reactor Demand Actions

   a. As reactor demand is decreased, reactor power will be reduced by regulating rod insertion.

   b. Reactor power will stabilize at 40% at the end of the transient.

9.3.3 Steam Generator/Reactor Master in Manual

Initial Conditions: The unit is at 75% power, and the operator places the Steam Generator/Reactor Master in manual and increases its output to a demanded value of 80%.

1. Feedwater and Reactor Demand Actions

   a. As the output of the steam generator-reactor master is increased, feedwater flow and reactor power increase in response to the increase in their demands.

   b. The increased energy is deposited into the OTSGs, and header pressure goes up.

2. Integrated Master Actions

   a. Since the unit is in TRACK, the turbine receives an unmodified header pressure setpoint. As header pressure is increased by the reactor and feedwater demand subassemblies, the turbine control valves open to return header pressure to the 1035 psia setpoint. As the turbine control valves open, load will increase to 80%.

3. ULD Actions

   a. Due to the tracking condition, the output of the ULD follows generated Mwe. This increase in ULD does nothing in this particular transient because (1) relay T_2 prevents the modification of header pressure setpoint to the turbine, and (2) the steam generator-reactor master is in manual and prevents the ULD signal from reaching the feedwater and reactor demands. However, the input to the steam generator-reactor master is increased as the ULD's output is increased and should help make the transfer back to automatic bumpless.

9.3.4 Both Feedwater Demand Hand/Automatic Stations in Manual

Initial Conditions: The unit is at 50% power, and the operator places both feedwater demand stations in manual. Both stations in manual causes the ICS to go into TRACK. After taking manual control, the operator increases loop A and loop B feedwater demands to 80%.

1. Feedwater Demand Actions

   a. With an increase in feedwater demand, feedwater flow is increased by the action of the feedwater regulating valves and the increase in main feed pump speed. The increase in feedwater flow causes an increase in energy transfer in the nucleate boiling sections of the OTSGs. This increase in heat transfer, combined with a turbine load of 50%, increases header pressure.

2. Integrated Master Actions

   a. With an increase in header pressure, the turbine valves open to restore header pressure to 1035 psia (unmodified setpoint due to TRACK).

   b. As the turbine valves open, generated megawatts (Mwe) increase to 80%.

3. ULD Actions

   a. As generated megawatts (Mwe) increase, the output of the ULD increases.

4. Reactor Demand Actions

   a. As the output of the ULD increases the reactor demand signal, regulating rods are withdrawn to increase reactor power to 80%.

b. If the increase in feed flow causes a decrease in T_{avg}, the T_{avg} error will be added to the reactor demand signal to restore T_{avg} to 601°F.

9.3.5 Reactor Demand Hand/Automatic Station to Manual

Initial Conditions: The unit is at 100% power, and the operator places the reactor demand hand/automatic station to hand and decreases its output to 90%. Placing the station in hand causes TRACK and also transfers T_{avg} control to the feedwater demand subassembly.

1. Reactor Demand Actions

   a. As the regulating rods insert due to a decrease in the reactor demand setpoint, reactor power decreases. With less energy being deposited into the OTSGs, header pressure decreases.

2. Integrated Master Actions

   a. The turbine control valves close to restore header pressure to 1035 psia.

   b. As the control valves close, turbine load decreases to 90%.

3. ULD Actions

   a. The output of the ULD tracks the decrease in turbine load and corresponding decrease in MWe.

4. Feedwater Demand Actions

   a. Feedwater flow decreases to 90% following the decrease in the ULD’s output.

   b. If a T_{avg} error exists, feedwater demand will be altered to return T_{avg} to 601°F.

TABLE 9-1 RUNBACK CONDITIONS

Condition	Runback Rate	Maximum Load Value
Loss of an RCP	50%/minute	75% generated Mw
Loss of 2 RCPs (1 RCP per loop)	50%/minute	50% generated Mw
Loss of a MFP	50%/minute	60% generated Mw
Asymmetric Rod	30%/minute	60% generated Mw
RCS Flow (Total Core Flow)	20%/minute	Value required to maintain correct power/flow ratio

TABLE 9-2 TRANSFER RELAY LOGIC

1. Unit load demand tracking relay - T_1

   a. Normal condition - passes the megawatt demand signal from the Unit Load Demand hand/automatic station to the remainder of the integrated control system.

   b. In TRACK - the value of actual generated megawatts is transferred to the remainder of the integrated control system as the demand signal. The following conditions cause TRACK:

      (1) reactor trip
      (2) generator output breakers open
      (3) electro-hydraulic control in manual
         (a) turbine trip
         (b) turbine in other than ICS control
      (4) Diamond rod control station in manual
      (5) major integrated control system hand/automatic stations in manual
         (a) reactor demand
         (b) steam generator/reactor master
         (c) both loop A and B feedwater demands
      (6) feedwater flow greater than feedwater demand by 5%
      (7) reactor or feedwater cross limits

2. Integrated master tracking relay - T_2

   a. Normal condition - allows header pressure setpoint modification.

   b. In TRACK - bleeds setpoint modification to zero (no modification) through an R-C network with a time constant of 100 sec.

3. Bias selection - T_3,T_4, T_5, T_6, and T_7

   a. <u>Always</u> selects reactor trip bias when the reactor is tripped.

   b. When the <u>reactor is not tripped</u>, selects turbine trip bias when:
      (1) the turbine is tripped
      OR
      (2) normal bias criteria are not met.

   c. When the <u>reactor and turbine are not tripped</u>, selects normal bias when:
      (1) turbine bypass valves are closed <u>AND</u> header pressure error is < 10 psi
      OR
      (2) unit load demand >15%.

TABLE 9-2 (Continued)

4. Condenser interlock - T_8

    a. Normal condition - passes pressure error (minus bias value) signal to turbine bypass valves.
    b. Closes turbine bypass valves if the following conditions exist:
        (1) low circulation water flow
        (2) condenser pressure higher than setpoint

5. Feedwater demand reactor trip - T_{10} and T_{11}

    a. Normal condition - transfers feedwater demand to feedwater regulating valves.
    b. Reactor trip—transfers low level limits signal to feedwater regulating valves when the reactor trips.

6. Feedwater demand low-level limit selection - T_{12} and T_{13}

    a. 2-ft level setpoint is selected if any reactor coolant pump is running.
    b. 6-ft level setpoint is selected if all reactor coolant pumps are tripped.

7. Reactor demand T_{avg} transfer - T_{14}

    a. Normal condition—allows the reactor demand subassembly to control T_{avg}.
    b. Feedwater control—transfers T_{avg} error to feedwater demand if <u>either</u> the reactor demand hand/automatic (H/A) station <u>or</u> Diamond rod control station is in manual;

        Feedwater demand will accept T_{avg} control if:

        (1) at least one once-through steam generator is not on low level limits,
        AND
        (2) at least one feedwater demand station is in automatic.

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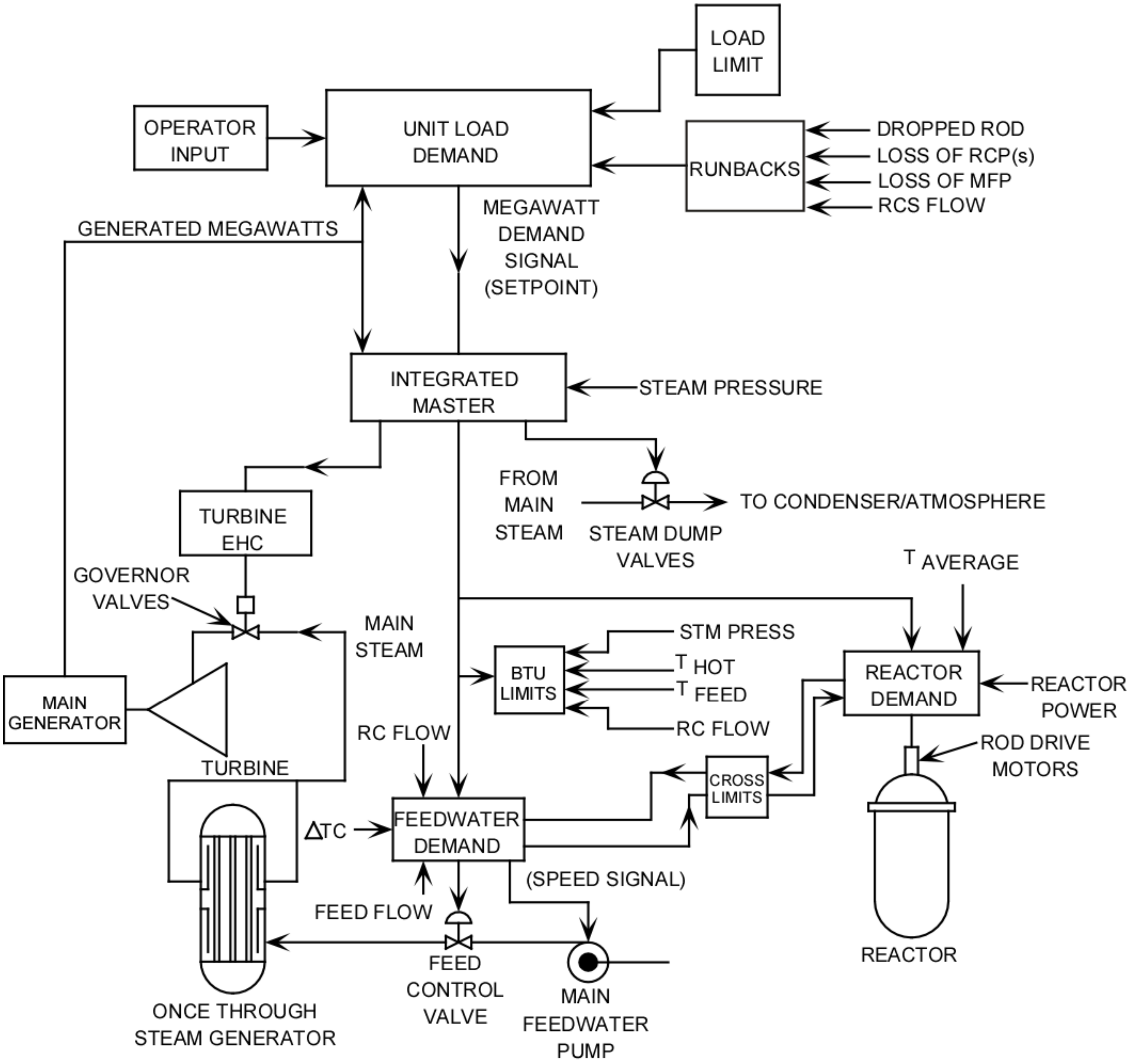

Figure 9-1 Simplified Integrated Control System

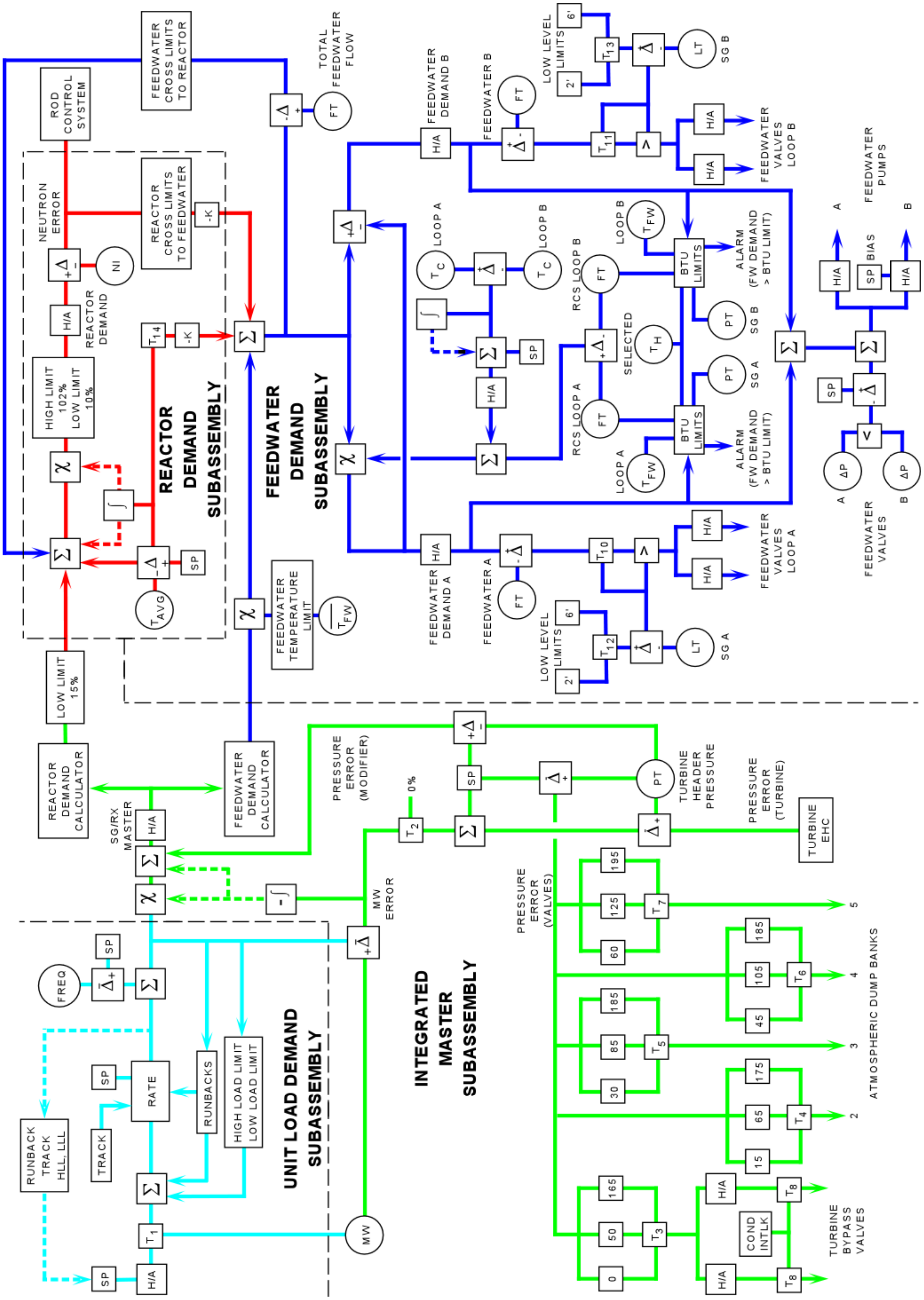

Figure 9-2 Integrated Control System

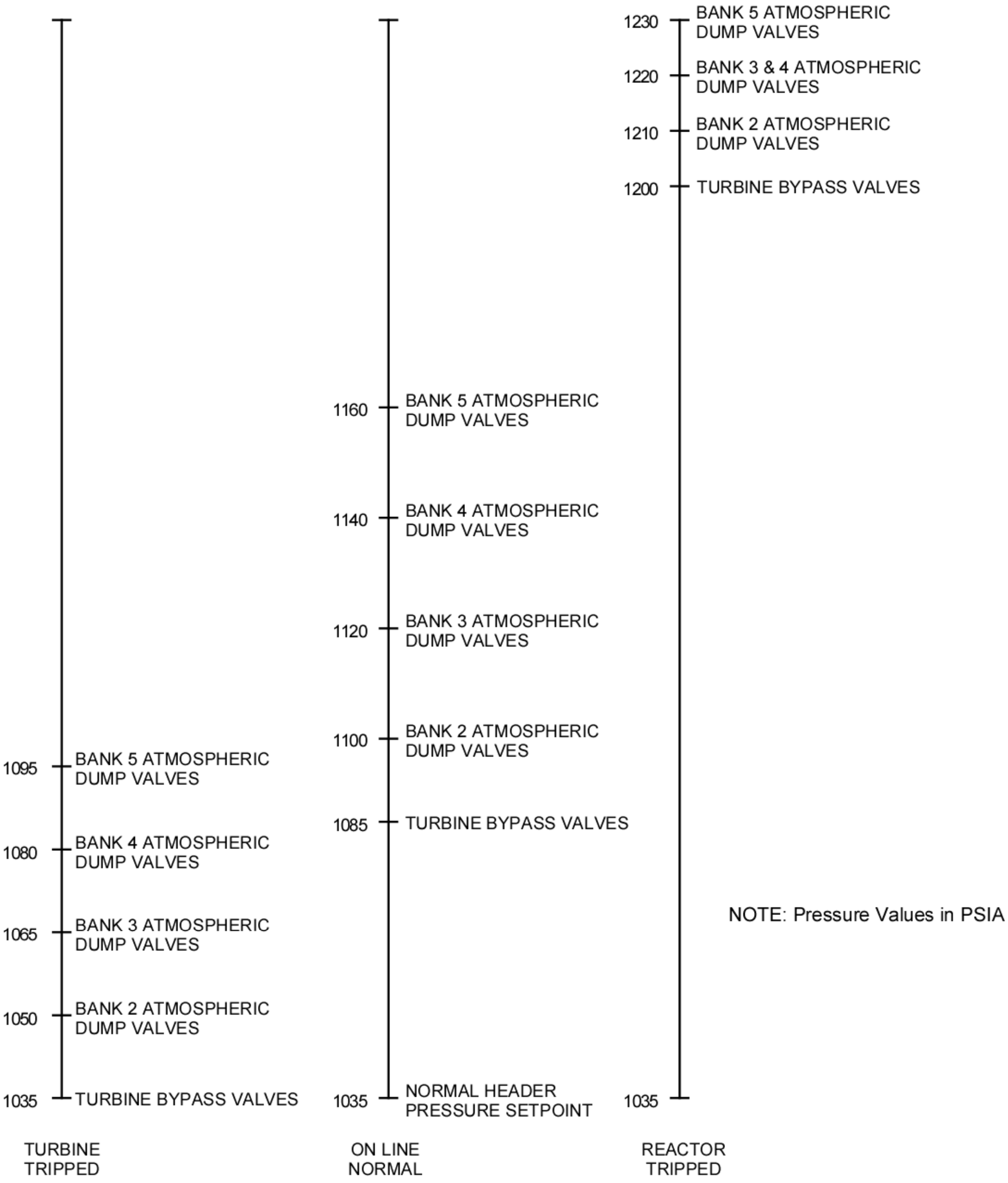

Figure 9-3 Steam Dump Setpoints

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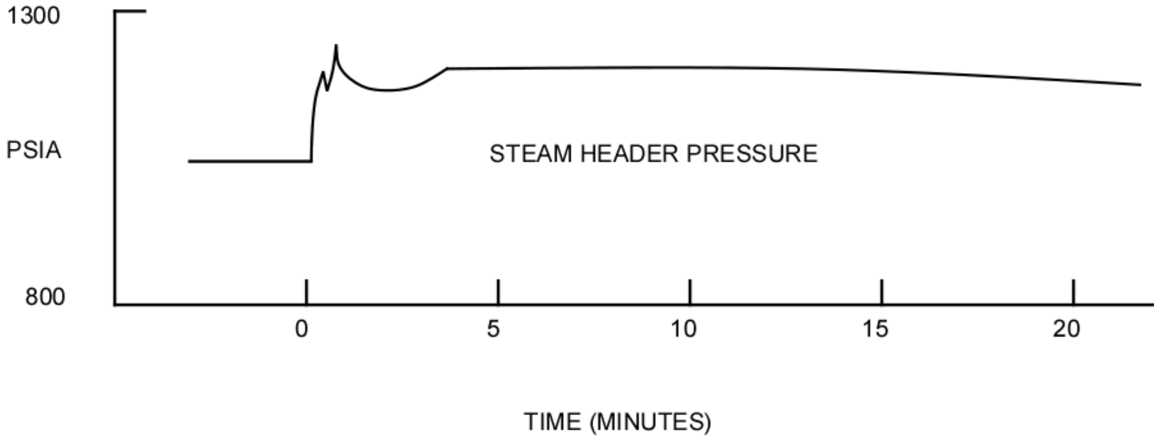

Figure 9-4 Response of Steam Pressure on a Reactor Trip

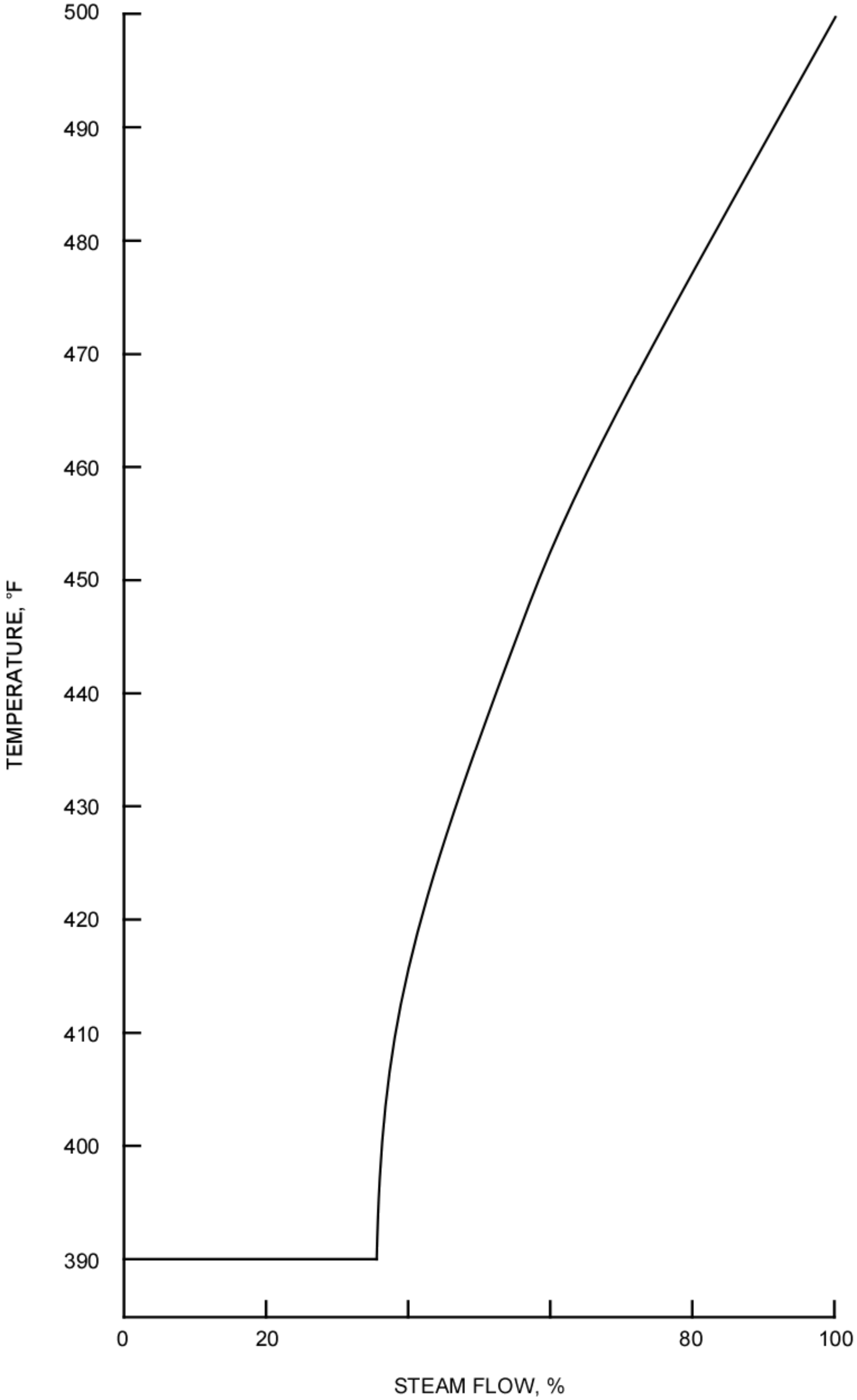

Figure 9-5 Feedwater Temperature vs. Steam Flow

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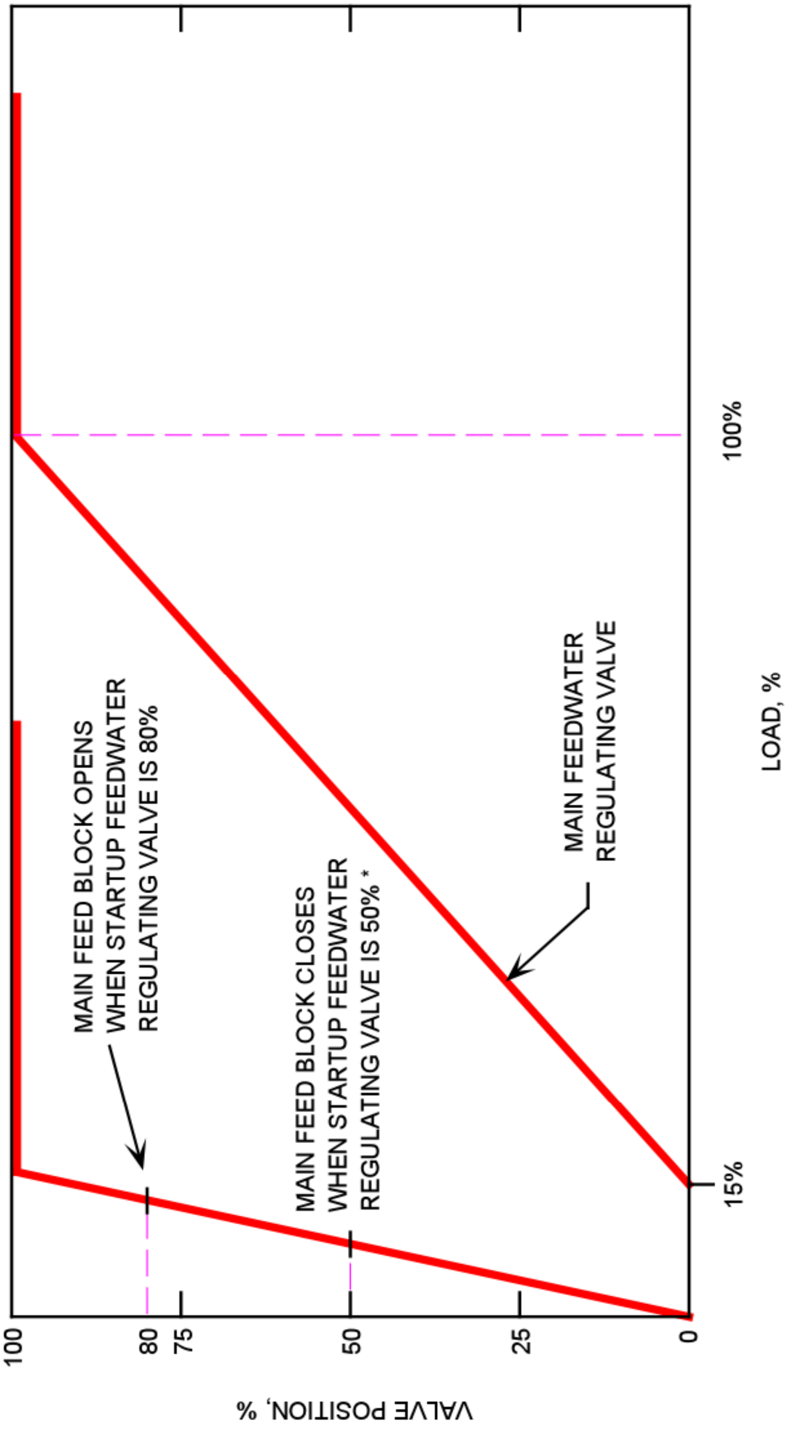

* <u>NOTE:</u>
MAIN FEED BLOCK VALVE AUTO CLOSES IF
BOTH MAIN FEEDWATER PUMPS ARE TRIPPED
OR IF ALL RCPS ARE TRIPPED.

Figure 9-6 Feedwater Regulating Valve Sequence

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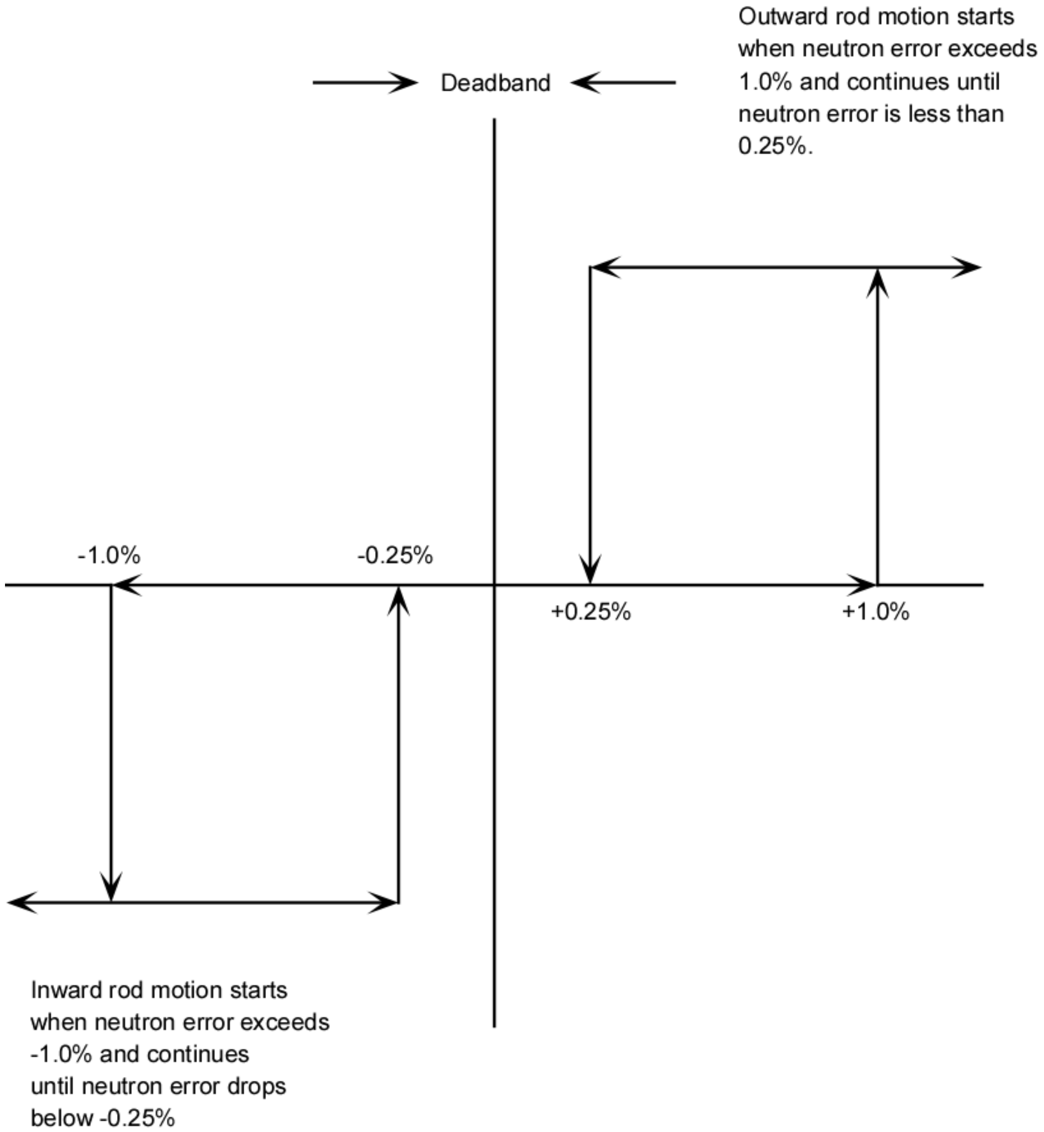

Figure 9-7 Rod Motion vs. Neutron Error

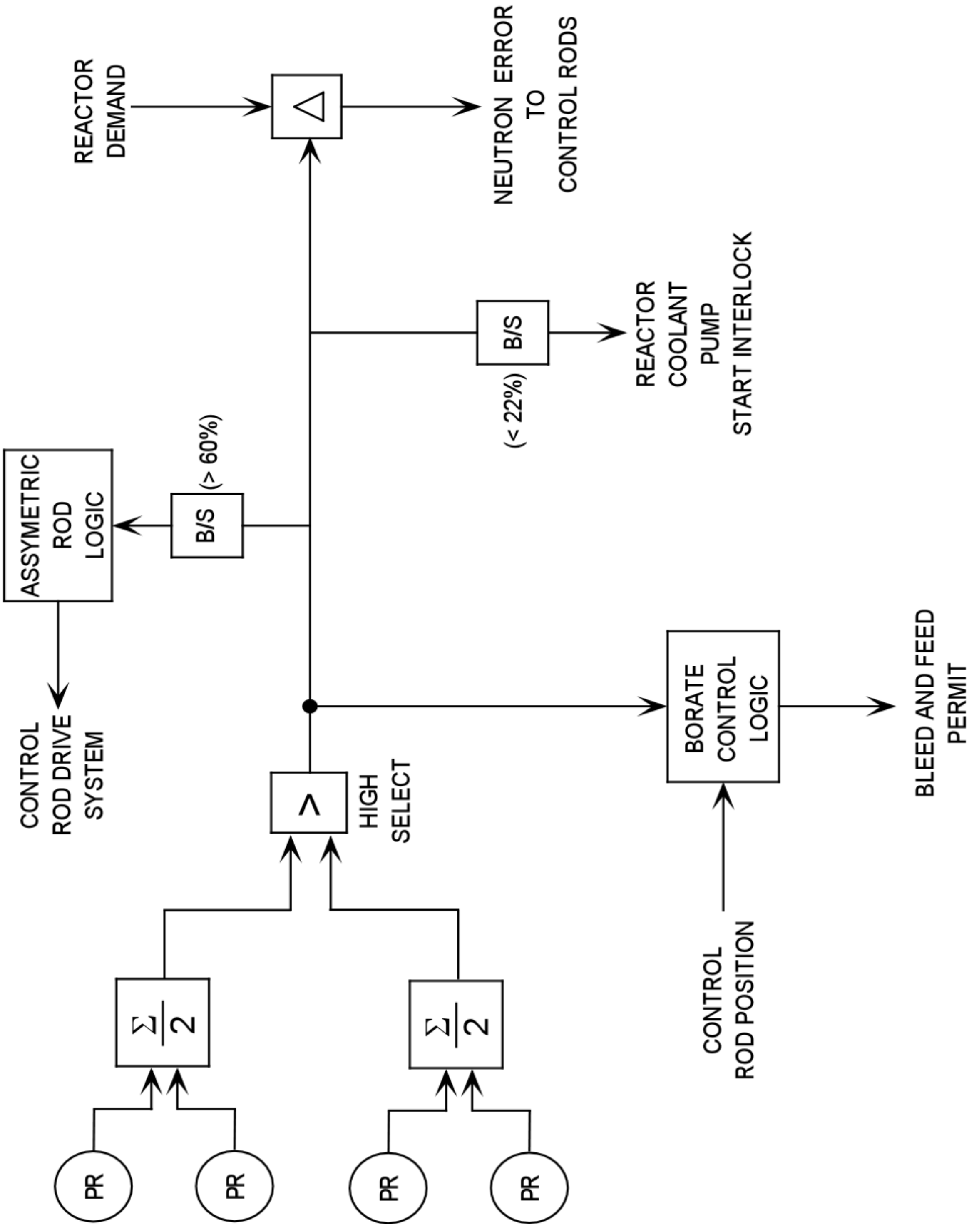

Figure 9-8 Reactor Demand Subassembly Interlocks

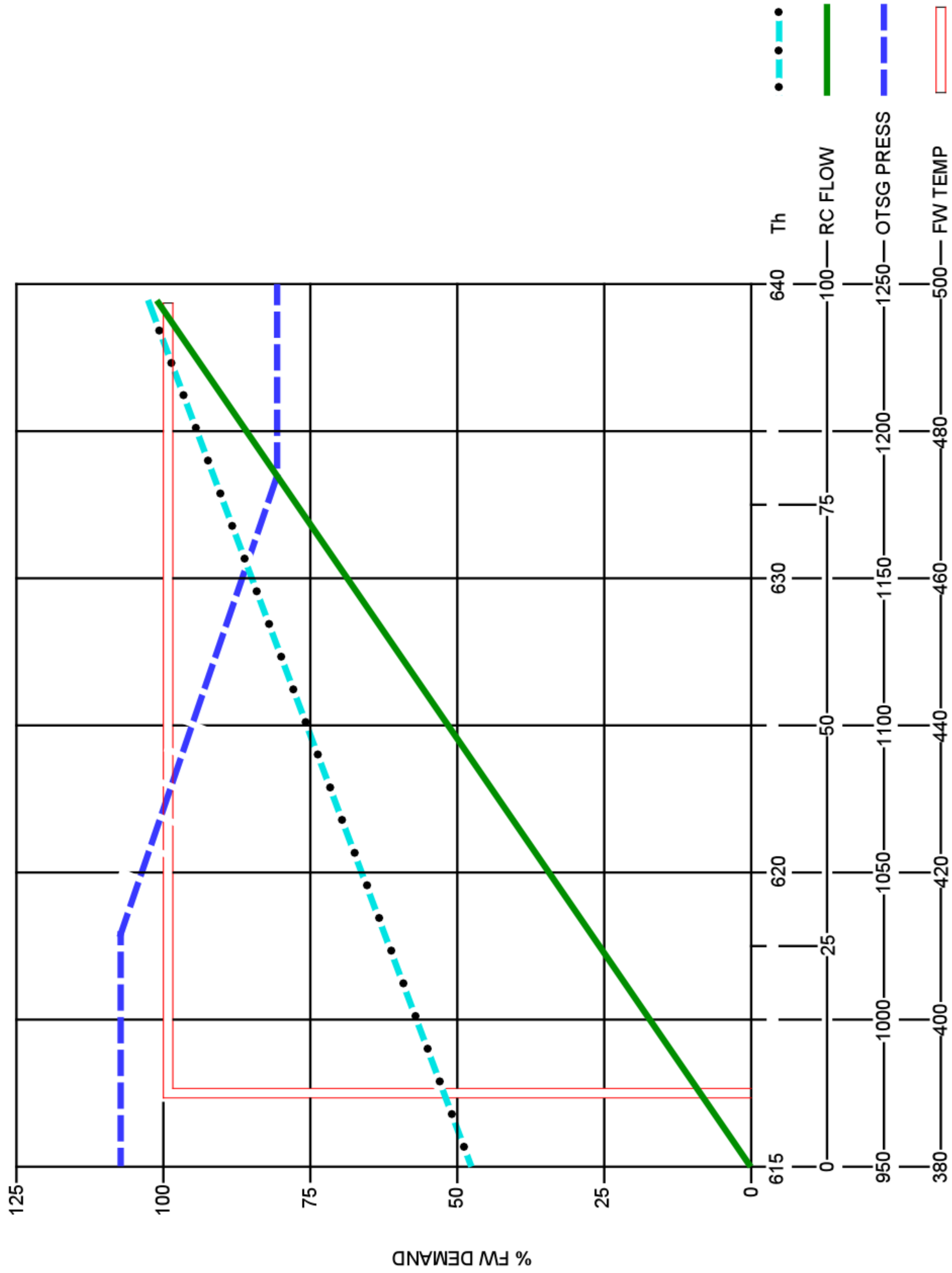

Figure 9-9 BTU Limits