Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 21.0

Advanced Control System

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21.0 ADVANCED CONTROL SYSTEM

21.1 Introduction

The purpose of the ACS is to match reactor thermal power with core thermal power demand while maintaining a balance between heat production in the primary system and heat removal in the secondary system.. As shown in Figure 21-1, the ACS accomplishes this purpose through four subsystems: Core Thermal Power Demand (CTPD), Integrated Master, Feedwater Control, and Reactor Control. Figure 21-2 is a more detailed diagram of the ACS.

The CTPD subsystem functions as a setpoint generator for the ACS. The Integrated Master receives the core thermal power setpoint from the CTPD subsystem and produces signals for feedwater control, reactor control, and steam valves. The ACS will maintain constant T_{ave}, steam pressure at setpoint, core thermal power within limits, and feedwater flow to obtain balanced steam conditions in the two steam generators.

Section 21.2 is a description and explanation of the operations of each of the four subsystems in the ACS. Section 21.3 is an explanation of the integrated operations of the ACS.

21.2 ACS Subsystems

21.2.1 Core Thermal Power Demand Subsystem

The Core Thermal Power Demand subsystem (CTPD) is the primary interface between the operator and the ACS. In the operator set mode, the operator can communicate to the CTPD a core thermal power setpoint and a rate. The CTPD also recognizes various limiting conditions of the plant or the ACS and will initiate either automatic load limiting or tracking.

21.2.1.1 Operator Set Mode

The Load Control Panel (LCP), shown in Figure 21-4, has the controls and indications that the operator uses to communicate with the CTPD. The operator uses the “increase” and “decrease” pushbuttons to establish a setpoint that will appear in the lower window of the LCP. The lower window is called “CTPD SET,” and it displays the target setpoint. The setpoint that is being processed by the rest of the ACS appears in the upper window which is called “CTP DEMAND.” The rate at which the setpoint in the upper window changes is determined by the “RATE SET” thumbwheels on the LCP. The operator can select any value from 0.0 to 9.9%. The scale, either % per minute or % per hour, is selected by a pushbutton. There is a “HOLD” pushbutton that will prevent changes from occurring while the operator is entering a setpoint and rate, or stop a power change in progress.

21.2.1.2 Automatic Load Limiting

There are several plant conditions which will cause the CTPD to automatically limit the maximum target setpoint. The lowest limit corresponding to a load limiting condition in effect will be selected by transfer function T1 (Fig. 21-2), and the operator input will be blocked. The automatic load limits are:

1. Loss of one reactor coolant pump (74%) sensed by breaker open contacts.
2. Loss of one feedwater pump (65%) sensed by low hydraulic oil in the turbine.
3. Asymmetric rod (55%) sensed by rod control logic using absolute position indication.
4. Loss of reactor coolant flow (variable limit) sensed by the sum of the loop flow signals.
5. Both generator output breakers open (20%).
6. Maximum runback (15%), when selected.

The rates for automatic load limiting are listed in Table 21-1.

21.2.1.3 Tracking

Tracking is a mode of operation that will be in effect when an ACS subsystem is unable to function normally, and the ACS may not be able to maintain the primary to secondary heat balance or automatic maneuvering. During tracking, the target setpoint is determined by a tracking parameter which enters the CTPD by transfer function T2 (Fig. 21-2), while manual control and automatic load limiting are blocked.

An ACS subsystem is unable function normally when it has become independent due to manual operation, maneuvering rate limitation, or by final component failure. The conditions that cause tracking are:

1. Reactor or feedwater cross limits.
2. Steam generator master in manual with at least one SG <u>not</u> on low level limit.
3. Blocking <u>both</u> feedwater loop flow control paths with at least one SG <u>not</u> on low level limit. (A control path is blocked by low level limit or manual operation of the loop master demand station or the controlling feedwater valve control station.)

NOTE: When both SGs are on low level limits, tracking will not occur due to a feedwater condition.

4. Reactor demand or rod control system in manual.

5. Turbine master in manual.

The tracking parameter that becomes the target setpoint in the CTPD is determined by the status of the ACS subsystems. When the feedwater subsystem is independent, total feedwater flow will be the target setpoint, and appears in the CTPD SET window. That signal will be fed to the CTP DEMAND window at 20% per minute. When the turbine control is independent, generated megawatts will be the tracking parameter. When reactor control is independent, NI flux will be the tracking parameter. If more than one subsystem is independent, the highest priority tracking parameter will be the target setpoint. Feedwater flow has the highest priority, followed by generated megawatts and the NI flux. An exception to this occurs when feedwater and reactor are both independent, in which case the CTP Best signal will be the tracking parameter.

21.2.2 Integrated Master

The integrated master (Fig. 21-2) sends demand signals to reactor control and feedwater control subsystems, and controls the turbine and turbine bypass valves, and coordinates their actions in order to maintain heat balance. There are four control variables that are measured and used by the ACS subsystems to control the plant. The control variables, in priority order, are T_{ave}, Turbine Header Pressure (THP), Core Thermal Power (CTP), and ΔT_C. T_{ave} and THP are indications of the heat transfer from the primary to the secondary system. Controlling CTP is the primary objective of the ACS. ΔT_C is related to the balance of heat transfer through the two SGs.

21.2.2.1 Calibrating Integrals

In the process of maintaining a balance between plant systems, an imbalance may develop because of changing efficiency, miscalibration, instrumentation drift, or SG heat transfer capability. Calibrating integrals are used in the ACS to compensate for imbalances and allow stable operation of the plant. The control variables are assigned to the integrals based on the mode of operation. The four calibrating integrals are the reactor integral, the feedwater integral, the EHC Load Reference Motor (LRM), and the ΔT_C integral in the feedwater subsystem.

During normal operation, T_{ave} is controlled by reactor control using the reactor integral, THP is controlled by the LRM, CTP is assigned to the feedwater integral, and ΔT_C is controlled by the ΔT_C integral. When reactor control is in manual, the feedwater integral takes over T_{ave} control, THP is still controlled by the LRM, the plant operator controls CTP, and ΔT_C is still controlled by the ΔT_C integral. Control variable assignments to integrals for other modes of operation are shown in Table 21-2.

21.2.2.2 Cross Terms

THP Error

The difference between the turbine header pressure and setpoint is applied to the reactor and feedwater demands to compensate for differences in response times of control systems and processes. The signal is limited to a maximum of ±50 psi.

T_{ave} Error

A proportional T_{ave} error is applied to feedwater demand to maintain proper heat balance. There is a deadband of ±1.2°F which must be exceeded before any modification is applied. In the event that feedwater has T_{ave} control, the deadband is removed and T_{ave} error is also applied to the feedwater integral.

RCS Pressure

When RCS pressure is above the setpoint, a correction term is applied to reactor demand, feedwater demand, and turbine demand. This is done to restore heat balance and prevent a high RCS pressure reactor trip. Reactor demand would be decreased during correction while feedwater and turbine demands would be increased.

21.2.2.3 Turbine Control

The turbine is normally controlled by the error between turbine header pressure and an operator selectable setpoint (THP error) and the error between CTP demand and feedback from the pulser through a compensator. The error is also increased when RCS pressure is higher than setpoint. The error signal drives a pulser that continues to demand turbine valve movement until the error is zero.

When there is a ±50 psi THP error for 5 seconds, the turbine master will switch to manual operation. However, this action is blocked during the following conditions when a large THP error is anticipated:

1. Crosslimits
2. Loss of RCP
3. Loss of FWP
4. Asymmetric rod
5. Loss of RCS flow
6. Both generator breakers open
7. Maximum runback

When the governor valve control system (EHC) assumes control due to a stator coolant runback or a power load unbalance, the transfer of the turbine control station to manual cannot be blocked.

21.2.2.4 Turbine Bypass Valves (TBVs)

There are three basic functions of the TBVs. When power is low and the turbine can not control THP (Turbine Load Status Flag is FALSE), or if the turbine is tripped, the bypass valves will control at the THP setpoint. When the turbine is operating and the turbine can control THP (Turbine Load Status Flag is TRUE), there is a 50 psi bias added to the THP setpoint, and the bypass valves act as pressure relief. When the reactor trips, a 125 psi bias is added to control at a higher pressure and limit the RCS cooldown. There is also an independent high pressure relief if the SG pressure exceeds 1035 psig.

The position demand for the TBVs is based on turbine header pressure (THP) when the turbine master is in automatic, and steam generator outlet pressure when the turbine master is in manual. The selection is made by the transfer function T7. In both cases, the setpoint is established by the operator at the turbine master. The transfer function T9 will block operation from the control room unless the condenser vacuum is greater than0 7". When vacuum is less than 7", the TBVs can be controlled only at the auxiliary shutdown panel (ASDP).

21.2.2.5 Turbine Loading and Unloading

During a normal plant startup, the reactor will be producing 10% to 20% power before the turbine is rolled and loaded. The TBVs will be dumping steam to the condenser and maintaining steam pressure at 885 psig. After the turbine is rolled to synchronous speed, it will be loaded with about 30 Mw. The operator can manually load the turbine by using the turbine master or the increase pushbutton on the EHC panel. As load increases, TBVs will close to maintain steam pressure at setpoint.

Another method of loading the turbine would be to use the turbine load pushbutton on the load control panel. When the CTPD is greater than 10%, pressing the load pushbutton will initiate automatic turbine loading. When the TBV demand is zero, the 50 psi bias is applied to the bypass valves. This happens because the Turbine Load Status Flag is set (TRUE). Pushing the unload pushbutton when CTPD is less than 20% resets the flag (FALSE). Table 21-3 shows the conditions that determine the status of the flag and its effects.

21.2.3 Feedwater Control Subsystem

The feedwater control subsystem normally maintains feedwater flow equal to feedwater demand while maintaining the correct balance of flow to the two steam generators. The subsystem must also maintain SG levels above minimum requirements and correct for heat balance problems during abnormal conditions.

When SG level is above 25" in the startup range, feedwater demand is compared to actual feedwater flow to position feedwater regulating valves. When startup level is 25" or less, valve position will be positioned according to a level error. Transfer functions T4 and T5 will select flow control or level control for SG A and B, respectively.

The integrated master converts the CTP demand into a feedwater demand signal, which is sent to the feedwater subsystem. This demand signal is corrected by a number of signals to produce the total feedwater demand.

21.2.3.1 Feedwater Demand Corrections

Feedwater Calibrating Integral

The input to the calibrating integral is either the CTP error, the T_{ave} error, or the THP error. During normal operation with all the ACS stations in automatic, CTP error is selected. When the reactor is in manual control, T_{ave} error will be selected. When T_{ave} is controlled by the reactor and the turbine is in manual control, THP error is selected (as long as the turbine load status flag is true).

THP Error

The THP error, up to a maximum of ±50 psi, is added to feedwater demand at all times.

T_{ave} Error

Any time the T_{ave} error exceeds ±1.2°F, the excess is added to feedwater demand. When the feedwater control subsystem takes control of T_{ave}, the deadband is removed.

RCS Pressure Error

When RCS pressure exceeds 2250 psig, then feedwater demand is increased proportionally.

CTP Error

The difference between the CTP demand and a the CTB Best calculation is added proportionally to the feedwater demand.

Neutron Error (Reactor Cross Limit)

Whenever the difference between reactor demand and neutron flux exceeds ±5%, the excess is added to feedwater demand. When reactor power is higher that demand by more than 5% (negative neutron error), feedwater demand is increased. A positive neutron error exceeding 5% will decrease feedwater demand. Reactor cross limit will also cause tracking with NI flux as the tracking parameter.

Feedwater (FDW) Temperature

At any given load, there is a balance of energy (BTU) exchange between primary and secondary during steady state conditions, and the BTU's transferred out of the primary should be equal to the BTU's transferred into the secondary side of the SG. For any feedwater flow rate there is an expected FDW temp. If feedwater temp. decreases without a change in flow rate; then the colder fluid would draw more heat from the primary, causing Tave to drop and reactor power to increase. More heat would be required to raise the feedwater to the proper SG outlet conditions. With a reduction of FDW temperature, the enthalpy (h) of the secondary would decrease. This creates a larger enthalpy difference between the primary and secondary causing the heat transfer (Q) to increase across the steam generator. To maintain a constant "Q", the mass flowrate of the FDW (M) is reduced by the ICS. This is performed in the FDW temperature modification circuit.

Feedwater demand is modified by a function of feedwater temperature when that temperature differs from what is expected for the load. When feedwater temperature is too low, feedwater demand is decreased to maintain the heat balance from primary to secondary. When temperature is too high, demand is increased.

21.2.3.2 Feedwater Loop Demands

Both steam generators receive coolant flow from the reactor at the same temperature (T_H). The temperature of the coolant returning to the reactor (T_C) from each steam generator is determined by the amount of heat transfer in that generator. It is desirable to maintain the outlet temperatures of the two steam generators nearly equal for core power distribution concerns. The only controlled variable available to control ΔT_C is feedwater flow. Feedwater flow to the two steam generators is rationed to maintain ΔT_C at zero while maintaining total flow equal to the demand.

As an example, consider that SG A has some fouling. Its heat transfer characteristics are lower than SG B. As a result, loop T_C is higher in loop A than in loop B. If the feedwater flow to SG A is increased, T_C in loop A will be decreased. At the same time, feedwater flow to SG B will be decreased so that the total flow matches the total demand.

Loop Demand Multiplier

The rationing of feedwater flow is done by controlling the multiplier used to modify the signal from total feedwater demand to loop A demand. The difference between the total demand and the loop A demand becomes the loop B demand. Normally, the multiplier is 0.5 so that half the total demand goes to SG A and half to SG B. When the multiplier is increased, more demand goes to SG A and less to SG B.

The multiplier is modified by two signals, RCS loop flow error and ΔT_C control. The RCS loop flow error anticipates a large change in ΔT_C and changes the multiplier immediately regardless of any other condition. When a reactor coolant pump is lost, flow in that loop and the associated SG decrease, with a corresponding decrease in energy input to the SG. T_C in that loop will decrease. Decreasing feedwater flow to that SG will restore T_C.

The second signal comes from ΔT_C control, which uses proportional and integral action to correct the measured temperature difference between the loops. The proportional part of the circuit is for the large T_C errors and the integral part is correction for small changes that occur over long periods. ΔT_C control is blocked when the control station is in manual, either loop master or feedwater valve is in manual, or either steam generator is on level control.

Loop Feedwater Flow Error

The actual loop feedwater flow is subtracted from the loop demand. This flow error is the signal that normally drives the valve controllers to position the feedwater valves. When conditions are abnormal, the flow error will be replaced by one of several level errors.

Level Errors

The first of these level errors is based on a high level limit. The level in the operating range should be maintained below the aspirating ports. The actual operating level is subtracted from a setpoint in the 92% to 96% range. This level error is normally higher than the flow error, so the low select unit selects the flow error. As the operating range level approaches the high level setpoint, the level error decreases and may become lower than the flow error.

The second level error is the startup level subtracted from a setpoint of 25”. This level error will be selected whenever the SG startup level is less than 25” or on low level limits (LLL). LLL is in effect on a SG if startup range level is less than 25” and loop T_{ave} is less than setpoint. The selection of “level control” is made by T4 on SG A and by T5 on SG B. Once initiated, LLL will be in effect until both initiating conditions clear. The SGs will normally be on LLL below 15% power. LLL will result in the following actions:

1. Both SGs on LLL releases T_{ave} from control priority, and T_{ave} error will not increase reactor demand when T_{ave} is below setpoint.
2. Both SGs on LLL limits CTPD rate to 1%/minute.
3. Both SGs on LLL prevents feedwater tracking.
4. Either SG on LLL blocks ΔT_C correction.

The third level error will be selected by the T6 transfer functions when all reactor coolant pump breakers are open. This will cause the startup valves to raise the SG levels to enhance natural circulation. The operating range level is subtracted from a setpoint of 50%, or 95% with a degraded containment (RB pressure > 3 psig).

Valve Sequencing (Figure 21-3)

Sequencing of the startup and main feedwater regulating valves is accomplished by composite valve demand controllers and sequence bias signals. Startup valves control feedwater flow up to about 15% power and the main valves control up to 100%. The main valves have a capacity about 10 times that of the startup valves. During a startup, each startup valve opens as power increases. At about 90% open, the main feedwater block valve opens automatically. At about 98% open, sequencing bias is applied that will ramp the startup valve to 10% and open the main valve enough to compensate. From this point on, the valves will open together, the startup valve opening 10 times faster, until the startup valve is fully open. On a power decrease, the main valve begins to close first. At some point, the startup valve begins to close at the same time. When it reaches about 9%, the sequencing bias is removed and the startup valves ramp to 90% and the main valve closes. As the startup valve reaches 50%, the main block valve closes.

21.2.3.3 Feedwater Pump Speed Control

Feedwater pump speed is adjusted to maintain a constant differential pressure across the feedwater valves. This will result in better control of feedwater by the feedwater valves over a wide range of flow.

The signal to control the speed of the pumps comes from the sum of the loop demands and the differential pressure error. The loop demands are the outputs of the loop masters. Valve ΔP is measured in each loop by two sensors and the higher of the two is selected. The differential pressure error is the difference between the lower of the selected loop ΔPs and a 35 psid setpoint.

21.2.4 Reactor Control Subsystem

The reactor control subsystem maintains the output of the reactor (neutron flux). It also matches heat production to heat removal capability by controlling T_{ave}. When the reactor master is in automatic, the reactor demand is CTP demand modified by a calibrating integral, T_{ave} error, THP error, and RCS pressure error.

21.2.4.1 Reactor Demand Corrections

Reactor Calibrating Integral

T_{ave} error is normally assigned to the reactor calibrating integral. If a steady state T_{ave} error exists, it indicates an error in the reactor demand signal that may be due to changes in SG or plant efficiency or neutron flux calibration errors. The integral will compensate and correct the demand.

When both SGs are on LLL, CTP error is assigned to the reactor integral unless the steam system is also unavailable, in which case THP error is assigned to the reactor integral.

T_{ave} Error

T_{ave} is subtracted from an operator adjusted setpoint and the resulting error is added to the reactor demand to control T_{ave} at a constant 579°F from 15% to 100% power. This will minimize volume changes in the RCS and compensate for changes in heat transfer capability in the SGs. Normally, unit T_{ave} is used, but if the flow falls below 95% in one loop, T_{ave} will be taken from the other loop. When both SGs are on LLL, T_{ave} error can only decrease reactor demand if T_{ave} increases above setpoint, but will not allow an increase in reactor demand.

THP Error

The THP error, up to a maximum of ±20 psi, is added to reactor demand at all times.

RCS Pressure Error

When RCS pressure exceeds 2250 psig, then reactor demand is decreased proportionally.

Reactor Demand Limit

There is a 101% limit on reactor demand to prevent a reactor trip on high power. Actual reactor power may increase above 101% due to a decrease in T_{ave}.

Feedwater Cross Limit

Feedwater cross limit, which initiates tracking, occurs when feedwater demand is more than 5% greater than the total feedwater flow. Feedwater flow will be the tracking parameter. Note that feedwater flow greater than demand does not cause feedwater cross limit.

21.2.4.2 Rod Control

Actual neutron flux from excore nuclear instruments is subtracted from reactor demand to produce neutron error. The neutron error will control rod movement. When power is above 10%, there is a 1% deadband and a 0.1% hysteresis. When the neutron error is greater than 1%, rods withdraw until the error is less than 0.9%. An error less than -1% inserts rods until the error is greater than -0.9%. When power is less than 10%, the deadband and hysteresis decrease proportionally.

21.3 Integrated Operations

21.3.1 Normal Power Increase

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

1. CTPD Actions

    a. The operator must input the desired load and the loading rate.

    b. In Figure 21-2, the new load demand (CTPD Set) passes through T1 and T2 and is applied to the rate unit. At the end of 1 minute, the output from the rate unit (CTP Demand) will have increased from 30% to35%.

    c. The demand signal is sent to the integrated master.

2. Integrated Master (IM) Actions

    a. The demand signal is sent to reactor control, feedwater control, and turbine control.

    b. The signal sent to turbine control anticipates a change in THP. THP will tend to increase due to the reactor power increase and the increase in feedwater flow. The THP error will ensure that the proper steam pressure is maintained in the secondary system by increasing turbine demand. If the RCS pressure exceeds 2250 psig, turbine demand will be increased.

3. Feedwater Control Actions

    a. The CTP demand is applied to a function generator, the output of which is a total feedwater demand. This demand may be modified by the CTP error, the THP error, the feedwater integral, or the T_{ave} error if the deadband is exceeded.

    b. After this modified signal passes through the SG master, it may be further modified by the feedwater temperature or reactor cross limit. If the RCS pressure exceeds 2250 psig, feedwater demand will be increased.

    c. The modified total demand is rationed to the two loop feedwater masters. Loop feedwater demand is compared with actual loop feedwater flow, and the resultant error signal opens the feedwater regulating valves.

d. The opening of the feedwater regulating valves decreases the valve ΔP. This signal and the increase in feedwater demand, increases main feedwater pump speed.

4. Reactor Control Actions

   a. The CTP demand is sent to reactor demand and may be modified by the T_{ave} error, the THP error, and the reactor integral. If the RCS pressure exceeds 2250 psig, reactor demand will be decreased.

   b. The modified reactor demand will be compared to NI flux and the resulting neutron error will be sent to the rod control system and rods will be withdrawn.

The actions described above will continue until the unit load is at 80%.

21.3.2 Loss of One Reactor Coolant Pump

Initial conditions: Unit load is at 90% power. Group 7 control rods are 90% withdrawn.

1. CTPD Actions

   a. When the reactor coolant pump is lost, an automatic load limit of 74% overrides the operator input.

   b. CTP demand will decrease at the rate of 25% per minute.

2. IM Actions

   a. The decreasing CTP demand closes the turbine valves.

   b. The closing of the turbine valves increases actual steam pressure. If steam pressure exceeds its setpoint by 50 psi, the turbine bypass valves will open to relieve excess energy.

   c. The CTP demand, reduced by the THP error, is sent to reactor demand and feedwater demand subsystems.

3. Reactor Control Actions

   a. The reduced demand signal from the integrated master will cause inward regulating rod motion. T_{ave} error will also decrease this demand signal. If RCS pressure exceeds 2250 psig, demand will be reduced.

b. Because the regulating rods are almost fully withdrawn, a large amount of rod motion occurs with little change in reactor power. This will result in reactor cross limit. Cross limits cause tracking. Since the tracking parameter is inserted downstream of the automatic load limit, the NI flux will be tracked at 20% per minute until the reactor cross limit clears.

4. Feedwater Control Actions

a. The reactor cross limits will limit the decrease in feedwater demand.

b. The actions of the RC flow and ΔT_C circuits will proportion feedwater between the OTSGs.

The actions listed above will continue until the load is stabilized at 75%.

21.3.3 Load Rejection

Initial conditions: Unit load is at 100% power. Group 7 rods are 90% withdrawn.

1. CTPD Actions

When the main generator output breakers are opened, an automatic load limit of 20% becomes the new CTPD SET. The output of the CTPD will decrease at 20% per minute.

2. IM Actions

a. The turbine load status flag is FALSE because the integrated master cannot control the turbine. However, the closing of the turbine valves by the turbine EHC (in its effort to prevent turbine overspeed) results in a large increase in steam header pressure.

b. A large header pressure error will be developed and cause actuation of the turbine bypass valves. The opening of these valves removes the excess energy from the RCS. The turbine load status flag being FALSE causes the bias to be zero, so the TBVs control at 885 psig.

c. The turbine control system will cause the turbine master to go to manual, but no tracking will occur because the turbine load status flag is FALSE.

3. Feedwater Control Actions

Feedwater flow will respond to the 20% per minute reduction in feedwater demand caused by the load limit. The reduction in feedwater flow will be tempered by cross limits from the reactor demand subassembly.

4. Reactor Control Actions

   a. The reduction in the reactor demand causes insertion of the regulating rods. Due to the low rod worth at the upper end of group 7, the actual decrease in reactor power will not keep up with the decrease in reactor demand. This will result in reactor cross limit to the feedwater demand subassembly.

   b. The reduction in reactor power continues until the reactor demand signal reaches 20%.

5. Final Conditions

   a. Reactor power is being maintained at 20%.

   b. Turbine bypass valves are dissipating the reactor's energy to the condenser while controlling header pressure at 885 psig.

21.3.4 Reactor Trip

When the reactor trips; the turbine trips. Therefore, the reactor demand subsystem cannot control the regulating rods and the integrated master cannot control the turbine.

1. CTPD Actions

   The reactor trip automatically limits load to 0% and the output of the CTPD decreases at 600% per minute.

2. IM Actions

   The reactor trip biases will be selected for control of the TBVs. As the energy of the RCS is removed by the TBVs, the pressure error will decrease. At the end of the transient, header pressure will be 1010 psig, with the excess energy being dissipated to the condenser by the TBVs.

3. Feedwater Control Actions

   a. When the reactor trip signal is received, a negative loop demand will be input to the valve controllers, causing a rapid reduction in feedwater flow, until level control takes over at 25” (T4 and T5). Feedwater valve and pump controllers will be put in automatic so that feedwater would decrease even if the SG master were in manual.

   b. The main feedwater block valves will close

c. The speed of the main feedwater pumps will decrease to a preset value.

4. Final Conditions

   a. Turbine bypass valves will be dissipating reactor decay heat and reactor coolant pump heat to the condenser by controlling header pressure at 1010 psig.

   b. Steam generators will be on LLL.

21.3.5 Turbine Master in Manual

Initial conditions: The unit is at 50% load, and the turbine master is put in manual. The operator initiates a load decrease to 40%.

1. CTPD Actions

   a. When manual control of the turbine is selected, the ACS goes into tracking. Actual generated MWE becomes the tracking parameter, which is transferred to the feedwater and reactor control subsystems.

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

2. IM Actions

   a. Since the turbine is being controlled by the operator, the signal from the ACS is not sensed by the turbine.

   b. Should header pressure exceed the 885 psig setpoint plus the "normal" bias values (50 psi), TBVs will open.

3. Feedwater Control Actions

   a. As the demand signal from the CTPD 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 Control 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.

21.3.6 Steam Generator Master in Manual

Initial Conditions: The unit is at 75% power, and the operator places the steam generator master in manual and increases its output to a demanded value of 80%.

1. CTPD Actions

   The ACS goes into tracking and will follow feedwater flow. The output or CTPD will follow at a rate of 20% per minute.

2. IM Actions

   The turbine receives the output of the CTPD, which will increase turbine demand. Also, as the turbine header pressure increases because of the actions of the reactor and feedwater control subsystems, the turbine control valves open to return header pressure to the 885 psig setpoint. As the turbine control valves open, load will increase to 80%.

3. Feedwater Control Actions

   Feedwater flow increases to both SGs as it follows the demand from the SG master.

4. Reactor Control Actions

   Reactor control receives the output of the CTPD, which increases reactor demand.

21.3.7 Reactor Master in 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 tracking and also transfers T_{ave} control to the feedwater demand subassembly.

1. Reactor Demand Actions

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

2. IM Actions

   a. The turbine control valves close to restore header pressure to 885 psig.

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

3. CTPD Actions

The output of the CTPD tracks the decrease in reactor power from NIs.

4. Feedwater Demand Actions

a. Feedwater flow decreases to 90% following the decrease in the CTPD output.

b. If a T_{ave} error exists, feedwater demand will be altered to return T_{ave} to 579°F.

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TABLE 21-1 AUTOMATIC LOAD LIMITS AND RATE LIMITS

Condition	Limit	Rate
Loss of an RCP	74% power	25%/minute
Loss of a MFP	65% power	25%/minute
Asymmetric Rod	55% power	1%/minute minimum (may be increased by operator)
RCS Flow	Variable (based on total RCS flow)	20%/minute
Both Generator Breakers Open	20% power	20%/minute
Maximum Runback	15% power	20%/minute
Reactor Trip	0%	600%/minute)
Tracking	None	20%/minute
Both SGs on LLL	None	1%/minute (may be decreased by operator)

TABLE 21-2 Control Variables and Calibrating Integrals

Operating Mode	Control Variable	Calibrating Integral
Normal	T_{ave} THP CTP ΔT_C	Reactor LRM Feedwater ΔT_C
Reactor in manual	T_{ave} THP CTP ΔT_C	Feedwater LRM Control Room Operator ΔT_C
Feedwater in manual	T_{ave} THP CTP ΔT_C	Reactor LRM Control Room Operator Control Room Operator
Turbine in manual	T_{ave} THP CTP ΔT_C	Reactor Feedwater Control Room Operator ΔT_C
Low level limits in both SGs	T_{ave} THP CTP ΔT_C	Uncontrolled LRM and TBVs Reactor Uncontrolled

TABLE 21-3 Turbine Loading Status Flag

<table>
<tr><th>CTP Demand</th><th>Flag</th><th>When Applicable</th><th>Effects</th></tr>
<tr><td>< 10%</td><td rowspan="2">FALSE</td><td>Always</td><td rowspan="2">Turbine cannot take THP control
No MWe tracking
TBVs control at setpoint</td></tr>
<tr><td rowspan="2">10% to 20%</td><td>UNLOAD depressed</td></tr>
<tr><td rowspan="2">TRUE</td><td rowspan="2">LOAD depressed and TBVs zero demand

Always (except load rejection)</td><td rowspan="2">Turbine can take THP control
MWe tracking
TBVs control at setpoint plus 50#</td></tr>
<tr><td>> 20%</td></tr>
</table>

TABLE 21-4 Transfer Functions

T1 - Automatic Load Limits

Overrides the operator's input with a load limit based on the plant condition. Refer to Table 21-1 for a list of plant conditions and corresponding load limits and rates.

T2 - Tracking

Inputs a tracking parameter when the ACS is in tracking. Note that tracking overrides automatic load limits. The tracking rate is 20% per minute.

T3 - Feedwater Control Correction

Selects the parameter to be input to the feedwater integral.

a. Normal - CTP error
b. Reactor in manual - T_{ave} error
c. Reactor in automatic, turbine in manual (turbine load status flag TRUE) - THP error

T4, T5 - Low Level Limit, SG A and B

Transfers feedwater control from flow control to level control.

a. Startup level < 25"
b. Low Level Limits (Startup level < 25" and T_{ave} < setpoint)

T6 - Startup Feedwater Valves Control

Transfers control of startup feedwater valves to level control on a loss of all RCPs. Level setpoint is 50% on the operating range (95% if the reactor building pressure > 3 psig).

T7 - Turbine Bypass Valve Control Error Selector

When the turbine master is in automatic, THP error controls TBVs. When the turbine master is in manual, SG pressure error controls TBVs.

TABLE 21-4 Transfer Functions (continued)

T8 - Turbine Bypass Valve Bias

Selects the proper bias for TBV setpoint based on plant conditions.

a. Reactor trip - setpoint + 125 psi
b. Turbine load status flag TRUE - setpoint + 50 psi
c. Turbine trip or turbine load status flag FALSE - no bias

T9 - Condenser Vacuum Interlock

Prevents automatic operation of TBVs when condenser vacuum < 7”.

T10 - Reactor Control Correction

Selects the parameter to be input to the reactor integral.

a. Normal - T_{ave} error
b. Both SGs on LLL - CTP error
c. Steam system unavailable while both SGs on LLL - THP error

T11 - Maneuvering Rate

Determines the rate of change of CTP demand for automatic load limiting, tracking, and other plant conditions.

a. Automatic load limiting - as shown in Table 21-1
b. Tracking - 20% per minute
c. LLL - 1% per minute
d. Reactor trip - 600% per minute

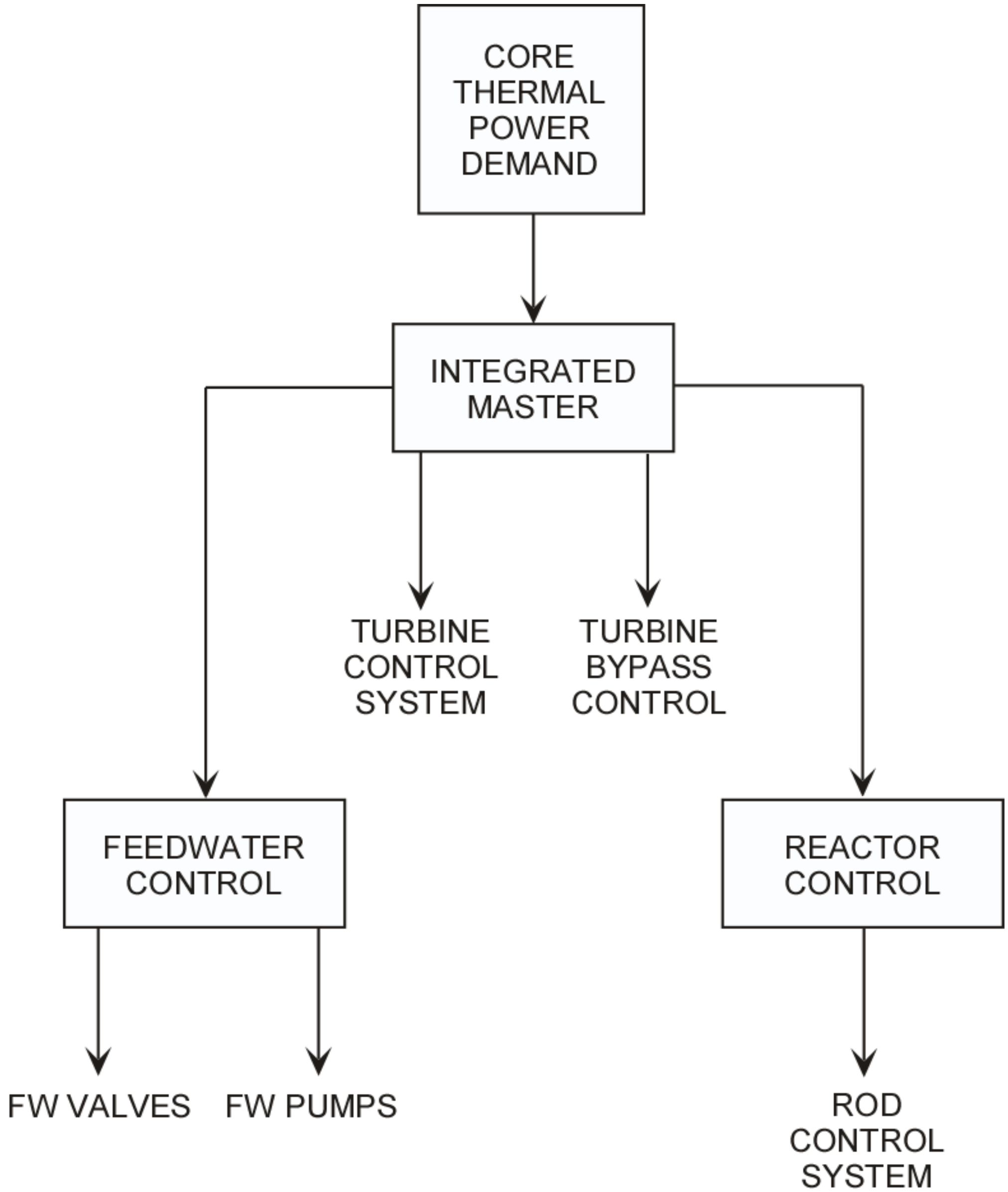

Figure 21-1 ACS Block Diagram

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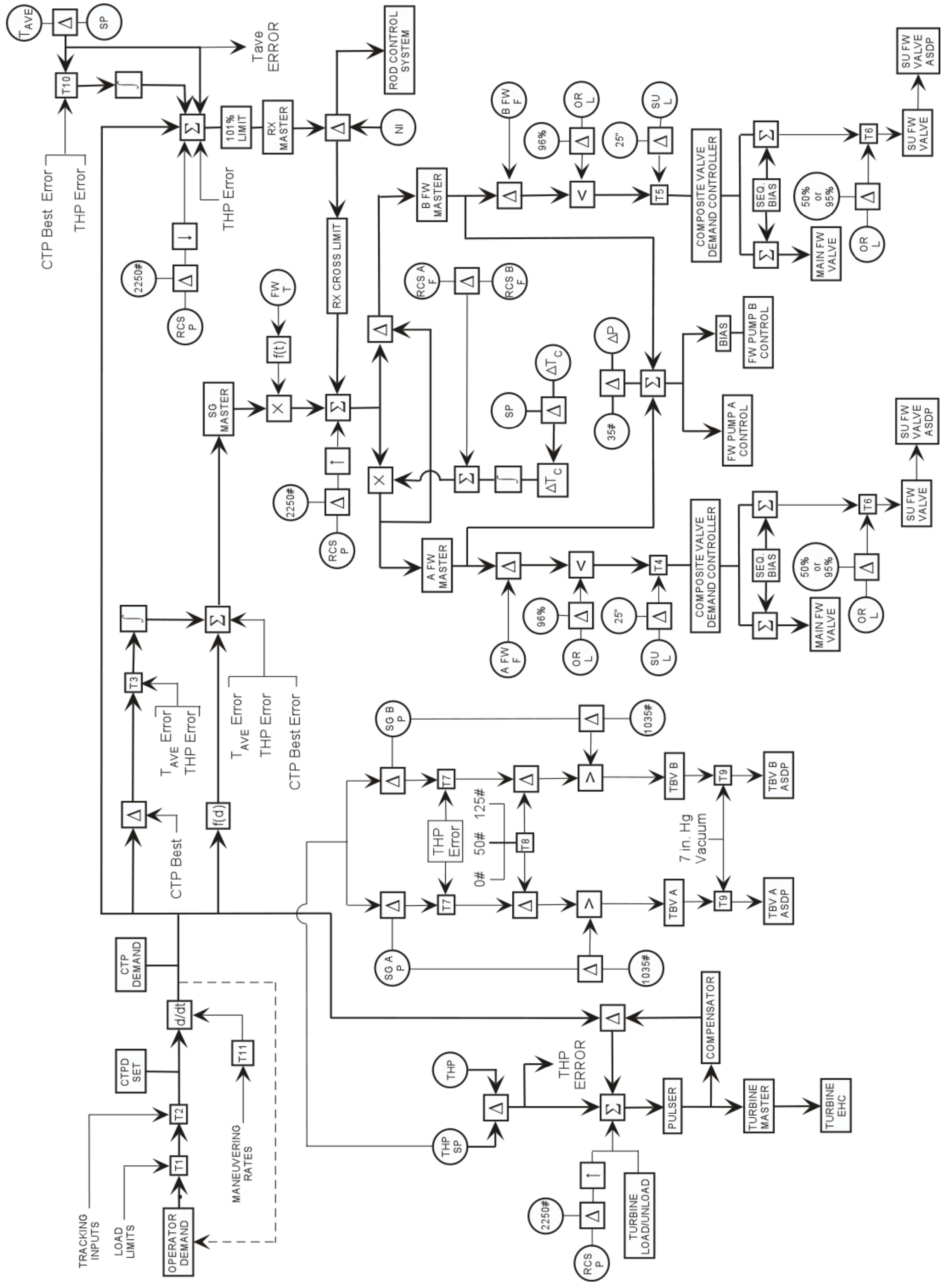

Figure 21-2 Advanced Control System

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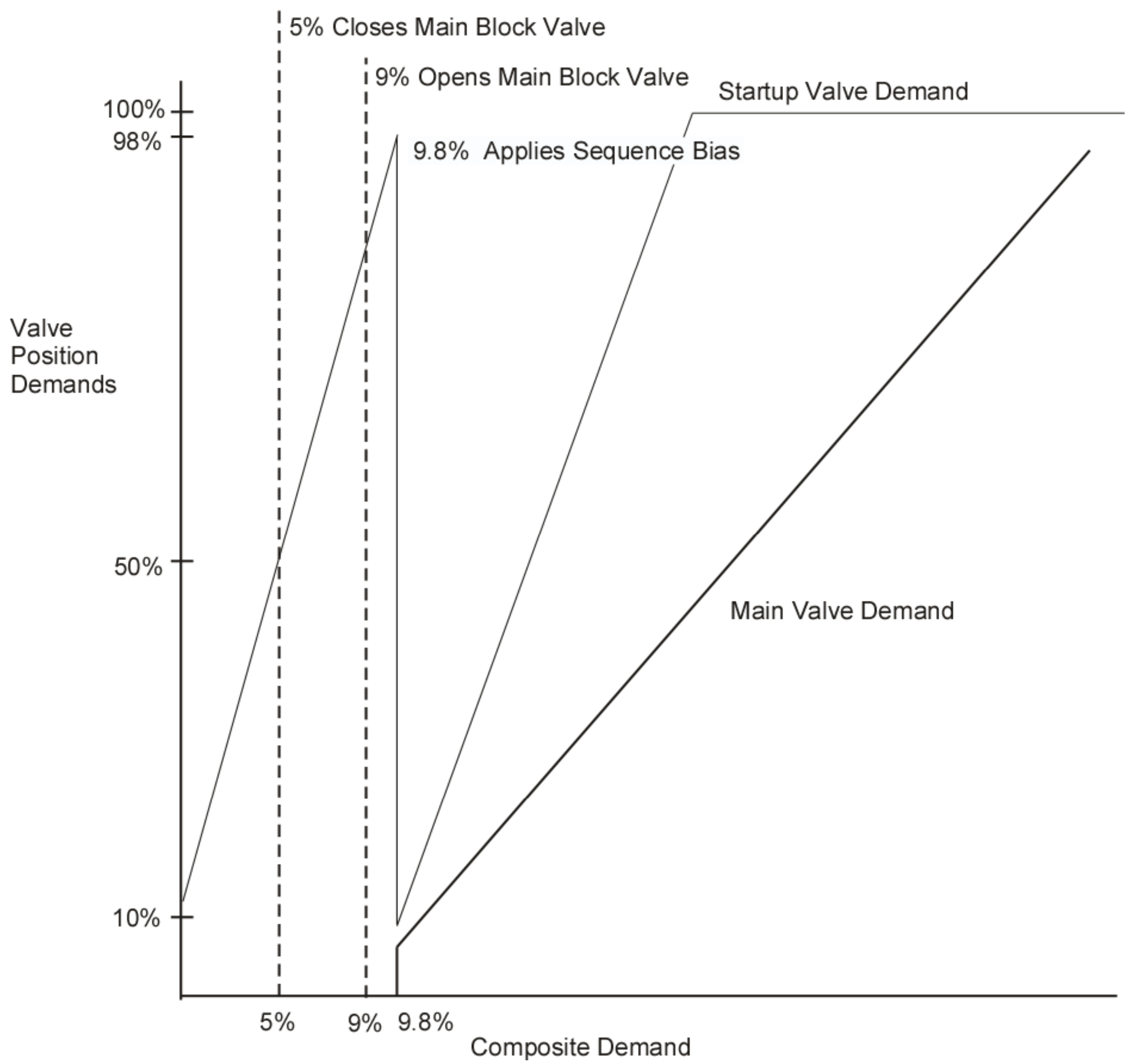

Figure 21-3 Feedwater Valve Operations

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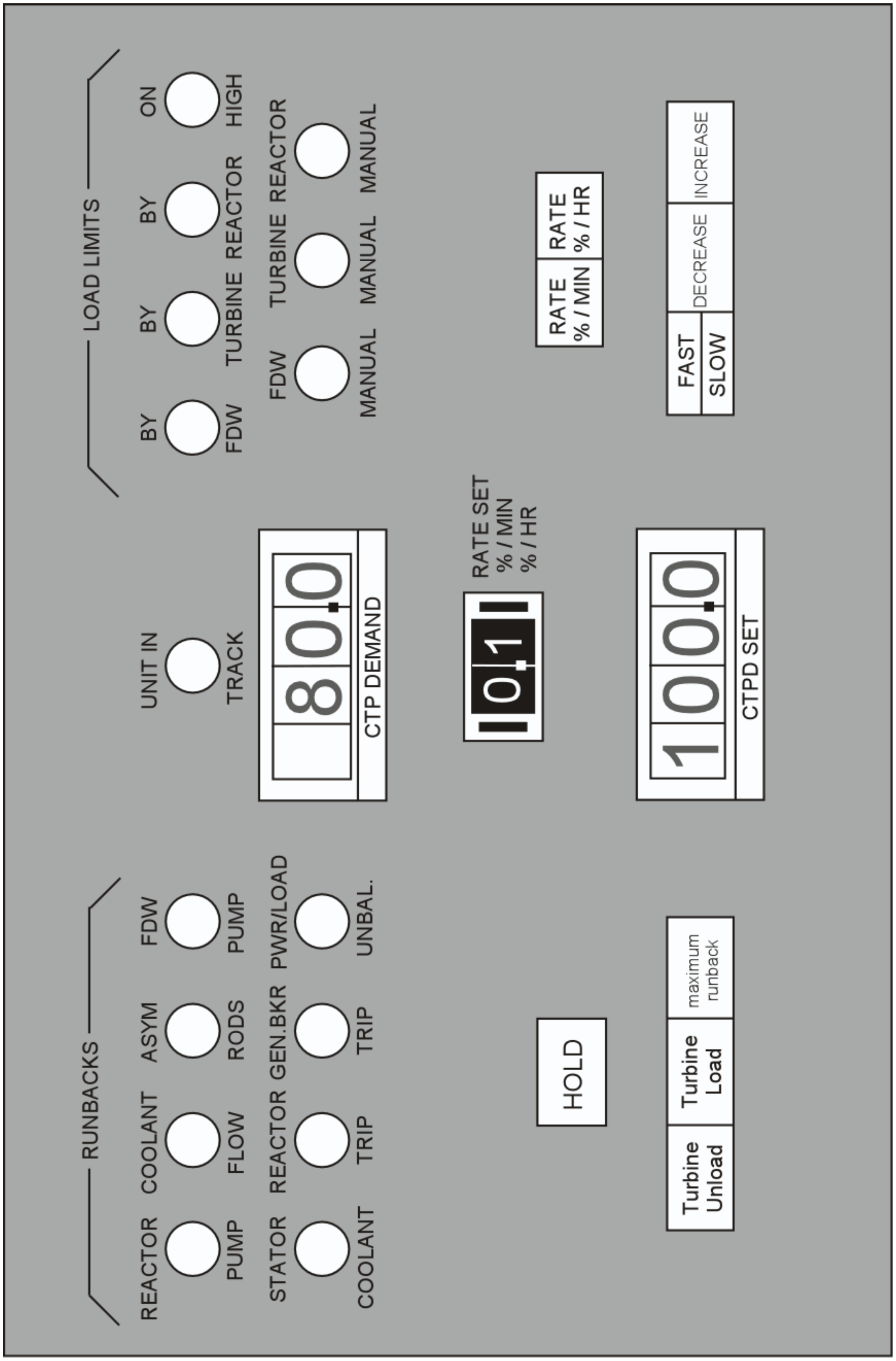

Figure 21-4 Load Control Panel

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