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2.3.0 Turbine Impulse Pressure Channel Functions

Learning Objectives:

1. List the protection system inputs provided by the turbine impulse pressure channels.
2. List the control signals provided by both channels of turbine impulse pressure.
3. Explain the plant response for a given scenario involving the failure of a turbine impulse pressure channel.

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2.3.1 Introduction

The Westinghouse design makes extensive use of signals derived from steam pressure measured in the first stage (impulse stage) of the high pressure turbine. This pressure, known as impulse pressure (P_{imp}), increases linearly as the turbine-generator load increases. Impulse pressure thus provides an indication of the secondary plant load on the primary. Because the P_{imp} signals are used in control and protection systems, the failure of an impulse pressure channel can have a significant impact on the plant. Without operator intervention, the failure of a P_{imp} channel could cause a transient that would result in a reactor trip and/or engineered safety features actuation.

Figure 2.3-1 shows three pressure instruments measuring steam pressure in the first stage of the high pressure turbine. The pressure in the turbine varies from condenser pressure at no load to approximately 610 psig at full load. The pressure signals are converted to equivalent electrical signals and supplied to various control and protection systems. Table 2.3-1 lists the functions of two of the three channels, PT-505 and PT-506. The third of the three pressure channels shown on Figure 2.3-1 (PT-3529) supplies signals exclusively to the turbine electrohydraulic control (EHC) system and is not discussed in this section. The inputs supplied by and the effects of failures of channels PT-506 and 505 are discussed in the following paragraphs.

2.3.2 Control System Inputs

2.3.2.1 PT-506

PT-506 supplies an input to the circuit that generates the C-7 loss of load interlock. The C-7 interlock arms the steam dump system (see Figure 2.3-2) if impulse pressure decreases in excess of 5% per minute or a 10% step. The C-7 interlock seals in and must be reset at the steam dump control section of the main control board to remove the arming signal. When selected, PT-506 also supplies an input to the steam generator level program generator. The selector switch is normally selected to PT-505.

2.3.2.2 PT-505

The control functions of channel PT-505 include (1) an input to the desired T_{avg} (T_{ref}) program generator, (2) an input to the rod control system power mismatch rate comparator, (3) an input to the rod control system variable gain unit, (4) an input to the C-5 interlock for the automatic rod withdrawal block below 15% power, and (5) an input to the steam generator water level program generator.

T_{ref} is programmed to increase from its no-load to its full-load value as the plant load is increased from 0 to 100%. The P_{imp} signal is supplied to the T_{ref} program generator for the generation of an equivalent temperature signal that is used by the steam dump and rod control systems (see Figures 2.3-2 and 2.3-3) as a reference signal. The rod control system also uses the P_{imp} signal in the power mismatch circuit (1) as a direct indication of secondary plant load for comparison to nuclear power in the rate comparator and (2) as an input to the variable gain unit that modifies the output of the rate comparator. The C-5 interlock ensures that the rod control system is operated in manual at low loads, where P_{imp} is not reliable as an indication of power.

PT-505 is normally selected to supply an input to the steam generator level program generator for the generation of a reference level to be used by the steam generator water level control system. At some plants the steam generator level setpoint is not varied, so the output of the program generator is set to a constant value.

2.3.3 Protection System Inputs

Impulse pressure channels PT-506 and 505 also provide inputs to the reactor protection system (RPS), engineered safety features actuation system (ESFAS), and ATWS mitigation system actuation circuitry (AMSAC). At first it might appear unacceptable to provide an input to the RPS that is derived from a control-grade instrument. The impulse pressure detectors and the majority of the hardware associated with the instrument loops are located in a non-seismically qualified area of the plant and cannot meet any of the requirements for protection-grade equipment. Westinghouse has justified the use of the signal by demonstrating that any failure of a P_{imp} instrument does not reduce the protection provided by the associated protective feature. This concept is discussed in more detail in section 2.3.4. A requirement for any instrument that supplies signals to both protection- and control-grade systems is that the outputs must be separated by isolation amplifiers (I/As). This feature prevents failures in the control systems from propagating into the protection systems and causing undesirable responses.

2.3.3.1 PT-506

Channel PT-506 supplies an input to permissive P-13, the turbine at-power permissive. The P-13 permissive is one of two inputs to permissive P-7, which automatically disables the at-power reactor trips (the low pressurizer pressure, high pressurizer level, and loss of reactor coolant system flow trips, and the reactor trip on turbine trip at some plants) below 10% power and reinstates them above 10% power (see Figure 2.3-4). The PT-506 input to the P-13 permissive logic is lost when impulse pressure decreases below 10%. The loss of both turbine impulse pressure channels removes the P-13 input to P-7. The second input to permissive P-7 is permissive P-10, which is derived from the excore power range signals. The P-13 permissive light on the main control board is illuminated as long as both turbine impulse pressure channels are below 10% and is extinguished when one pressure channel increases above 10%. The P-7 permissive light is illuminated as long as both turbine and nuclear power remain below 10% and is extinguished when either goes above 10%.

Channel PT-506 also provides an input to the high steam line flow ESFAS setpoint generator for protection channel II. At some plants the high steam flow ESF actuation signal (see Figure 2.3-5) initiates an ESF actuation after a steam line break of sufficient severity. The high steam flow setpoint varies with the value of impulse pressure. The setpoint is 1.4×10^6 lbm/hr from no load to 20% load, and it increases linearly to 110% of full-power steam flow at 100% power. Each main steam line has two steam flow detectors. The flow signal from one of the two detectors on each of the steam lines is compared to the setpoint from the channel II setpoint generator, and a bistable is tripped if the flow exceeds the setpoint. If a flow exceeding the high steam flow setpoint is sensed by either detector in at least two main steam lines, part of the logic necessary for an ESF actuation is satisfied. An ESF actuation is initiated when the high steam flow signal is coincident with

either T_{avg} below the permissive P-12 (low-low T_{avg}) setpoint (553°F) or main steam pressure below 600 psig.

Channel PT-506 supplies an input to the AMSAC logic for starting auxiliary feedwater pumps and for tripping the turbine when conditions indicative of an ATWS are present. The AMSAC logic is satisfied when at least three steam generator narrow range levels are less than the low-low level setpoint and both turbine impulse pressure channels (PT-505 and PT-506) exceed 40%.

2.3.3.2 PT-505

The protection-grade inputs provided by channel PT-505 are completely analogous to those provided by channel PT-506. A redundant input to permissive P-13 is provided by channel PT-505. Also, the channel I high steam flow ESFAS setpoint generator receives its input from channel PT-505; it provides a setpoint for comparison to the signal from one steam flow detector on each steam line. Additionally, channel PT-505 supplies a second turbine power input to the AMSAC logic, as described above.

2.3.4 Channel Failures

A channel failure can be caused by the loss of power, the application of high voltage, an open circuit, a short circuit, or a physical malfunction in the detector itself. The following paragraphs consider only the effects of a signal from a failed channel going to its minimum or maximum value. A failure could cause the signal to go to some intermediate value, but this type of failure is not discussed because of the large number of possible outcomes. Each failure is assumed to occur at 100% power.

2.3.4.1 PT-506 Fails High

If PT-506 fails high, there is no immediate effect on the permissive P-13 logic. Since the initial plant load already exceeds 10%, there is no change in the P-13 status when the signal goes to maximum. If the unit were to be shut down following the failure, the P-13 input to permissive P-7 could not be removed, and therefore P-7 would not automatically block the at-power trips when all other inputs to P-7 are less than 10% power.

In addition, the high steam line flow ESFAS setpoint for protection channel II goes to its maximum value. Since the plant is already at 100% power, there is no effect on the setpoint. If the failure were to occur at a lower power level, the setpoint would be increased to a value that is farther from the actual steam line flow. This would appear to be a non-conservative failure. Westinghouse has demonstrated that protection is provided even for steam breaks at lower power levels with the high flow setpoint at 110% of rated steam flow.

The failed-high instrument has no immediate effect on the steam dump control system, because the C-7 interlock is generated only by a negative change in load. If a load reduction were to occur after the failure, the steam dumps could not be armed because the output of channel PT-506 would not respond to the actual impulse pressure decrease.

2.3.4.2 PT-506 Fails Low

If channel PT-506 fails low, its input to the permissive P-13 logic would be lost, but the P-13 input to P-7 remains intact because the output of the other turbine impulse pressure channel is still above 10%.

Also, the high steam line flow ESFAS setpoint for protection channel II decreases to its minimum value, causing the channel II high steam line flow bistables to trip (this will happen with any initial power level greater than 40%). An ESF actuation does not occur because T_{avg} and steam pressure remain at their normal full-power values; the high steam flow ESF actuation logic is not completely satisfied.

The steam dump system is armed by the C-7 interlock, but the steam dump valves remain closed because there is no temperature error present. This failure illustrates one reason why the high steam line flow ESF actuation signal and the steam dump control system are designed with coincidence features. A single failure cannot cause an ESF or steam dump actuation.

If plant power is > 40%, AMSAC will "disarm" after a 6 minute delay (see figure 4.7-4). Both PT-505 and PT-506 must be above 40% to enable AMSAC response. After either channel drops below 40% a timer holds the arming signal for an additional 6 minutes. After the timer elapses, AMSAC is not functional until operator action is taken at the AMSAC panel.

2.3.4.3 PT-505 Fails High

If channel PT-505 fails high, the effects on the channel I protection features (permissive P-13 and the high steam line flow ESFAS setpoint) are the same as those associated with a PT-506 failure (section 2.3.4.1).

The effects on the control systems are more pronounced. The T_{ref} program generator generates a reference temperature of 584.7°F (desired full-power T_{avg}). With the unit already at full load, the channel failure has no effect, but at lower loads it would cause control rods to be withdrawn because T_{avg} would be less than T_{ref}. The P_{imp} input to the rod control system power mismatch circuit causes outward rod motion. The maximum signal from the failed channel is equivalent to 120%; therefore, even with an initial power of 100%, a difference in the rate of change exists between impulse pressure and auctioneered high nuclear power (the channel is assumed to fail to 120% instantaneously). The rods move out until the power mismatch signal decays to zero (the rate comparator provides an output when there is a changing difference between primary and secondary power), after which the rods adjust reactor power until T_{avg} equals T_{ref}. Outward rod motion likely would be limited by one of several rod stops (overtemperature and overpower ΔT, high nuclear power, and interlock C-11, which stops control bank D withdrawal at 223 steps); a rod stop would probably stop outward rod motion before the rate comparator signal completely decays off.

During a plant shutdown following the channel failure, the C-5 interlock would not actuate even though the actual impulse pressure would decrease, so there would be no block of automatic rod withdrawal below 15% load.

The steam generator level setpoint goes to its maximum value (44%) as a result of the failure, but with the plant load above 20%, the setpoint is already at its maximum value. The channel failure thus has no effect on steam generator water levels.

2.3.4.4 PT-505 Fails Low

If channel PT-505 fails low, the effects on the channel I protection features (permissive P-13 and the high steam line flow ESFAS setpoint) are the same as those associated with a PT-506 failure (section 2.3.4.2).

The effects on the control systems are more significant. Because PT-505 is failing to its minimum value, the C-5 interlock is actuated, and automatic rod withdrawal is blocked. Rod withdrawal in manual is not affected.

The steam generator water level program generator reduces the level setpoint to its minimum value (33%). Feedwater flow decreases until the steam generator levels decrease to the new setpoint.

T_{ref} is reduced to its no-load value (557°F). A temperature error (T_{avg} - T_{ref}) is input to the steam dump system and the rod control system (T_{avg} is greater than the failed-low T_{ref}). Both T_{avg} mode controllers in the steam dump control system have maximum demands, but the steam dump valves do not open because there is no arming signal. If they become armed or another failure occurs, the steam dump valves would open.

The channel failure has a dual affect on the rod control system. The temperature error (T_{avg} greater than T_{ref}) causes inward rod motion. In the power mismatch circuit, there is a large rate of change in P_{imp} with respect to the stable excore nuclear power input. The rate comparator thus also calls for inward rod motion. The result of the inward rod motion is a decrease in nuclear power. T_{avg} decreases because the rate of energy removal from the primary system in the steam generators exceeds the rate of energy production by the reactor. Because it is unaffected by the failed impulse pressure channel, the turbine EHC system attempts to maintain the original load on the turbine (assuming impulse pressure feedback as an input to the turbine EHC system). Inward rod motion stops when the power mismatch signal decays to zero, but before it does, there are significant reductions in T_{avg}, pressurizer level, pressurizer pressure, and steam pressure. During the transient T_{avg} probably decreases to a value lower than the no-load T_{ref}, but the C-5 interlock prevents rod withdrawal. With the large mismatch between primary and secondary power, T_{avg} will likely continue to decrease until a reactor trip occurs. The possible causes of a trip are (1) low pressurizer pressure and (2) a high steam line flow ESF actuation (the high steam line flow bistables are tripped because of the channel failure, and T_{avg} or steam pressure might decrease below its setpoint).

This failure has the same effect on AMSAC as the low failure of PT-506, discussed in paragraph 2.3.4.2.

2.3.5 Operator Response

Each failure description discussed above assumes no operator response to terminate the subsequent plant transient. To determine the proper response and to preclude an unnecessary reactor trip, numerous indications and alarms are available to the operator in the control room. The resulting transient from each of these failures is slow enough that a trained operator would have sufficient time to detect and terminate it.

The initial operator response would be to verify that there is no valid need for rod motion (e.g., a reduction in turbine load) and then to take manual control of the rod control

system. The operator would then scan the main control board for failed inputs to the rod control system. During this time the operator would reposition the control rods to maintain T_{avg} at its programmed value for the existing load. At some plants the non-failed channel of impulse pressure can be selected as the input to the T_{ref} program generator for the rod control system. If this is the case, then once the operator has selected away from the failed channel and T_{avg} has been adjusted to the correct value, the operator can put the rod control system back in automatic. If the operator is unable to select away from the failed channel, then the control rods must be operated in manual until the failed channel is repaired.

TABLE 2.3-1 Turbine Impulse Pressure Functions

PT-505	PT-506
Protection	Protection
1. Input to P-13 (turbine at-power) permissive (protection channel I)	1. Input to P-13 (turbine at-power) permissive (protection channel II)
2. Input to high steamline flow ESFAS setpoint generator (protection channel I)	2. Input to high steamline flow ESFAS setpoint generator (protection channel II)
3. Input to AMSAC	3. Input to AMSAC
Control	Control
1. Generates T_{ref} signal for rod control system temperature mismatch circuit and steam dump loss of load controller	1. Provides arming signal for steam dump control system (C-7 loss of load interlock)
2. Input to rod control system power mismatch circuit rate comparator	2. Generates reference level for steam generator water level control system when selected (normally not selected)
3. Input to rod control system variable gain unit	
4. Input to C-5 interlock, which blocks automatic rod withdrawal when turbine load less than 15%	
5. Generates reference level for steam generator water level control system when selected (normal)	

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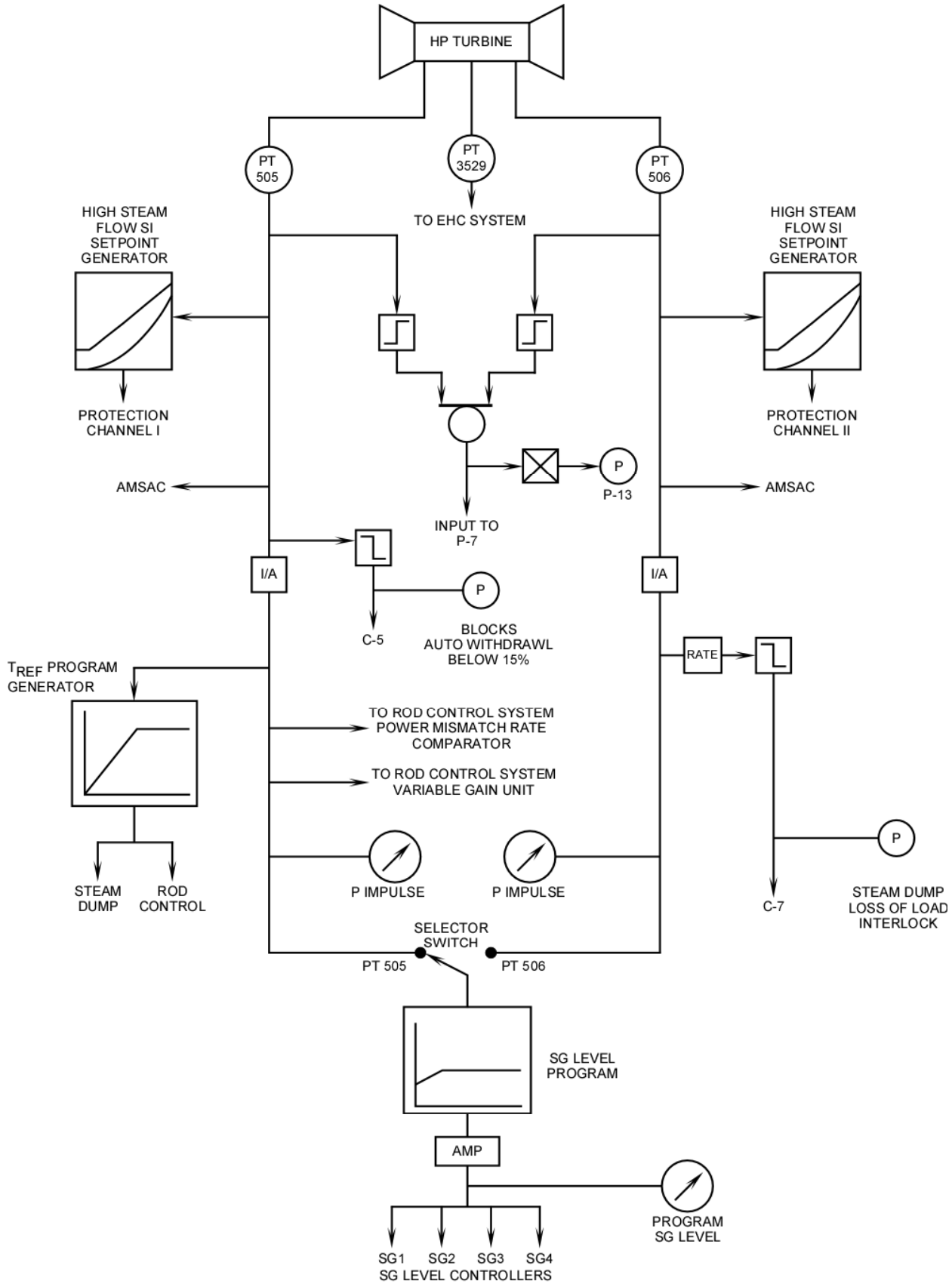

Figure 2.3-1 Turbine Impulse Pressure Functional Diagram

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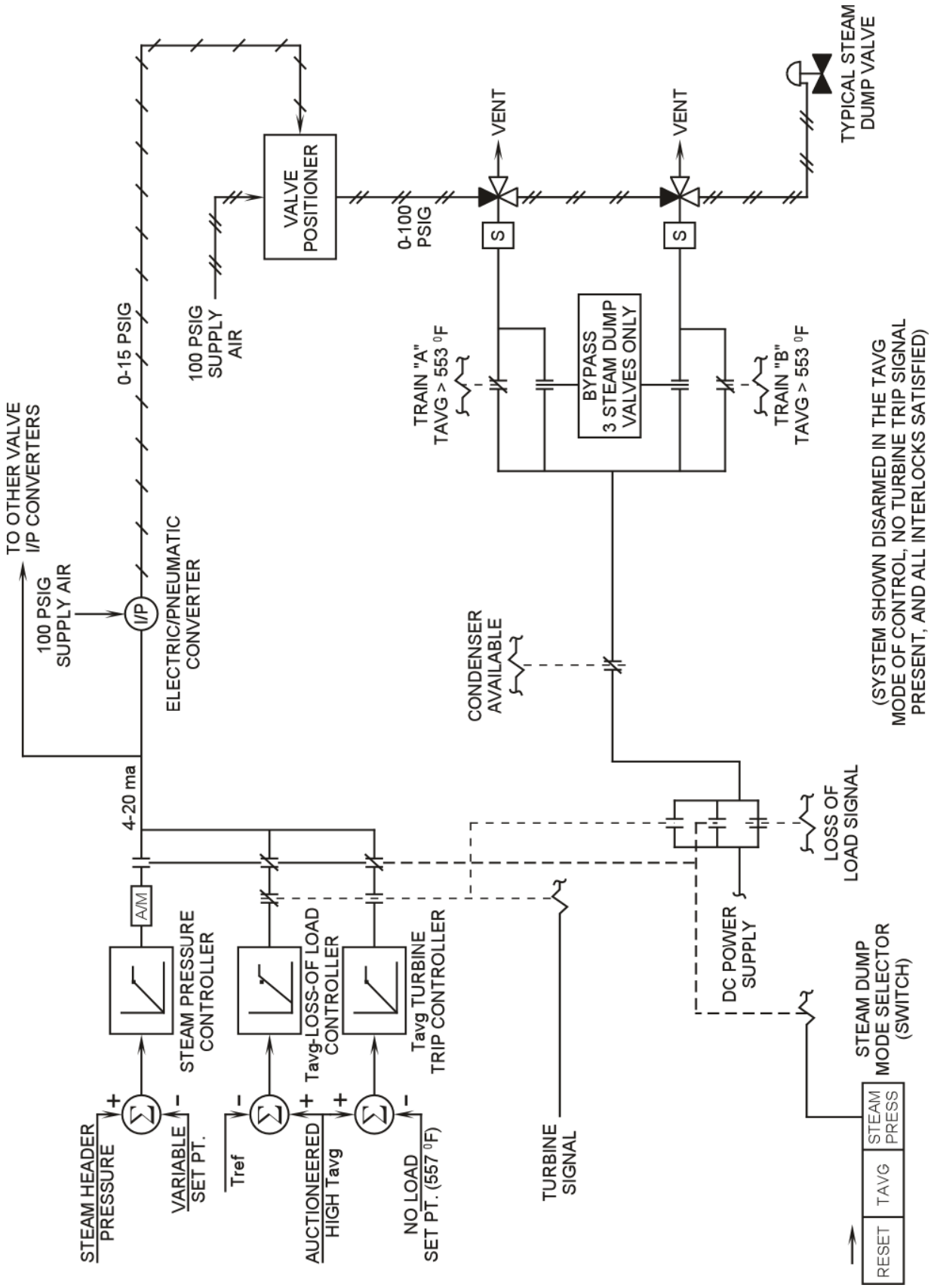

Figure 2.3-2 Steam Dump Control System

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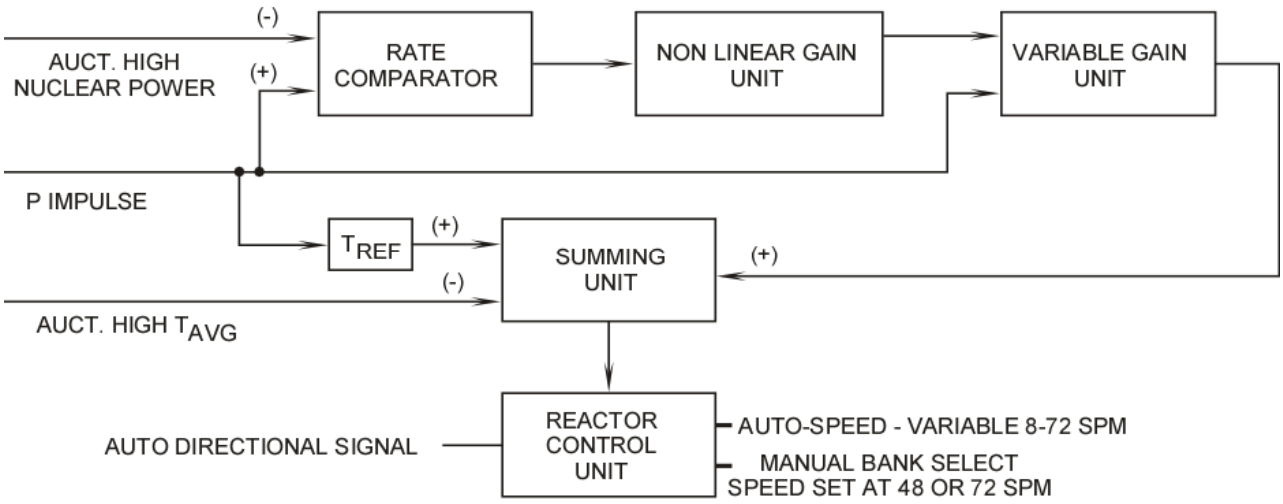

Figure 2.3-3 Rod Control Automatic Demand

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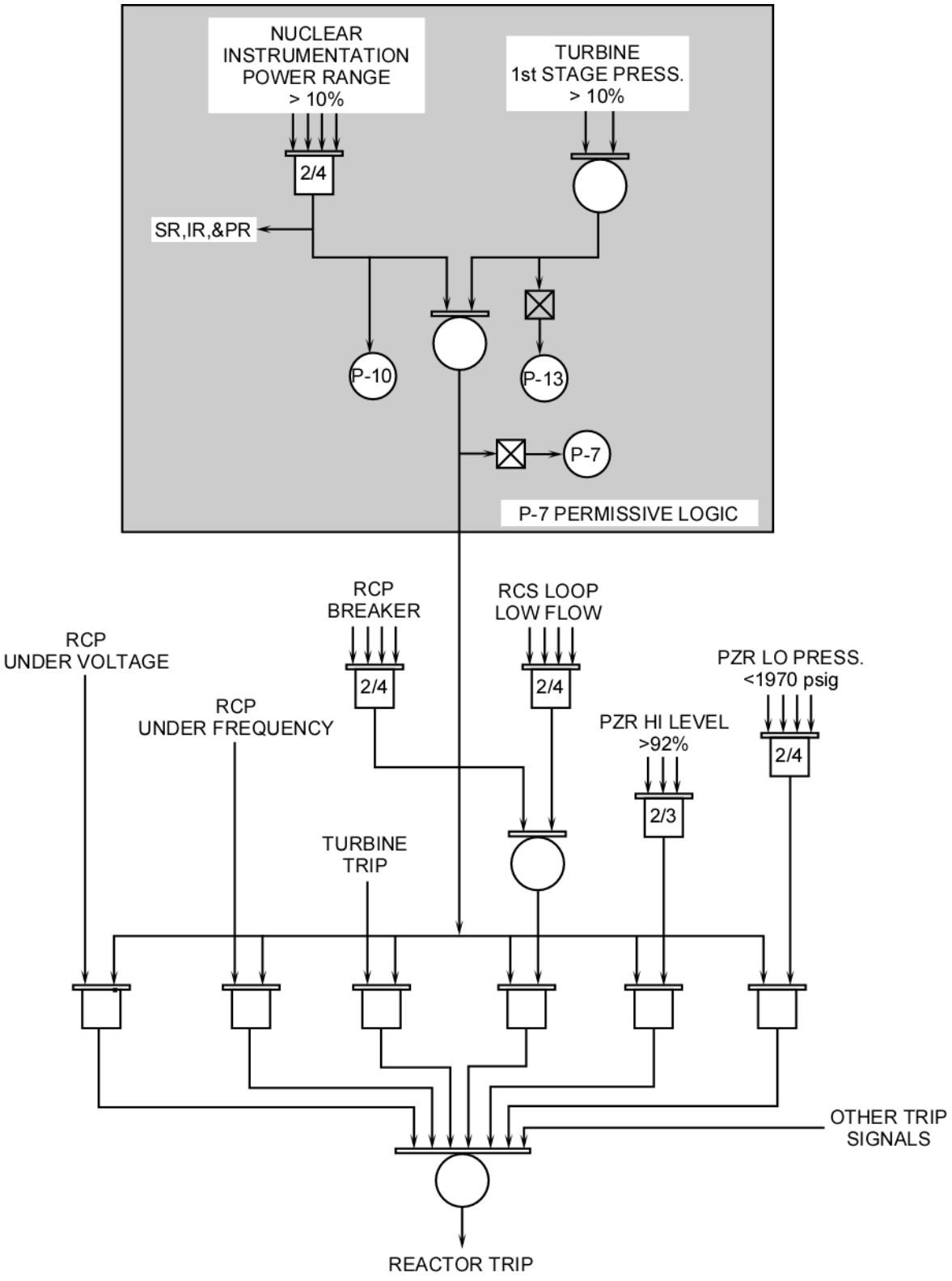

Figure 2.3-4 At-Power Reactor Trip Logic

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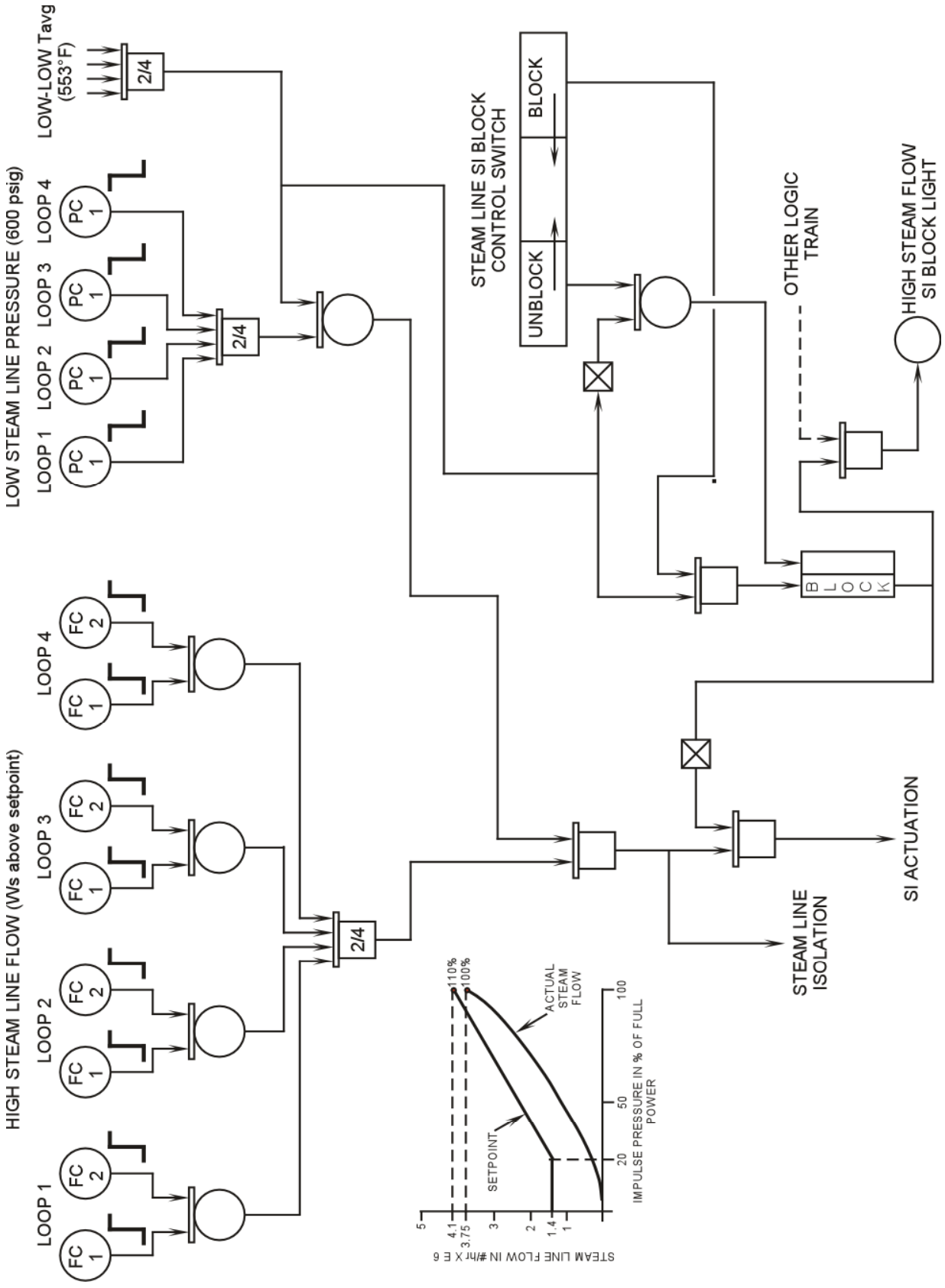

Figure 2.3-5 Hi Steamflow ESF Actuation Logic

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