General Electric Systems Technology Manual

Chapter 3.2

Electro Hydraulic Control System

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

3.2 ELECTRO HYDRAULIC CONTROL SYSTEM

Learning Objectives:

1. Recognize the purposes of the Electro Hydraulic Control (EHC) system.

2. Recognize the significance of reactor pressure control to boiling water reactor operation

3. Evaluate how the system operates to adjust turbine load in response to reactor power changes.

4. Recognize the relationship between reactor vessel pressure, turbine inlet pressure and pressure setpoint.

5. Recognize the purpose of the following limiters:
   a. Load Set
   b. Load Limit
   c. Maximum Combined Flow

6. Recognize the purpose, function and operation of the following EHC system subsystems:
   a. Pressure Control Unit
   b. Speed Control Unit
   c. Desired Load Control Unit
   d. Valve Control Unit
   e. Hydraulic Power Unit

7. Given Figure 3.2-1, evaluate how the system accomplishes the following:
   a. Normal steady state power operations
   b. Power maneuvering
   c. Plant shutdown and cooldown

8. Recognize how the Electro Hydraulic Control system interfaces with the following systems:
   a. Main Steam System (Section 2.5)
   b. Condensate and Feedwater System (Section 2.6)
   c. Reactor Protection System (Section 7.3)
   d. Turbine Building Closed Loop Cooling Water System (Section 11.5)

3.2.1 Introduction

The purposes of the EHC System are to:

- provide normal reactor pressure control by controlling steam flow consistent with reactor power
- control reactor pressure during startup, heatup, and cooldown evolutions,
- control the speed and electrical load on the turbine generator,
- provide protection for the main turbine, main generator and main condenser.

The functional classification of the EHC System is that of a power generation system.

Because a boiling water reactor operates as a saturated system, pressure changes can have a pronounced effect on reactor power. If pressure is increased in a BWR during power operation, steam voids, which contribute significant negative reactivity to the core, collapse, increasing core moderator density. This increase in moderation results in more thermal neutrons being available for the fission process increasing reactor power. As reactor power increases, pressure increases even further, and a "snowball effect" occurs. If reactor vessel pressure decreases, some of the moderator flashes to steam. This flashing increases the void content in the reactor core resulting in negative reactivity and a reduction in reactor power. This reduction decreases reactor pressure even further.

Because of the effects mentioned above, a pressure control system was developed in which reactor power is first changed, followed by a change in turbine generator output. An increase in reactor power causes an increase in both reactor vessel and turbine throttle pressure (Figure 3.2-6). This pressure increase is due to the increased heat generation by the reactor core producing more steam without a subsequent increase in steam flow rate. The throttle pressure increase is sensed by the pressure control system. The pressure control system signals the Turbine Control Valves (TCVs) and/or ByPass Valves (BPVs) to open wider, accommodating the increased steam production. This increase in turbine steam flow compensates for the reactor vessel pressure rise, and increases generator output.

Reducing reactor power decreases reactor vessel pressure and turbine throttle pressure (Figure 3.2-6). The pressure control system responds to the decrease in throttle pressure by throttling the TCVs and/or BPVs decreasing turbine steam flow. Reducing steam flow stops the steam pressure decrease and lowers generator output. Using this control system, the turbine follows or is "slaved to" the reactor.

The EHC System has both electronic and hydraulic parts. The main EHC System control logic, shown in Figure 3.2-1, positions the TCVs and BPVs to control the turbine inlet pressure, as indicated in Figure 3.2-2 and 3.2-6, and hence the reactor pressure. The operator controls and indications for the EHC System can be seen in Figure 3.2-3.

In addition to normal pressure control, the EHC System also contains the electronic and hydraulic components necessary for positioning of the intercept (control valve) portion of the Combined Intermediate Valves (CIVs) and trip control of the TCVs, the intercept portion of the CIVs, Turbine Stop Valves (TSVs), and the stop valve portion of the CIVs. The EHC System hydraulic power unit is shown in Figure 3.2-4 while the various fluid supplies are shown in Figure 3.2-5. Figure 3.2-6 shows the arrangement of the Main Steam System with respect to the EHC System.

3.2.2 Component Description

The major components of each Electro Hydraulic Control System are discussed in the paragraphs which follow.

3.2.2.1 Pressure Control Unit

The Pressure Control Unit subsystem is part of the main EHC System logic and is shown in the lower left of Figure 3.2-1 and in Figure 3.2-1a. There are two pressure regulators, A and B. The pressure regulators are proportional type controllers, which require a 30 psi difference between steam throttle pressure and the pressure setpoint (pressure error) to open the TCVs to the 100 percent steam flow position. The pressure at the steam throttle (turbine inlet) varies 30 psi from 0 percent steam flow to 100% steam flow, or 3.33% flow/psi. This is shown in Figure 3.2-2. Also shown is a curve of reactor vessel pressure. This curve is not linear because of the pressure drops across the flow restrictors, MSIVs, and steam line piping which are proportional to the square of the flow.

The relationship between pressure error and steam flow was determined by experimentation and gives a rapid response which is relatively stable. The pressure regulators compare the steam throttle pressure with the pressure setpoint (normally set at 920 psi) and generates a valve position demand based on the difference. If steam throttle pressure is less than or equal to the pressure setpoint, the TCVs and BPVs receive a closing demand signal from the Pressure Control Unit and remain closed.

Each pressure regulator, A or B, has two summers associated with it. The first summer for each pressure regulator receives the pressure setpoint signal (adjustable by increase and decrease pushbuttons) and a bias signal and algebraically sums them together. The bias signal for the A regulator is 0 psig while the bias signal for the B regulator is +3 psi. This places the A regulator in control and the B regulator in standby. The outputs of these first summers are sent to another set of summers where the steam throttle pressure signals are added to this negative value. The outputs of these second two summers are then sent to a High Value Gate (HVG) which passes only the highest positive value of its two inputs. The signal from the A regulator is normally 3 psi greater than the signal from the B regulator because of different bias inputs. The output of the HVG is directed to the pressure to percent flow gain amplifier. Here the pressure error signal is converted to an equivalent percent steam flow demand signal. The gain of this amplifier is 3.33% steam flow for each 1 psi pressure error. The output of this amplifier is two of the inputs to the Valve Control Unit used for TCV and BPV positioning.

3.2.2.2 Speed Control Unit

The Speed Control Unit subsystem is shown in the upper left of Figure 3.2-1 and in Figure 3.2-1c. It receives two turbine speed signals from the shaft speed pickups and compares them to an operator chosen speed reference signal to produce two speed error signals. The Speed Control Unit differentiates one of the speed signals to produce an acceleration signal. This is compared to an operator chosen acceleration reference signal. The acceleration error signal is then integrated and sent to a Low Value Gate (LVG) which passes only the lowest value of its three inputs (2 speed errors and 1 acceleration error) to produce two outputs. One output is applied to a 1.11%/RPM gain amplifier. This amplifier's output is one of the inputs to the Desired Load Control Unit for startup and overspeed control. The other gain amplifier applies a 2.77%/RPM output to the intercept portion of the CIVs for turbine overspeed control. The speed and acceleration setpoints are selected by the operator using pushbuttons. This Speed Control Unit is primarily used for initial turbine startup to rated speed.

During normal power operations when the turbine generator is synchronized to the electrical grid, turbine speed is controlled by electrical grid frequency which is nominally at 60 cycles/second (1800 rpm). Normal minor variations in grid frequency have no effect on TCV positioning. Large changes in grid frequency (grid instability) or large reductions in generator load have the potential of overspeeding the turbine. In this case, the output of the Speed Control Unit can affect both TCV and Intercept Valve positions.

3.2.2.3 Desired Load Control Unit

The Desired Load Control Unit subsystem is shown in the upper right of Figure 3.2-1 and on Figure 3.2-1d. The major part of the Desired Load Control Unit subsystem is the load set motor. The position of this motor is used to compute the final value of desired load called the Load Set reference value. The purpose of the Load Set reference is to protect the main generator from excessive loading, depending on conditions. Once the load set motor has been moved one way or the other and stopped, the load set remains constant until such time as the load set motor is again moved. The operator can control the position of the load set motor by using the load selector increase or decrease pushbuttons.

The load set motor has a runback circuit which energizes the motor, under certain conditions, to run the load reference value down to zero. A runback to zero will occur any time synchronous speed (1800 rpm) is not the speed selected by the operator. This ensures that the Speed Control Unit controls the turbine acceleration rate on a turbine roll. Another condition which causes a runback is the load reject circuit.

The load reject circuit senses turbine power by measuring HP turbine exhaust pressure (crossover pressure) and generator load (stator amps). Whenever the load reject circuit sees a mismatch of $\geq$40%, a load rejection has occurred. The load set motor will run back towards zero as long as the mismatch exceeds 40%. This feature gives an electronic follow up close signal to the TCVs which are also hydraulically closed by the load reject circuitry via fast acting solenoids.

Finally, a loss of stator cooling signal will also cause the runback circuit to be activated. This runback is actuated by low inlet water pressure (<13 psig) or high outlet water temperature (>95ºC) in the Stator Cooling Water System. The loss of stator cooling signal insures proper cooling is available to cool the generator stator by causing a runback to <25% generator load as measured by stator amps.

The load set value is always summed with any signal which may be coming from the Speed Control Unit. The resultant output signal is a speed/load control signal that is sent to the Valve Control Unit.

There is also a line speed matcher circuit with the Desired Load Control Unit. When selected, it positions the load set motor to adjust turbine generator speed to synchronize the generator frequency with that of the grid. The operator must manually close the main generator output breaker to complete paralleling to the grid.

3.2.2.4 Valve Control Unit

The Valve Control Unit subsystem is shown in the lower right of Figure 3.2-1 and on Figure 3.2-1b. The Valve Control Unit subsystem establishes the steam flow demand signals to the TCVs and to the BPVs. An integral part of the Valve Control Unit is the pressure/load LVG. The pressure/load LVG receives signals from the Pressure Control Unit, the Desired Load Control Unit, the Load Limiter, the Maximum Combined Flow Limiter and the turbine trip logic. The values of the Load Limit and the Maximum Combined Flow Limit are determined by manual potentiometers. The Load Limit value establishes the maximum amount of rated reactor steam flow which is allowed to go through the turbine and is normally set at 100%. The purpose of the Load Limit limiter is to protect the main turbine from excessive steam flows/loads. The Maximum Combined Flow Limit establishes the maximum amount of rated reactor steam flow which is allowed to go to the condenser through the combination of the TCVs and the BPVs. The Maximum Combined Flow Limit is normally set at 105% on the potentiometer. The purpose of the Maximum Combined Flow limiter is to protect the main condenser from excessive loading. The input from the Desired Load Control Unit is normally slightly greater than 100% (from the Load Set motor) unless other variables require setting a lower Load Set value. The output of the pressure/load LVG is the TCV demand. The inputs to the LVG ensure that TCV demanded position is modulated by the Pressure Control Unit. This will make the turbine respond to changes in main steam header pressure, thus making the turbine follow or slave to the reactor.

The BPV demand is established by comparing the pressure/load LVG output to the Pressure Control Unit output. The Small Close Bias prevents continuous opening and closing of the BPVs. A BPV demand can be artificially created independent of pressure/load conditions by means of the Cooldown Bypass Jack. Any difference is sent to a LVG which also receives the difference between the Maximum Combined Flow Limit and the TCV demand. The Cooldown Bypass Jack is used during normal cooldown of the plant after the reactor is shutdown. The BPV demand is automatically adjusted to zero if condenser vacuum drops to a very low value (<7" hg).

3.2.2.5 Hydraulic Power Unit

The EHC Hydraulic Power Unit (HPU) shown in Figure 3.2-4 consists of a fluid reservoir, pumps, fluid coolers, strainers, filters, and accumulators. The pumps are motor driven, variable delivery, piston pumps. Normally one pump is running with the other in standby. If the running pump fails, the standby pump will automatically start when system pressure decays. System overpressure protection is provided by relief valves at the discharge of each pump. The hydraulic drain lines from the various steam valves are routed through tube and shell coolers which are cooled by the Turbine Building Closed Loop Cooling Water System.

The HPU provides high pressure hydraulic fluid which is divided into several different oil supply paths to various steam valves. The different oil paths are necessary to affect specific valve responses for pressure control and turbine protection. Pressure control is affected by positioning the TCVs and BPVs. Turbine protection against many potentially unsafe conditions is provided by turbine trips. These are rapid closures of the TSVs accomplished by dumping the hydraulic fluid pressure which previously kept the valves open. Large springs rapidly close the TSVs when the hydraulic oil pressure is removed. The stop valve portion of the CIVs will also trip closed on a turbine trip in the same manner as the TSVs.

The TCVs are rapidly closed upon a load rejection sensed by the load reject circuit as described in section 3.2.2.3.

The intercept valve portions of the CIVs, normally fully open, are throttled using hydraulic fluid under certain overspeed conditions to provide turbine protection.

There are five major hydraulic fluid streams developed by the hydraulic power unit. The five different streams are necessary to cause specific valve responses for pressure control and turbine protection. These fluid streams and their affected valves can be seen in Figure 3.2-5.

- The Fluid Actuator Supply (FAS) is the fluid that hydraulically positions the:
  - stop valve portion of the CIVs
  - BPVs
  - and the TSVs.

- The Fluid Actuator Supply Trip Control (FASTC) is the fluid that hydraulically positions the:
    - TCVs
    - intercept portion of the CIVs.
- The Fluid Jet Supply (FJS) is a high pressure fluid used to position spool valves that port the FAS and FASTC actuating oil to the above valves.
- The Fluid Cooler Drains (FCD) is a common drain network which routes the various oil stream drains back to the oil reservoir via the cooler.
- The Emergency Trip Supply (ETS) provides high pressure hydraulic oil to hold the disk dump valves closed on the below listed valves. Rapid closure of these valves is affected by a turbine trip signal which removes ETS from these disk dump valves which rapidly drains the hydraulic oil that opened the below valves against spring pressure:
    - stop valve portion of the CIVs
    - TSVs

In almost all cases of a turbine approaching some potentially damaging condition (including overspeed) the best protective action is to trip the turbine (i.e., close all steam admission valves rapidly). This is accomplished by the Emergency Trip System shown in Figure 3.2-5. The turbine trip signals are described in Table 3.2-1.

The ETS consists of three hydraulic valves connected in series and piped to a number of actuating devices. The three valves are the mechanical trip valve, the lockout valve, and the master trip solenoid valve. High pressure hydraulic fluid from the HPU passes through these three valves and becomes the ETS fluid.

When a turbine trip signal is generated, the ETS drains this fluid to cause fast closure of all steam admission valves as described above. Release of ETS pressure also causes the air relay dump valve to close. This closes the steam extraction line valves. These prevent reverse flow of the extraction steam returning back to the low pressure turbines from the feedwater heaters (possibly causing the turbine to overspeed). All turbine trip signals (except mechanical overspeed) seal in and require operator action to reset once the condition has cleared. ETS is also supplied to the relay trip valve which blocks actuating oil to the TCVs and the intercept portion of the CIVs allowing them to close in response to the trip signal. The ETS is failsafe, in that a loss of hydraulic fluid pressure will result in closure of all the steam admission valves.

3.2.3 System Operations

A short discussion of various system operating features is given in the paragraphs which follow.

3.2.3.1 Chest and Shell Warming

If the High Pressure (HP) turbine shell inner temperature is less than 250ºF, it is necessary to manually pre-warm the shell prior to rolling the turbine. The turbine must first be placed on the turning gear to prevent/correct rotor bowing. Shell drains are also opened to remove condensate from the shell.

Shell warming is used to minimize the differential expansion between rotating and stationary components of the HP turbine that may result in physical contact. It is also desirable to warm large metal components as much as possible to prevent combined stress failure of these components because of the imposition of centrifugal and thermal stresses.

When shell warming is selected, the intercept portion of the CIVs remain closed, the stop portion of the CIVs close (they open during turbine reset), and the TCVs are fully open. Crossover steam line drain valves close to permit shell pressurization. These valves are interlocked open anytime "All Valves Closed" is selected. Selection of shell warming overrides the open interlock. All other main steam line drain valves remain open and do not impede shell pressurization because of the capacity of the #2 TSV internal bypass. The bypass is capable of passing up to twice the steam flow required to maintain the turbine at rated speed with no load on the generator. The HP turbine shell is pressurized to between 60 and 100 psig via adjustment of the #2 TSV internal bypass (without rolling the turbine off the turning gear) and allowing the shell to "soak" until the desired temperature is reached.

Even though some chest warming occurs during HP shell warming, chest warming is used to prepare the steam chest for the higher temperatures to which it will be exposed. The steam chest is the small interconnected volume between the TSVs and TCVs. Chest warming is accomplished by pressing the decrease pushbutton until the off light under shell/chest warming illuminates, then deselecting "Shell Warming" and selecting "Chest Warming". The TCVs then close and the stop portion of the CIVs open. By pressing the increase pushbutton, steam is admitted to the chest through the #2 TSV's internal bypass.

3.2.3.2 Turbine Roll

The turbine is rolled by selecting the proper acceleration rate (depending on HP turbine shell inner temperature) and the desired speed, usually 1800 rpm. When this is done several events take place. The speed error was zero while the “All Valves Closed” speed was selected and the acceleration demand signal was saturated high because one of the acceleration rates is always selected. When a speed is selected, the two sections are both at full demand. As the unit starts to roll, the speed error and the acceleration error signals become smaller. Shortly into the turbine roll, the acceleration error becomes the limiting signal thus controlling the rate of rise in turbine speed. As the turbine approaches the selected speed, the speed error becomes the limiting signal thus controlling the acceleration into and the overshoot of the selected speed. At selected speed, the unit will modulate as speed varies slightly around the selected speed.

3.2.3.3 Normal Operation

In the normal mode of operation with reactor thermal power at 100% and the generator loaded to 100% capacity, a listing of the parameter and controller setpoint values follows:

Reactor power	2436 MWt
Generator power	880 MWe
Reactor pressure	1005 psig
Throttle pressure	950 psig
Pressure setpoint	920 psig
Maximum Combined Flow Limit	105%
Load Limit	100%
Turbine speed	1800 rpm
Load Set	~100.1%

The TSVs are fully open, and the TCVs are passing 100% rated steam flow. Both CIVs (the intercept valve and the stop valve portions) are fully open supplying low pressure steam to the low pressure turbines.

The pressure error signal is 30 psi, which corresponds to a 100% steam flow demand to the TCVs and modulating on pressure control. Using Figure 3.2-1 the following should be observed:

- Turbine speed error is 0 (1800 rpm) and acceleration error is maximum (0 rpm/min) resulting in a 0 output from the Speed Control Unit LVG.
- That 0 signal combines with a 100% bias signal and a 100.1% Load Set signal multiplied 2.5 times to result in a >350% open signal to the intercept portion of the CIVs.
- The 0 signal also combines with the Load Set output of 100.1% resulting in a Valve Control Unit LVG input of 100.1% from the Desired Load Control Unit.
- The Pressure Control Unit is sensing 950 psig throttle pressure against a setpoint of 920 psig resulting in a regulator output of 30 for the ‘A’ regulator and 27 (3 psi bias) for the ‘B’ regulator.
- The Pressure Control Unit HVG passes the 30 psi signal to the pressure to flow amplifier resulting in a 100% signal to the Valve Control Unit LVG and BPV summer.

- This being the low value in the Valve Control Unit LVG, it passes this value on to result in a 100% steam flow demand to the TCVs and negates the same signal to the BPV summer keeping all BPVs closed on the negative Small Close Bias signal.

3.2.3.4 Power Maneuvering

Generator power changes are made by first changing reactor power and then allowing the pressure change due to the power change to reposition the TCVs for the new generator output.

Assume that the operator desires to reduce the reactor power to 80%. The core flow resulting in 80% reactor power is determined, and the control room operator then starts reducing recirculation flow to achieve the 80% reactor power. As flow is decreased, more boiling occurs in the core which adds negative reactivity and causes reactor power and steam generation rate to decrease. The TCVs are still initially passing 100% steam flow. As the reactor attempts to continue to generate 100% steam flow, moderator temperature and pressure decrease. As reactor pressure decreases, steam throttle pressure decreases causing a decrease in pressure error, As the pressure error decreases, the TCVs begin to close. As the TCVs close, the pressure decrease is slowed because reactor steam flow is "catching up" with TCV position. Finally at 944 psig steam throttle pressure, the pressure error is reduced to 24 psi which calls for 80% steam flow and corresponds to the steam generation rate the reactor can provide while maintaining criticality, and pressure no longer decreases. Final conditions are reactor power 80%, turbine steam flow 80%, steam throttle pressure 944 psig, and pressure error 24 psi. Note that neither the desired Load Control Unit nor the Speed Control Unit played any part in the change. Raising reactor power results in the opposite responses. Using Figure 3.2-1 the following 80% power steady state conditions are observed:

- Turbine speed error is 0 (1800 rpm) and acceleration error is maximum (0 rpm/min) resulting in a 0 output from the Speed Control Unit LVG.
- This 0 signal combines with a 100% bias signal and a 100.1% Load Set signal multiplied 2.5 times to result in a >350% open signal to the Intercept Valves.
- This 0 signal also combines with the Load Set output of 100.1% resulting in a Valve Control Unit LVG input of 100.1% from the Desired Load Control Unit.
- The Pressure Control Unit is sensing 944 psig steam throttle pressure against a setpoint of 920 psig resulting in a regulator output of 24 for the ‘A’ regulator and 21 (3 psi bias) for the ‘B’ regulator.
- The Pressure Control Unit HVG passes the 24 psi signal to the pressure to flow amplifier resulting in a 80% signal to the Valve Control Unit LVG and BPV summer.
- This being the low value in the Valve Control Unit LVG, it passes on to result in a 80% steam flow demand to the TCVs and negates the amplifier signal to the BPV summer keeping all BPVs closed.

3.2.3.5 Plant Shutdown and Cooldown

The turbine generator is normally unloaded prior to shutting it down. Reactor power is decreased to a point well below the BPVs capacity (< 100 MWe generator load or ~20% reactor power), and then the turbine trip pushbuttons are depressed causing a selected speed value of "All Valves Closed." The TSVs and TCVs fast close, the CIVs (stop and intercept) close, and the BPVs open in response to the valve control logic. The BPVs then control reactor pressure. Using Figure 3.2-1 the following steady state conditions are observed subsequent to the turbine trip:

- The turbine has been tripped (and assume stopped) so the turbine speed error is 0 (all valves closed) and acceleration error is maximum (0 rpm/min) resulting in a 0 output from the Speed Control Unit LVG.
- This 0 signal combines with a 100% bias signal and a 0% Load Set signal multiplied 2.5 times to result in a 100% open signal to the CIVs. This signal is negated by a turbine trip 0 signal to the CIV's LVG resulting in a CIV closure.
- This Speed Control Unit 0 signal also combines with the load selector output of 0% resulting in a Valve Control Unit LVG input of 0% from the Desired Load Control Unit.
- The Pressure Control Unit is sensing 926 psig throttle pressure against a setpoint of 920 psig resulting in a regulator output of 6 for the ‘A’ regulator and 3 (3 psi bias) for the ‘B’ regulator.
- The Pressure Control Unit HVG passes the 6 psi signal to the pressure to flow multiplier resulting in a 20% signal to the Valve Control Unit LVG and BPV summer.
- The Valve Control Unit LVG also has a 0 input from the turbine trip logic so the output TCV demand will be 0. This same 0 signal is sent to the BPV summer allowing the BPV summer to pass the full input from the Pressure Control Unit resulting in a 20% steam flow demand to the BPVs.

When the reactor is shutdown, the cooldown rate of the reactor vessel can be controlled by using the Cooldown Bypass Jack (sometimes just called the bypass jack) or by reducing the Pressure Set setpoint. This causes more or less steam to be passed to the condenser, thus controlling the depressurization rate of the reactor vessel. If a pressure decrease is controlled in a saturated system, then this will also control the temperature decrease (or cooldown rate). Using Figure 3.2-1 the following conditions are observed during plant cooldown using the Cooldown Bypass Jack:

- The turbine has been tripped (stopped) so the turbine speed error is 0 (all valves closed) and acceleration error is maximum (0 rpm/min) resulting in a 0 output from the Speed Control Unit LVG.
- This 0 signal combines with a 100% bias signal and a 0% Load Set signal multiplied 2.5 times to result in a 100% open signal to the CIVs. This signal is negated by a turbine trip 0 signal to the CIV's LVG resulting in a CIV closure.
- This Speed Control Unit 0 signal also combines with the Load Set output of 0% resulting in a Valve Control Unit LVG input of 0% from the Desired Load Control Unit.

- The Pressure Control Unit is sensing (assumed value) 922 psig throttle pressure (due to decay heat) against a setpoint of 920 psig resulting in a regulator output of 2 for the ‘A’ regulator and -1 (3 psi bias) for the ‘B’ regulator.
- The Pressure Control Unit HVG passes the 2 psi signal to the pressure to flow multiplier resulting in a 6.7% signal to the Valve Control Unit LVG and BPV summer.
- The Valve Control Unit LVG also has a 0 input from the turbine trip logic so the output TCV demand will be 0. This same 0 signal is sent to the BPV summer allowing the BPV summer to pass the full input from the Pressure Control Unit resulting in a 6.7% steam flow demand to the BPVs.
- Now the operator increases the Cooldown Bypass Jack's signal to a value exceeding 6.7%. This input signal to the BPV HVG is the highest value and is passed to the BPVs and the BPVs open further.
- This results in steam flow exceeding the heat production from decay heat and reactor pressure will trend downward commensurate with the amount of BPV opening demand.

Using Figure 3.2-1 the following conditions are observed during plant cooldown using the Pressure Control Unit:

- The turbine has been tripped (stopped) so the turbine speed error is 0 (all valves closed) and acceleration error is maximum (0 rpm/min) resulting in a 0 output from the Speed Control Unit LVG.
- This 0 signal combines with a 100% bias signal and a 0% Load Set signal multiplied 2.5 times to result in a 100% open signal to the CIVs. This signal is negated by a turbine trip 0 signal to the CIV's LVG resulting in a CIV closure.
- This Speed Control Unit 0 signal also combines with the load selector output of 0% resulting in a Valve Control Unit LVG input of 0% from the Desired Load Control Unit.
- The Pressure Control Unit is initially sensing (assumed value) 922 psig throttle pressure (due to decay heat) against a setpoint of 920 psig resulting in a regulator output of 2 for the ‘A’ regulator and -1 (3 psi bias) for the ‘B’ regulator.
- The Pressure Control Unit HVG passes the 2 psi signal to the pressure to flow multiplier resulting in a 6.7% signal to the Valve Control Unit LVG and BPV summer.
- The Valve Control Unit LVG also has a 0 input from the turbine trip logic so the output TCV demand will be 0. This same 0 signal is sent to the BPV summer allowing the BPV summer to pass the full input from the Pressure Control Unit resulting in a 6.7% steam flow demand to the BPVs.
- Now the operator depresses the Pressure Set pushbutton to reduce the pressure setpoint to 915 psig.
- If the Pressure Set response was instantaneous, this would create a 7 psi pressure error that when multiplied 3.33 times results in a BPV opening demand of 23% steam flow. Since the response is not instantaneous, peak opening demand will be less than described.
- Steam flow is now in excess of the heat associated with decay heat (~7%) and reactor pressure starts to reduce. When reactor pressure gets to 917 psig, the pressure regulator error signal is again 2 for the ‘A’ regulator and -1 for the ‘B’

regulator resulting in BPV demand returning to 6.67% steam flow and assuming that decay heat has not changed, pressure stabilizes at 917 psig.

3.2.3.6 Pressure Regulator Failures

The most probable EHC System pressure regulators failure is a failure of the throttle pressure sensor which can fail in three different ways:

- **upscale** which is limited to a maximum sensed pressure output of 1050 psig and results in maximum valve opening demand from the Pressure Control Unit.
- **downscale** which is limited to a minimum sensed pressure output of 150 psig and results in a minimum valve opening demand from the Pressure Control Unit.
- **as is** which result in a constant valve opening demand from the Pressure Control Unit.

If the operating pressure regulator fails upscale, the Pressure Control Unit signal to the pressure/load LVG increases. The Load Limit signal prevents the pressure/load LVG output from increasing above its setpoint of 100% so CV demand would not change. The BPVs open to pass the remainder of the steam flow demanded by the Pressure Control Unit and is limited only by the Maximum Combined Flow Limiter setpoint of 105%. Since the open TCVs and BPVs are passing more steam flow than the reactor is providing, the plant will depressurize. When the main steam pressure is reduced to ≤825 psig with the reactor mode switch in the run position, the main steam isolation valves will close. This in turn will cause a reactor scram and terminate the transient.

If the operating pressure regulator fails downscale, its output to the pressure/load HVG goes to zero. As soon as the operating pressure regulator output signal decreases to the level of the standby regulator, the standby regulator's input signal to the HVG will be the controlling value. The standby regulator's lower output value (due to the 3 psi bias) will send a lower value to the Valve Control Unit LVG causing the TCVs to begin closing. The decrease in steam flow will cause reactor pressure to increase causing an increased output from the standby pressure regulator. The net result will be that the plant is operating at the same power level as prior to the fault, but at a pressure 3 psig higher.

If the operating pressure regulator fails as is there is no immediate effect on the plant as long as steady state conditions remain unchanged. There are no alarms, and the plant does not deviate from its present state. The control room operator will be unaware that a failure has occurred. If a transient occurs involving a reactor vessel pressure change, indications of this malfunction occur because of the plant response characteristics will be other than expected.

3.2.3.7 Turbine Trips

The EHC System master trip solenoid receives turbine trip signals as described in Table 3.2-1

3.2.4 System Interfaces

Main Steam System (Section 2.5)

The EHC System provides positioning control for TCVs, BPVs, and the intercept portion of the CIVs and provides trip control for TSVs and intermediate stop valve portion of the CIV's. Main steam also provides turbine throttle pressure indication which is the major control parameter for the EHC System.

Condensate and Feedwater System (Section 2.6)

When a turbine trip occurs, EHC System hydraulic oil causes the extraction relay dump valve to remove air pressure from the extraction non-return check valves in the extraction steam lines resulting isolating steam in the feedwater heaters from the main turbine. Whenever condenser vacuum is below 7" Hg, the BPVs are interlocked closed.

Reactor Protection System (Section 7.3)

The Reactor Protection System (RPS) monitors the pressure of the hydraulic fluid from the EHC System through pressure transmitters mounted in the hydraulic oil supply to the TCVs. The RPS scrams the reactor when a significant decrease of the hydraulic fluid pressure is sensed, indicating fast closure of the TCVs in response to a generator load reject.

In addition, the RPS also monitors the TSV positions through limit switches mounted on each of the TSVs. The RPS scrams the reactor when the TSVs, which are fully open during normal operation, start to move in the close direction in response to a turbine trip signal.

Turbine Building Closed Loop Cooling Water System (Section 11.5)

The EHC System hydraulic power unit (HPU) coolers are supplied cooling water by the Turbine Building Closed Loop Cooling Water System.

3.2.5 Summary

Classification - Power generation system

The purposes of the Electro Hydraulic Control (EHC) System are to:

- provide normal reactor pressure control by controlling steam flow consistent with reactor power
- control reactor pressure during startup, heatup, and cooldown evolutions
- control the speed and electrical load on the turbine generator
- provide protection for the main turbine.

Components - Pressure Control Unit, Speed Control Unit, Load Control Unit, Valve Control Unit and Hydraulic Power Unit.

System Interfaces - All Systems providing turbine trip signals; Main Steam System; Condensate and Feedwater System; RPS; Turbine Building Closed Cooling Water System.

TABLE 3.2-1 Turbine Trip Conditions

Trip	Setpoint and Reason
Reactor Vessel High Level	56.5" An excessively high water level could result in moisture carry over to the turbine resulting in blade erosion or damage.
EHC Fluid Header Pressure Low	<1100 psig Loss of EHC oil pressure would indicate a potential for no control since this is the hydraulic source for valve actuation.
Thrust Bearing Wear	~35 mils Indicates a potential misalignment between the diaphragms and buckets which could result in mechanical damage to the turbine.
Mechanical Overspeed Trip Backup Electrical Overspeed Trip	110/112% Indicates potential turbine damage due to excessive turbine speed and the resultant forces and misalignment.
Exhaust Hood High Temperature	225ºF Excessive temperatures would result in thermal stress, damage to exhaust hood or potential misalignment.
Stator Cooling Failure	<13 psig or >95 ºC Indicates operation of the generator under abnormal conditions. To prevent damage to the generator the turbine is tripped after a 70 second time delay if generator amps are >5811.
Low Main Shaft Oil Pump Pressure	<105 psig @ >1300 RPM A turbine trip is required to prevent bearing damage due to a loss of lubricating oil if turbine speed is >1300 RPM.
Low Bearing Oil Pressure	8 psig Prevent turbine damage due to loss of lubrication
Loss of Both Speed Feedback Channels to EHC Unit	Trips turbine because of potential overspeed condition if turbine speed is >200 RPM
Low Condenser Vacuum	22.5" Hg Indicates a loss of heat sink and operation of turbine at conditions for which it was not designed
Turbine/Generator High Vibration	10 mils Anticipates turbine damage due to excessive vibration

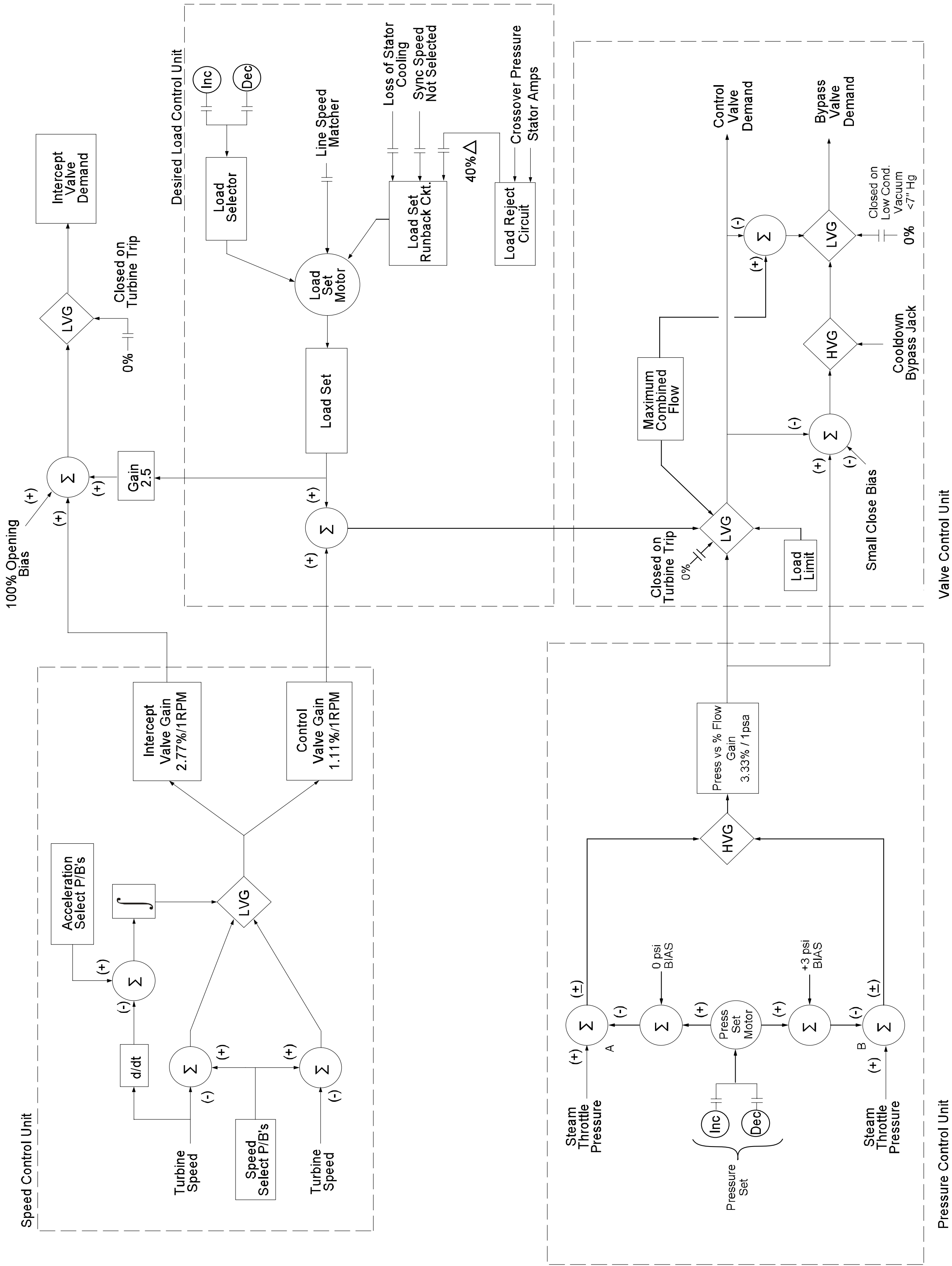

Figure 3.2-1 Electro Hydraulic Control System Logic

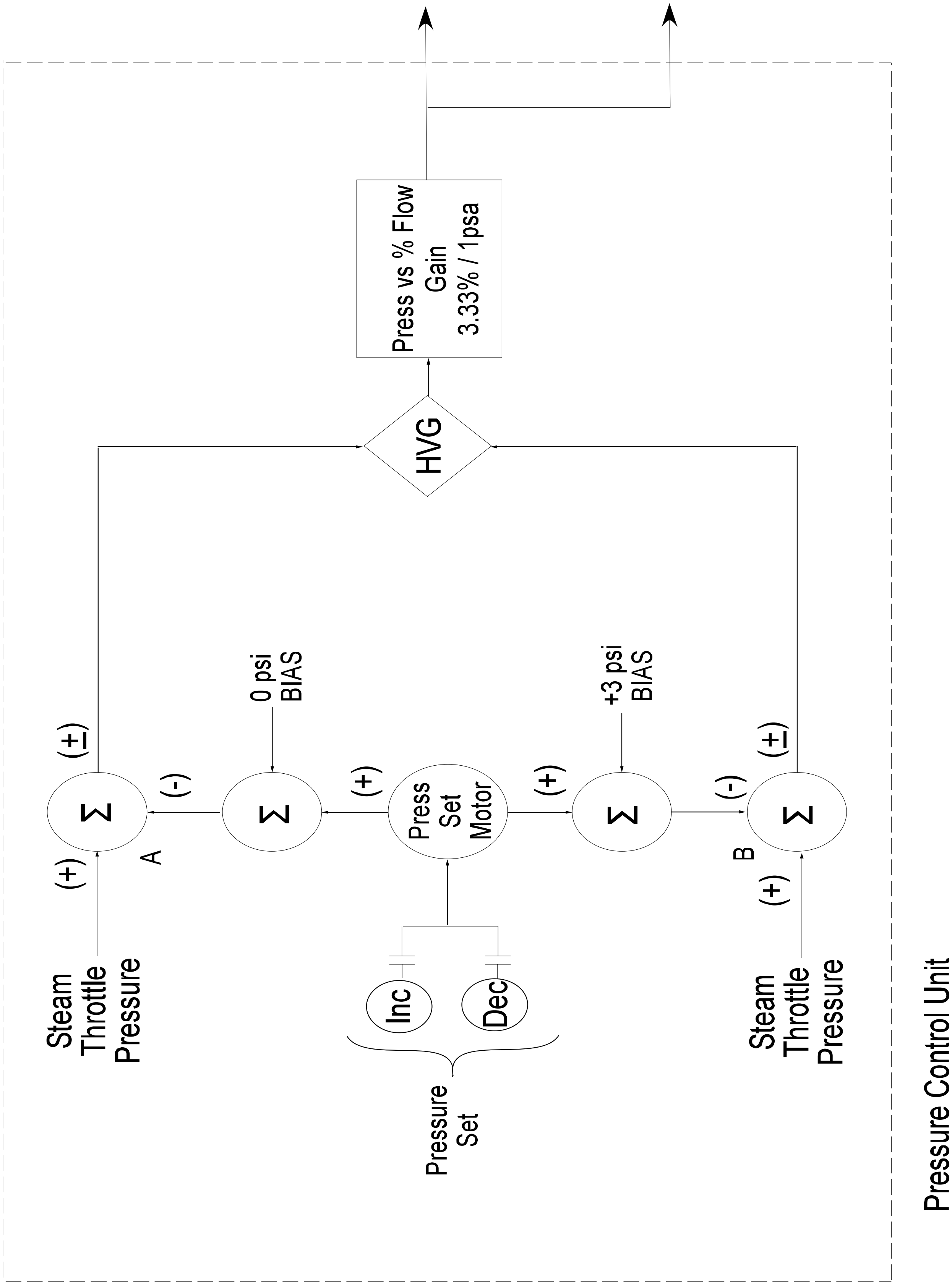

Figure 3.2-1a Pressure Control Unit

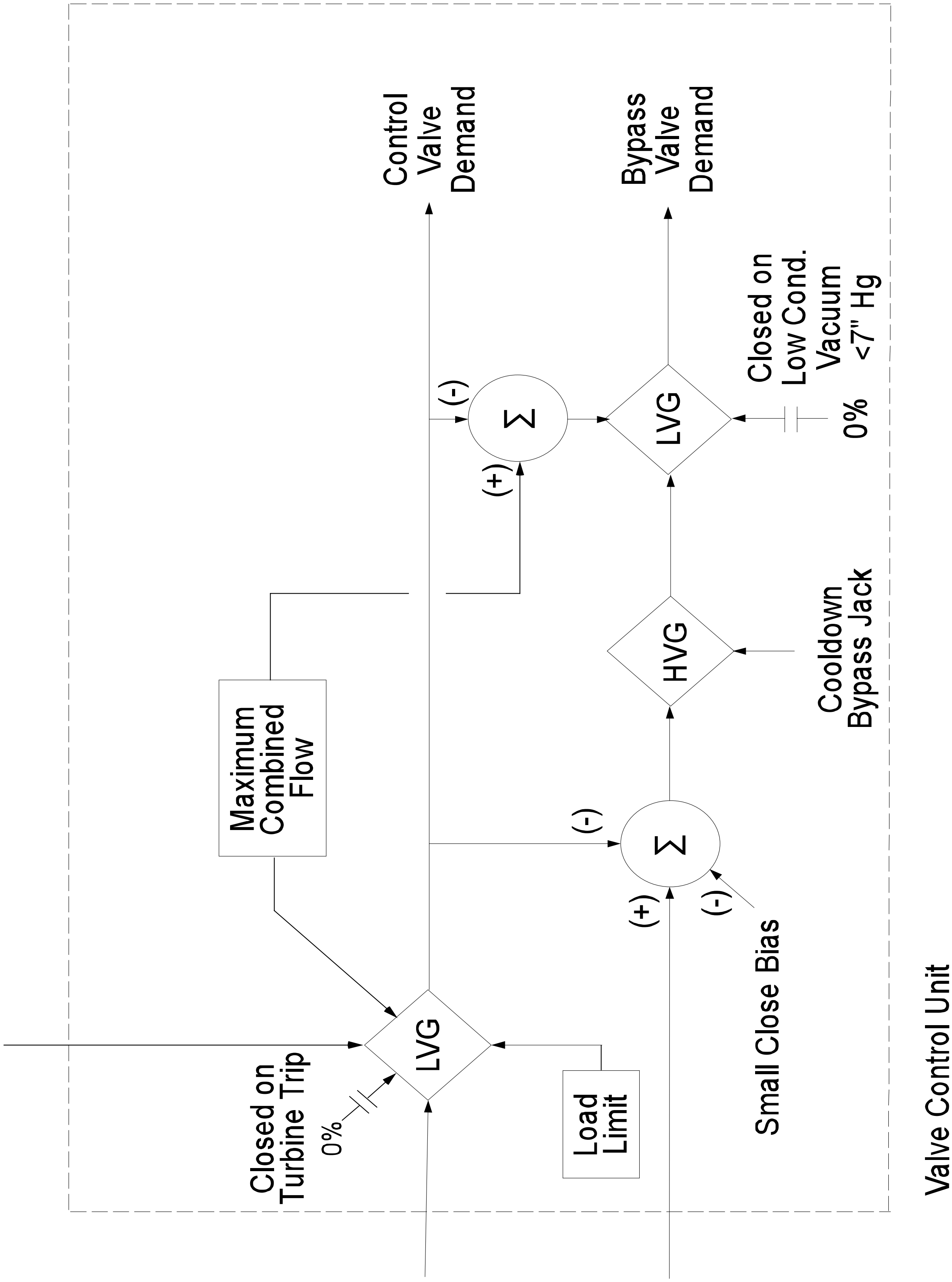

Figure 3.2-1b Valve Control Unit

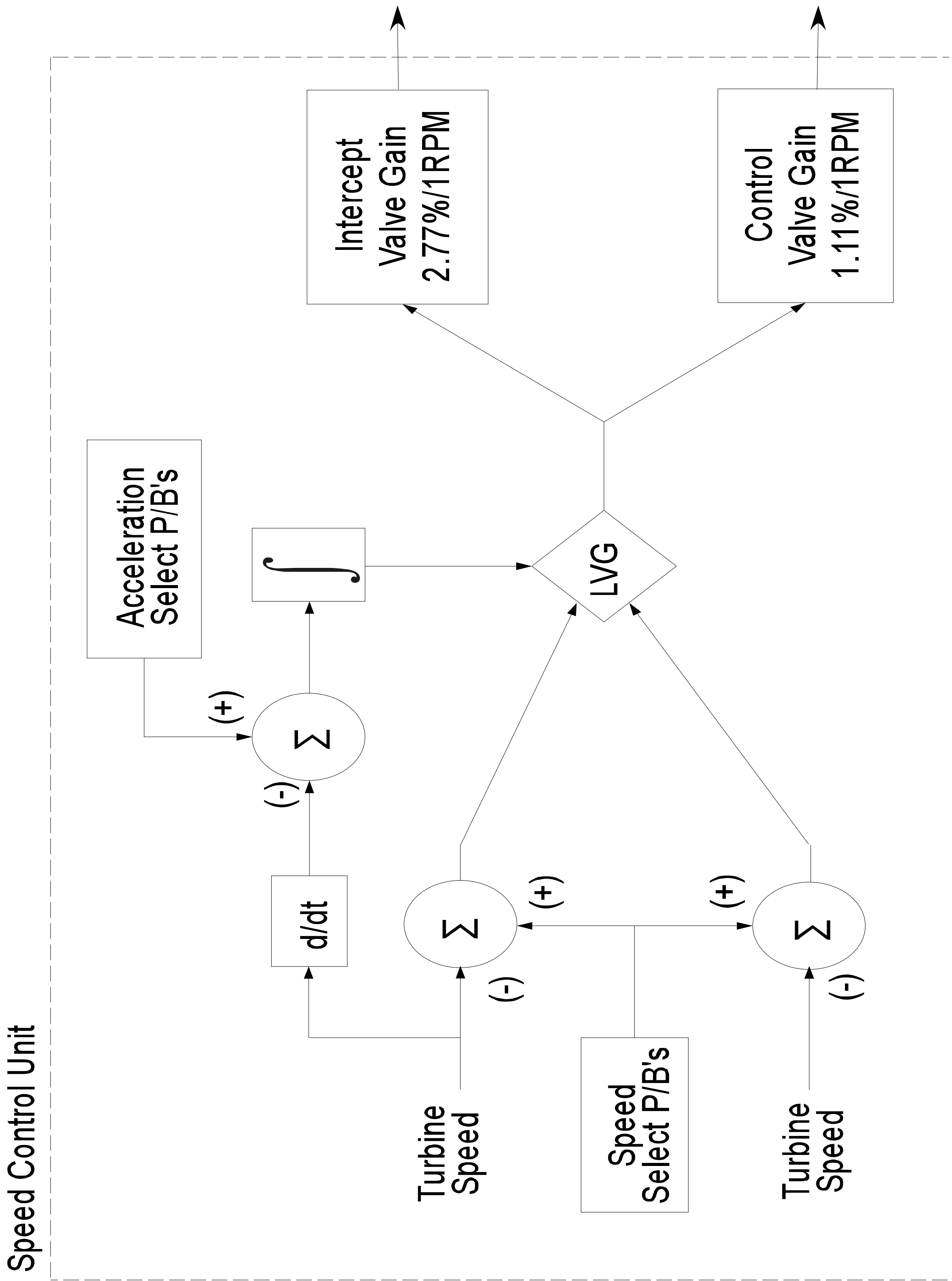

Figure 3.2-1c Speed Control Unit

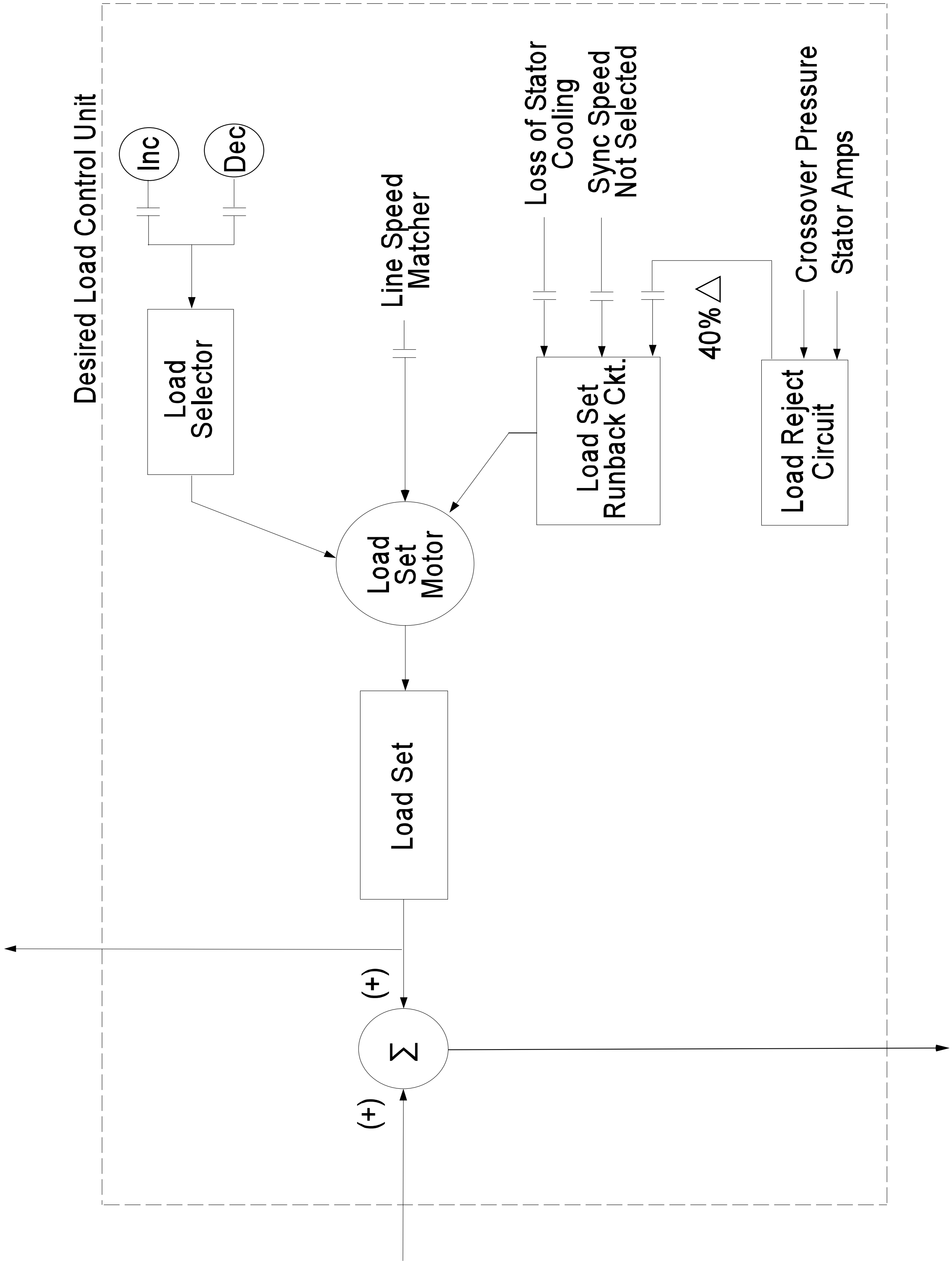

Figure 3.2-1d Desired Load Control Unit

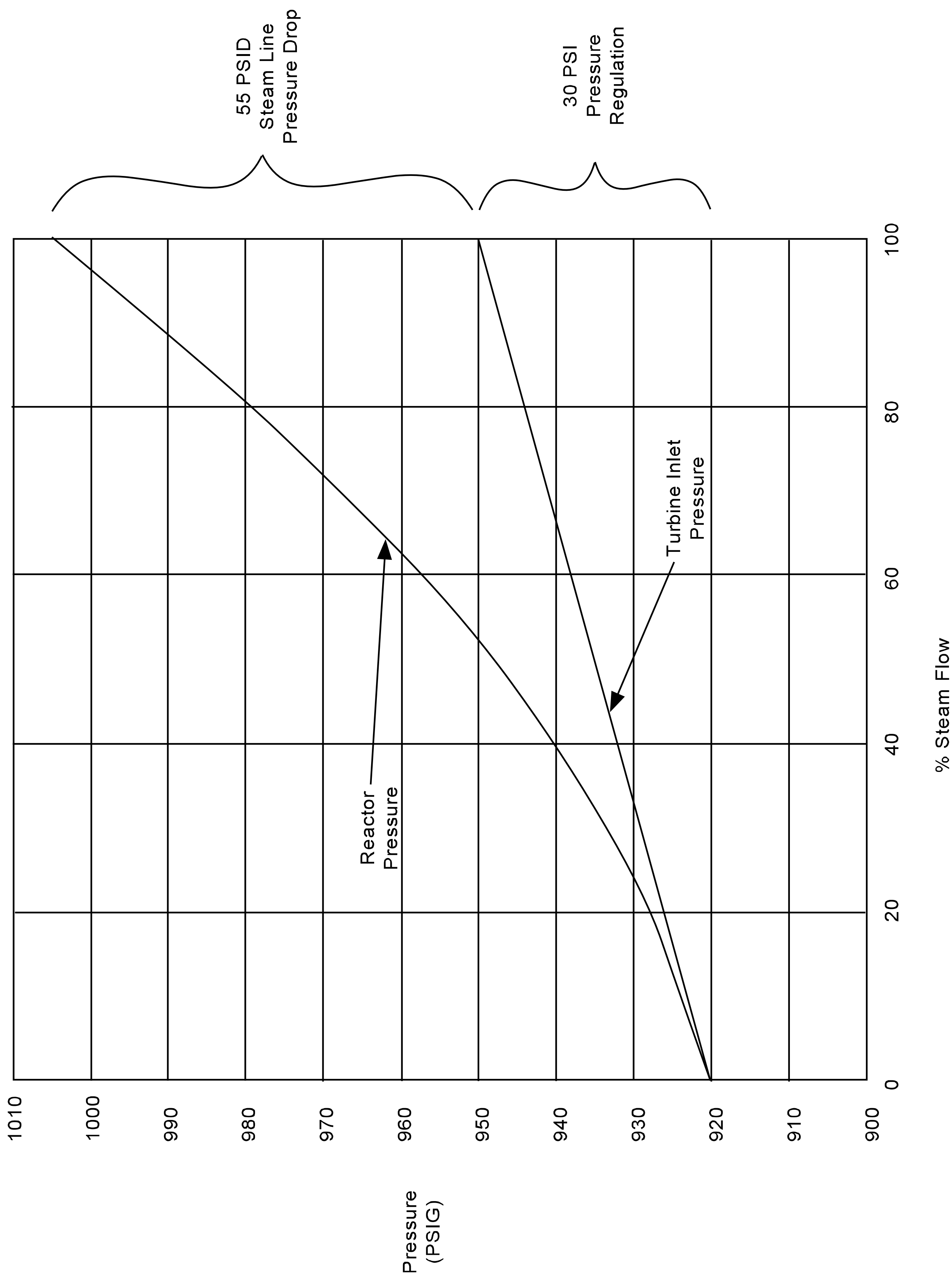

Figure 3.2-2 Pressure Control Spectrum

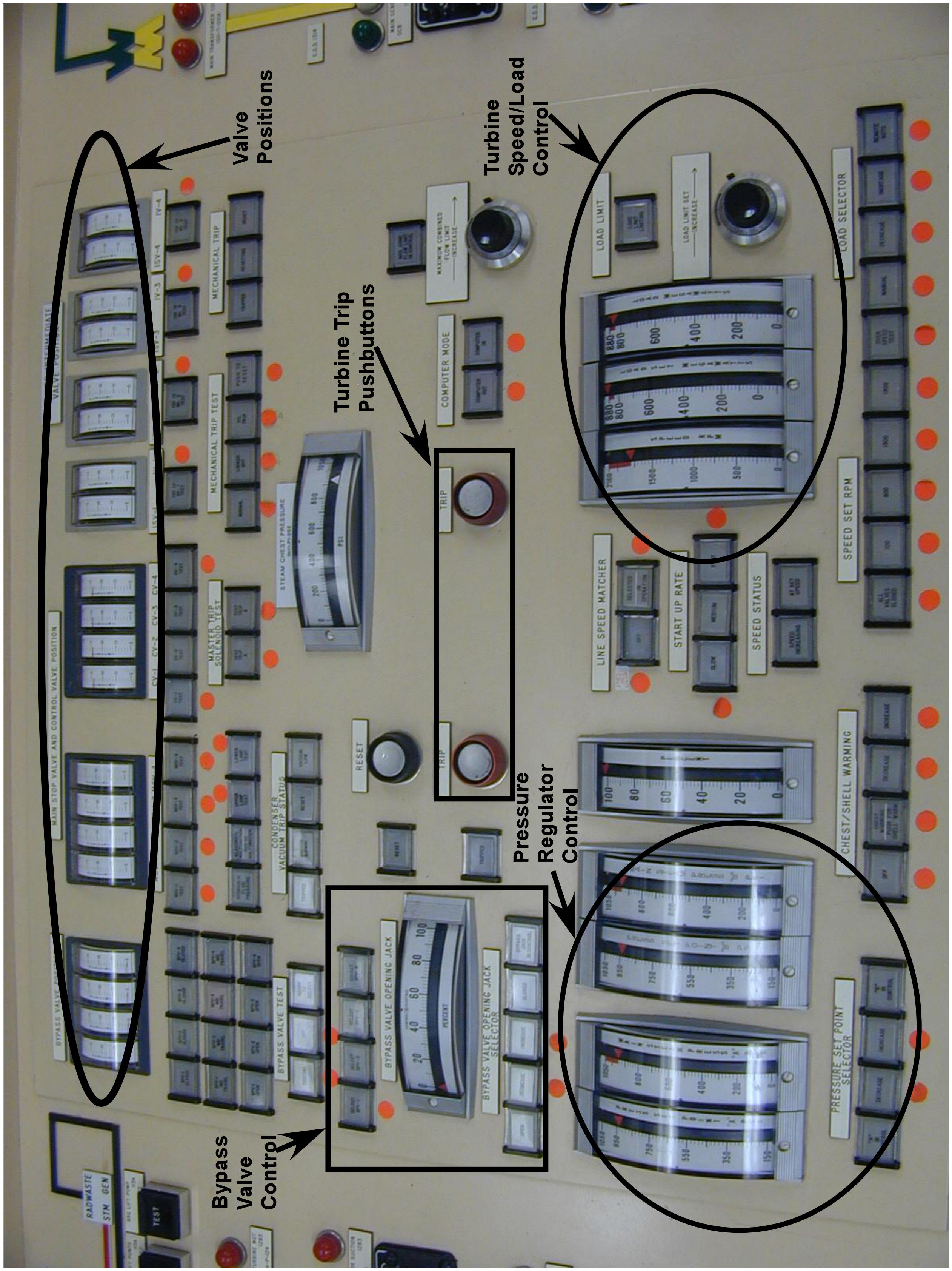

Figure 3.2-3 EHC Operator's Console

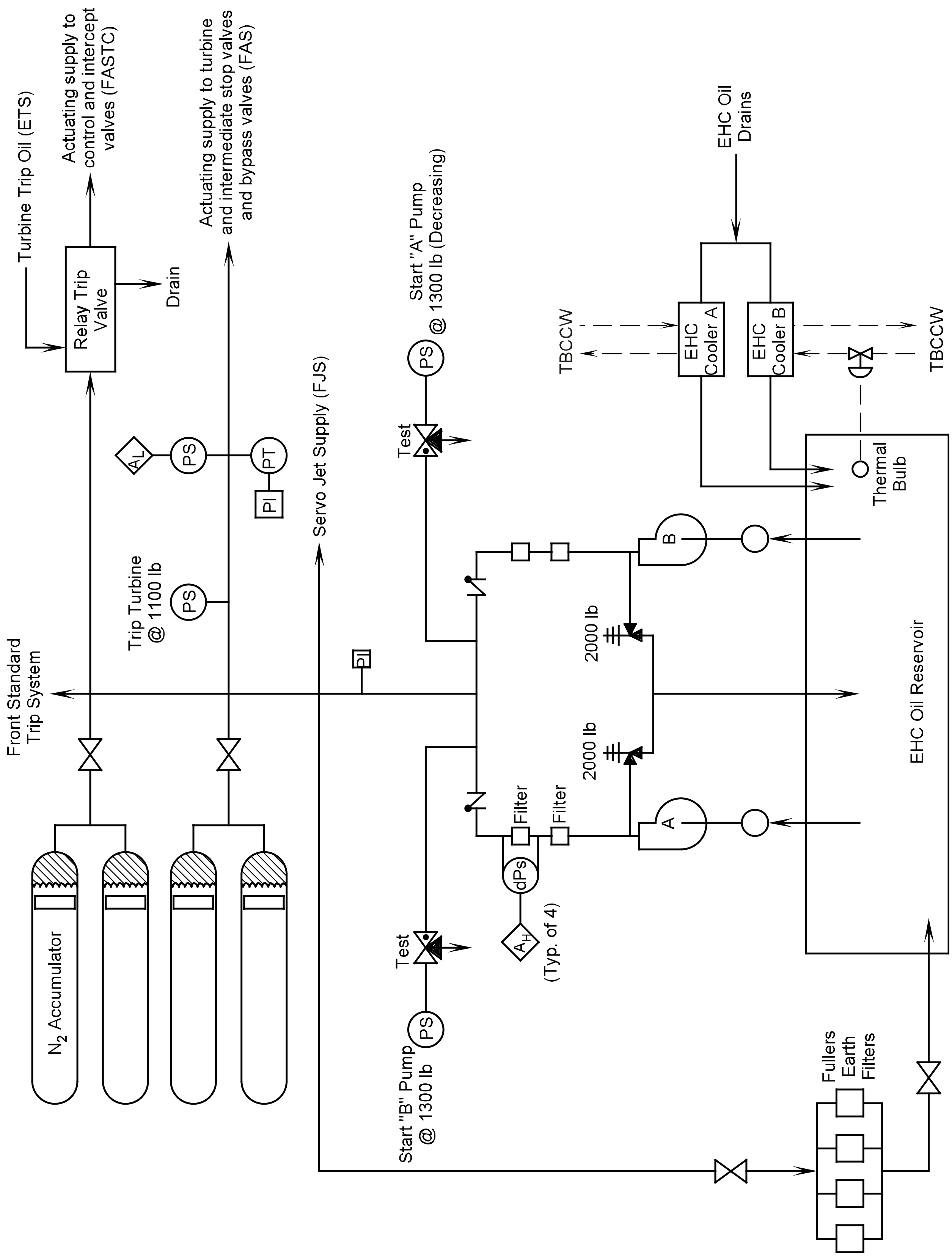

Figure 3.2-4 EHC System Hydraulic Power Unit

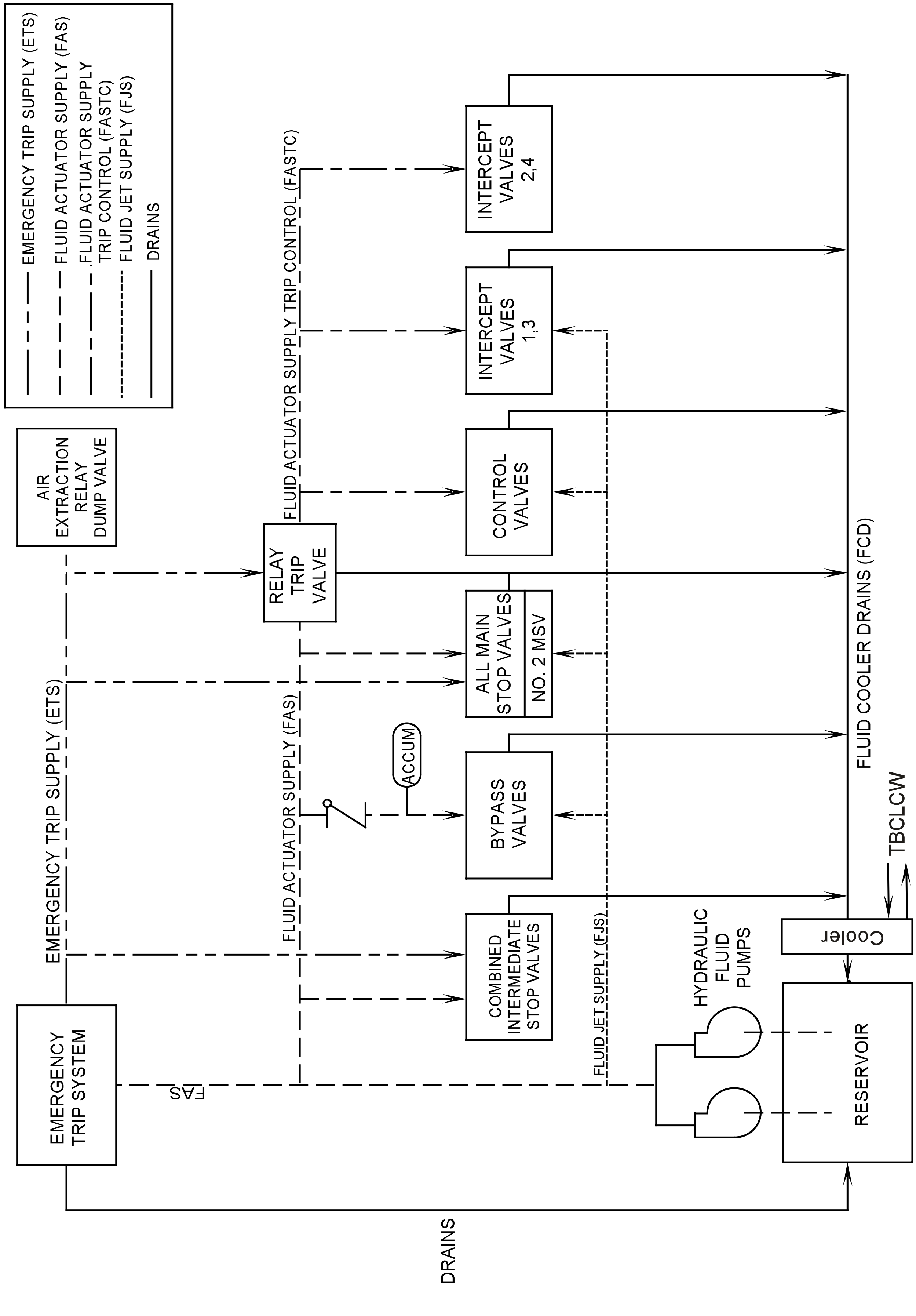

Figure 3.2-5 EHC Fluid Supplies

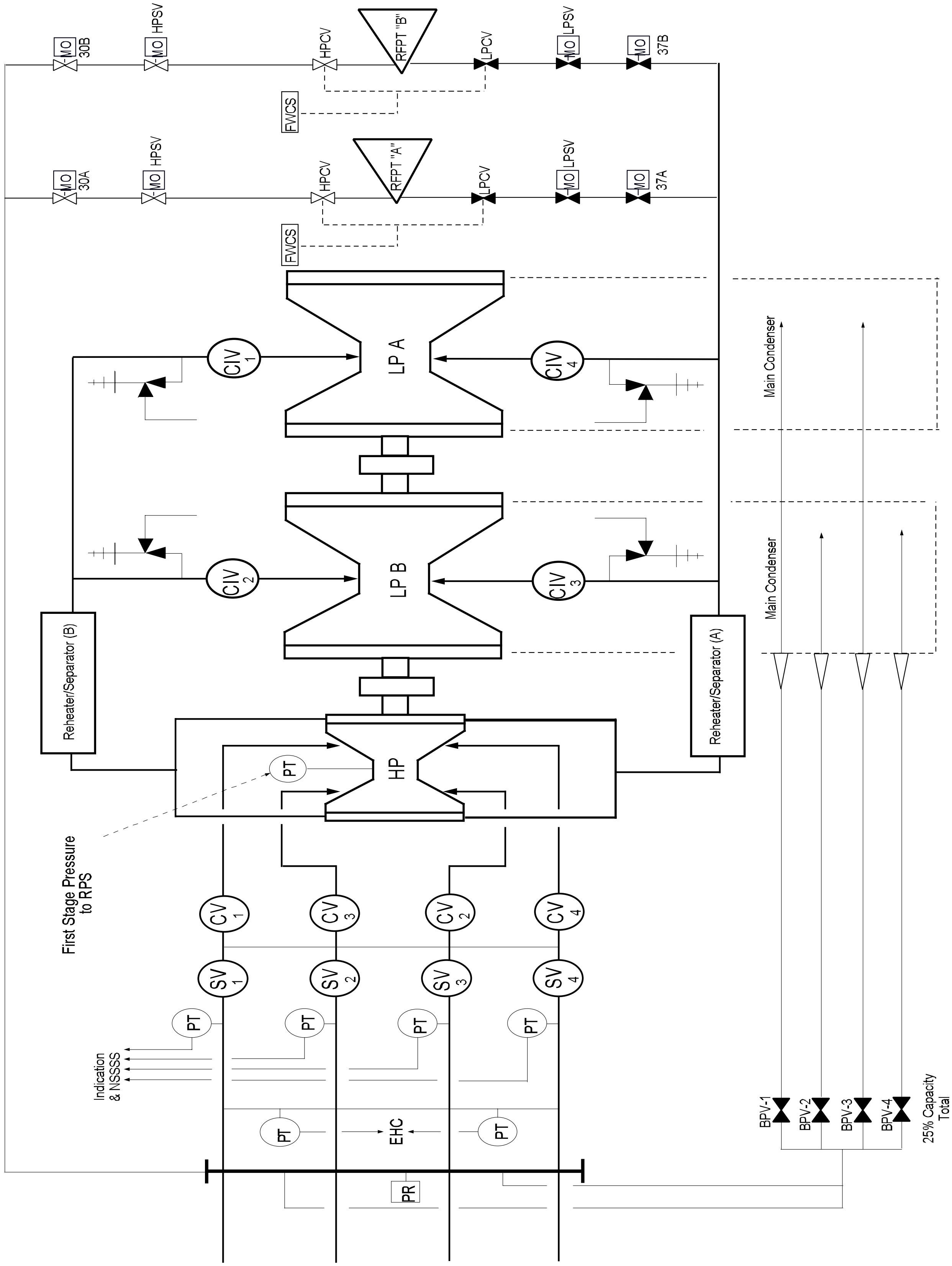

Figure 3.2-6 Main Steam Line and EHC Orientation