Turbine, Generator & Auxiliaries - Course 234

STEAM CONTROL TO THE TURBINE

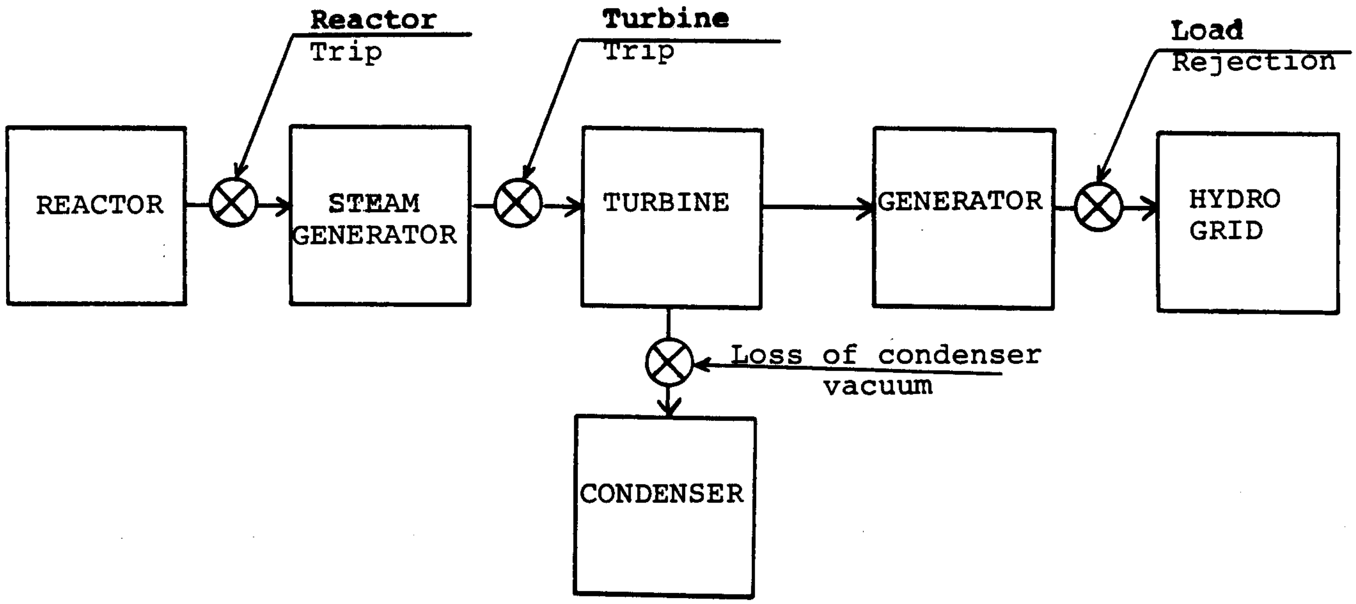


Figure 2.1

The steam generators of a large nuclear generating station produce on the order of 4,000,000 kilograms of steam per hour. The function of this steam is to transmit thermal power from the steam generators to the turbine. During normal, full power operation, the thermal power added to the steam in the steam generators is removed in the turbine (33%) and the condenser (67%). The power delivered by the steam is converted first to mechanical shaft power by the turbine and then to electrical power in the generator. This electrical power is then fed to the Hydro grid. The flow of power from the heat transport system to the Hydro grid is shown in Figure 2.1. Also shown are the points at which this flow can be interrupted. Since the capability of the system to store energy is rather limited, the interruption of power flow at some point imposes an urgent need to restore a balance between power input from the heat transport system and power output. The method of achieving this control is the subject of this lesson.

Boiler Pressure Control

In order to appreciate the control of steam in a CANDU generating station, it is necessary to understand how steam pressure in the steam generators is maintained. As a starting point consider the thermal power transferred across the tubes of the steam generators. This power may be expressed by the equation

$$\dot{Q} = UA\,\Delta T \tag{2.1}$$

where: $\dot{Q}$ = the thermal power conducted from the heat transport system to the water in the steam generator.

U = the overall heat transfer coefficient of the tubes.

A = the total tube area.

ΔT = the temperature difference between the average heat transport system temperature in the tubes and the temperature of the water in the steam generator riser.

As power level is increased the left hand side of this equation obviously increases. If the equality is to be maintained, the right side of the equation must likewise increase. But the tube area (A) doesn't change and the overall heat transfer coefficient (U) changes only slightly. This means if the right hand side of the equation is to increase, then ΔT must increase.

$$\overset{\uparrow}{\dot{Q}} = \vec{U}\vec{A}\,\overset{\uparrow}{\Delta T}$$

So for the type of steam generators we have in our CANDU generating stations, as power level goes up, then the difference between heat transport system temperature and steam generator temperature increases.

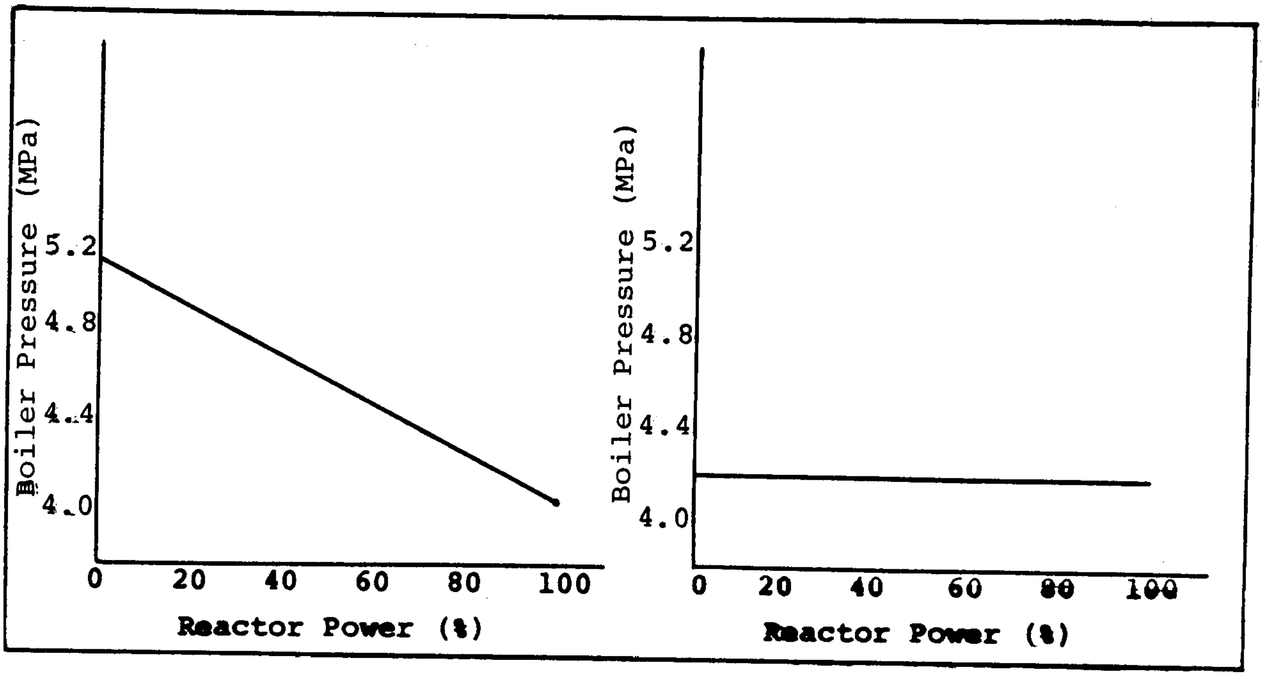
The temperature difference ΔT is :

$$(T_{\substack{\text{average}\\ \text{HTS}}} - T_{\substack{\text{steam}\\ \text{generator}}})$$

For ΔT to increase the average heat transport system temperature must go up or the steam generator temperature must go down or both must occur simultaneously.

In some plants (Pickering NGS A for example) it is desired to hold the heat transport system temperature constant to minimize the swell and shrink associated with the volumetric expansion and contraction of the heat transport system. If this is done then as power level increases, the steam generator temperature must decrease. If steam generator temperature decreases, then since the steam generator is a saturated system, steam generator pressure must decrease. Figure 2.2 shows this effect for Pickering NGS A.

In other plants (Bruce NGS A for example) there is a pressurizer which can accommodate the volume changes in the heat transport system. In such systems, the steam generator temperature is held constant and the heat transport system temperature is allowed to increase as power level increases. This results in a constant steam generator pressure as is shown in Figure 2.3.



Pickering NGS

Bruce NGS

Steam Pressure Vs Power

Figure 2.2

Figure 2.3

The shape of the boiler pressure curve (Figure 2.2 or 2.3), for the particular plant, determines the desired boiler pressure for a given power level. Once the shape of the boiler pressure curve is established, then for each power level, all the other parameters are adjusted to maintain the correct boiler pressure, corresponding to that power level.

The boiler pressure control system has basically two means of restoring boiler pressure to the correct programmed value:

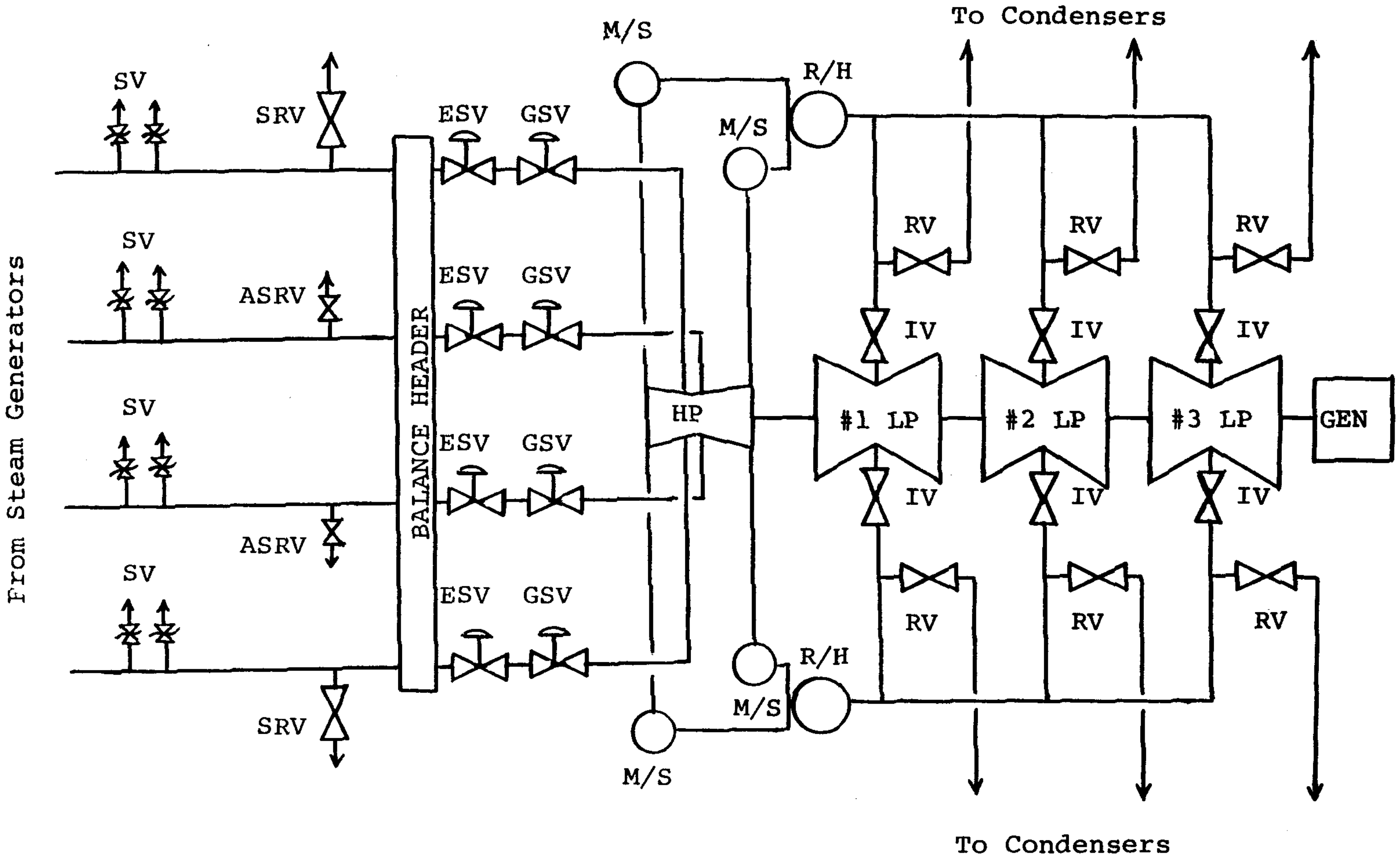
1. adjust the flow of steam out of the steam generators,
2. adjust the flow of heat into the boilers by changing reactor power.

Loss of Heat Source

If the heat source is either partially or fully lost, through a reactor trip, stepback or setback, then thermal power is leaving the steam generators at a faster rate than it is being added by the heat transport system. In this case, steam generator pressure will begin to fall and with it, heat transport temperature and ultimately heat transport pressure. The turbine speeder gear is runback, to avoid lowering heat transport system temperature. The runback will generally be terminated when boiler pressure stabilizes at the programmed level, indicating reactor power is again matched with steam power.

If reactor power is lowered far enough, the speeder gear will unload the turbine completely and the turbine unit will motor. To avoid poisoning out following such a reactor trip, the reactor power must be raised to above about 60-70% of full power, in approximately 40 minutes. The time limits for the recovery would be on the order of:

Diagnose and clear trip:	25 minutes
Regain criticality:	11 minutes
Raise power to 60-70% F.P.:	4 minutes
	40 minutes.



SV = Steam Generator Safety Valves
SRV = Large Steam Reject Valves
ASRV = Small Steam Reject Valves
ESV = Emergency Stop Valves

GSV = Governor Steam Valves
RV = Steam Release Valves
IV = Intercept Valves

Figure 2.4

Turbine Trip

Figure 2.4 shows the control valves associated with a large CANDU generating station. On a turbine trip these valves must function to accomplish three goals:

1. shutdown the turbine,

2. exhaust the steam which was formerly going to the turbine, to prevent a rapid rise in steam generator pressure, and

3. keep the reactor at sufficiently high power to prevent a poison out before the turbine can be brought back into service.

When the turbine trips, the governor steam valves and emergency stop valves shut as a result of governor power oil being dumped. At the same time the intercept valves shut and the release valves open. The generator output breaker opens and the turbine and generator begin to slow down.

Steam flow to the turbine stops much more rapidly than reactor power can be reduced and pressure in the steam generator increases. This excess steam pressure is relieved by exhausting the steam to atmosphere, through the steam generator safety valves or through reject valves, depending on the design of the particular station.

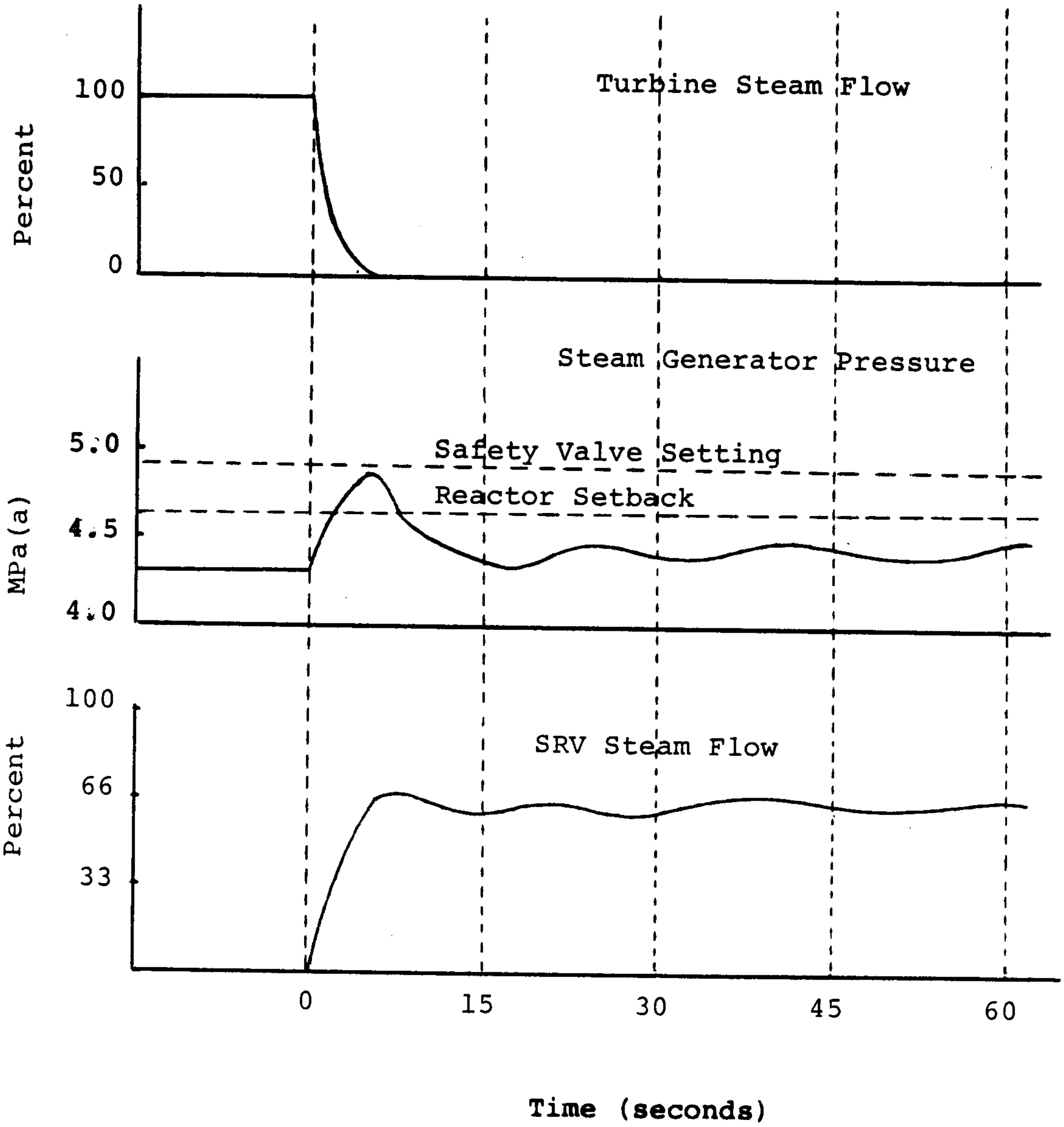
Large CANDU generating stations have two sets of reject valves:

1. small valves (three inches in size) which are used for minor pressure transients

2. large valves (ten inches in size) which are used for large pressure transients and to maintain steam flow above 60% during a turbine outage, to prevent xenon poison out.

On a turbine trip at 100% full power, steam generator pressure increases, as is shown in Figure 2.5. The small reject valves open, then the large reject valves open, and finally the reactor is set back on high boiler pressure. This action is sufficient to limit steam generator pressure and prevent the steam generator safety valves from lifting.

If reactor power was allowed to drop to zero (to match turbine power), the reactor would poison out in about 40 minutes. To prevent this from occurring, the reject valves are used to remove about 60% of full power steam flow. This allows the reactor to remain at a sufficiently high power level, to prevent poison out.



Turbine Trip

Figure 2.5

There are three basic types of reject systems used for poison prevent following a turbine trip:

(a) reject to atmosphere,
(b) reject to main condenser, and
(c) reject to a reject condenser.

(a) Reject to Atmosphere is the simplest form of reject system. In this system both the small and large reject valves discharge to atmosphere. The steam generators produce steam equivalent to about 70% of full reactor power of which 60% is rejected to atmosphere, via the reject system and 10% is sent to the deaerator for feedheating. The rejection of 60% of full power steam to atmosphere, results in a tremendous loss of water, which must be made up through the condensate makeup system. Since makeup water is being consumed faster than it can be produced by the water treatment plant, the reject system can only operate for four to six hours before the reactor must be shutdown due to low water inventory.

(b) Reject to the Main Condenser avoids this problem by condensing the reject steam in the main condenser and pumping it back to the steam generators, via the normal condensate and feedwater systems. The small reject valves go to atmosphere but are not used during poison prevent, so no water is lost during reject system operation. While rejecting to the main condenser greatly increases the length of time during which poison prevent operation may be conducted, it requires that the main condenser be available and under normal vacuum for the system to operate.

(c) Reject to a Reject Condenser enables the reject system to operate independently of the main condenser and still not deplete the station water inventory. However, this system is more costly than either of the other two systems and requires either that the system be available at all times, or that some other reject system (atmospheric reject or safety valves) be available while the reject condenser is being put into operation.

Load Rejection

If the generator load is lost through the opening of the output breaker, the counter torque which the load current exerts on the generator rotor is lost. Unless the steam supply to both the high pressure and low pressure turbine are rapidly shut off, the turbine speed rapidly increases and in a matter of seconds reaches a point between 175% and 200% of operating speed where the stress on the largest wheels in the low pressure turbines exceeds the ultimate tensile strength of the metal. At this point the blade wheel ruptures into several large fragments (60° to 120°) and many smaller ones. These pieces may be thrown through the casing severing steam lines and lube oil lines.

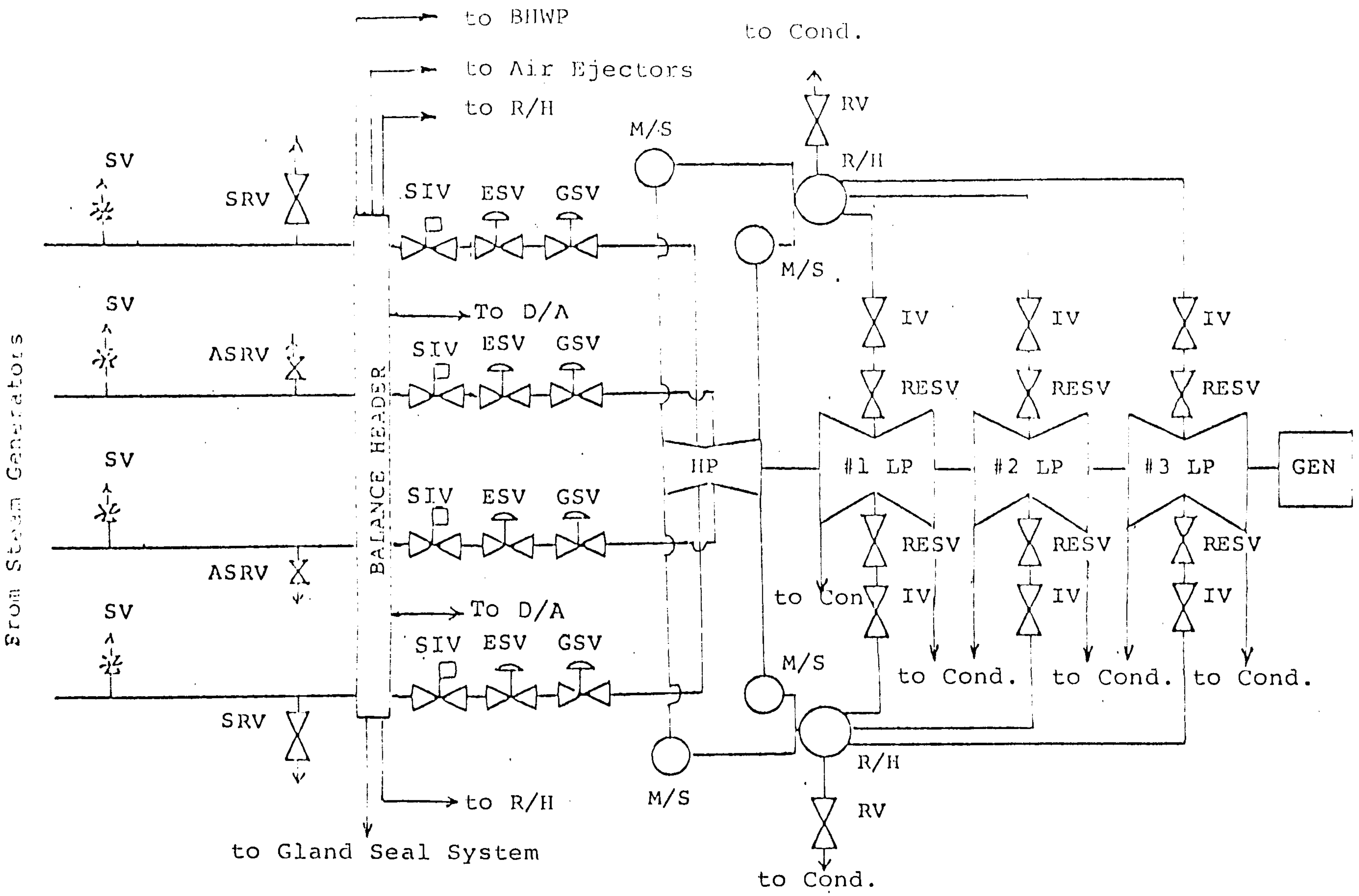
The prevention of such an unterminated overspeed is dependent on the speed with which steam is shutoff. The governor will sense the speed increase and close the governor steam valves. The governor may not be able to operate fast enough to limit the overspeed to acceptable levels. In turbines with such slower acting governors, the emergency stop valve is designed to shut for a short time period, (about five seconds), to rapidly reduce steam flow to the HP turbine, until the governor is capable of handling the overspeed. After sufficient time has elapsed for the governor steam valve to shut, the emergency stop valve will reopen.

On large, multicylinder steam turbines, the volume of steam, which has already passed the governor steam valves, is sufficient to overspeed the turbine by expansion through the low pressure turbine. This "entrained steam", which is contained in the HP turbine, moisture separator, reheater and LP piping, must be prevented from entering the LP turbine. An intercept valve, located on each inlet line, to each LP turbine, performs this funtion. These valves shut at the same time that steam is shutoff to the HP turbine. When the intercept valves shut, the entrained steam must be removed from the turbine unit. This may be done by release valves, which exhaust the steam to the condenser or reheater blow-off valves which exhaust the steam to atmosphere.

In Figure 2.4 there is one release valve for each intercept valve. On some stations there are only two release valves, one for each reheater. While this arrangement, which is shown in Figure 2.6, saves on initial valve cost and maintenance cost, the reduced release capacity requires two modifications to the system:

1. reheater bursting discs are installed to prevent overpressure of the LP pipework in the event of a reheater tube rupture (six release valves will relieve this overpressure, two will not);

2. reheat emergency stop valves are placed in series with each intercept valve. The reduced release valve capacity means that entrained steam is released less rapidly and the consequences of an intercept valve sticking open are more severe. Therefore, two valves are used on each LP turbine steam admission line.



SV = Steam Generator Safety Valves
SRV = Large Steam Reject Valves
ASRV = Small Steam Reject Valves
ESV = Emergency Stop Valves
SIV = Steam Isolating Valves

GSV = Governor Steam Valves
RV = Steam Release Valves
IV = Intercept Valves
RESV = Reheat Emergency Stop Valv

Figure 2.6

Another source of steam, which may continue to drive the unit by expansion in the LP turbine, is the extraction steam contained in the lines to the feedheaters and deaerator. On a turbine trip, this steam tends to flow back to the turbine as the pressure in the turbine decreases. In addition, water in the feedheaters may flash to steam, on decreasing turbine pressure, following a trip. To prevent this from occurring, air motor assisted check valves are placed in the extraction steam lines. These valves close on reverse steam flow and prevent the extraction steam from returning to the low pressure turbine. There are generally no check valves in the extraction steam lines to the first two low pressure feedheaters as the steam pressure is too low to do any real work by backflow and expansion in the remaining LP stages.

Normal Startup

When the turbine is at low speed on the turning gear, the governor senses a speed well below the minimum at which it can control the turbine. The governor speeder gear typically, cannot be set below about 1650 rpm, for an 1800 rpm machine. In this condition the governor steam valves are fully open (calling for maximum steam flow to the turbine) and, therefore, cannot be used to control steam flow to the unit on a startup, while it is below operating speed. The emergency stop valves are used for this purpose.

The turbine is brought up to near operating speed by throttling steam through the emergency stop valves. When the turbine speed rises above about 1650 rpm, the governor becomes able to control the speed of the unit through the governor steam valves. Synchronizing is controlled through the action of the speeder gear and governor controlling the governor steam valves.

Once the generator is synchronized to the grid, it can only run at the speed determined by the grid frequency (1800 rpm for a four pole, 60 Hz generator). The admission of more steam, by further opening the governor steam valves, increases the electrical load supplied to the grid.

When loading of the generator is to begin, steam generator pressure control is transferred to the governor speeder gear. In this mode of pressure control, the speeder gear is under computer control and will open the governor steam valves to reduce steam generator pressure to the desired setpoint. Loading is thereby accomplished by raising reactor power which in turn raises heat transport system temperature and steam generator pressure. This causes the speeder gear to open the governor steam valves and thereby return steam generator pressure to the desired setpoint. If the turbine is unable to accept the additional steam (HOLD turbovisory parameter, exceeds maximum loading rate, etc), the reject system will operate to maintain the desired steam pressure. Through this system turbine/generator power will follow reactor power up to the desired operating load.

ASSIGNMENT

1. Explain how the steam control valves in your station respond to the following:
   - (a) reactor trip
   - (b) turbine trip
   - (c) load rejection
   - (d) normal startup and loading.

2. What would be the consequences of failure for each valve(s) listed below? (Consider the three cases: the valve fails open, the valve fails shut, the valve fails in its normal operating position.)
   - (a) Steam generator safety valve
   - (b) Steam reject valve
   - (c) Emergency stop valve
   - (d) Governor steam valve
   - (e) Intercept valve (plant without reheat emergency stop valves)
   - (f) Intercept valve (plant with reheat emergency stop valves)
   - (g) Release valve.

3. Explain how steam generator pressure is related to heat transport system temperature. Include in your discussion the variation of steam generator pressure with power level and the effect on the type of heat transport system pressurizing system used.

4. Explain "poison prevent" operation including:
   - (a) under what conditions is it used?
   - (b) why is it necessary?
   - (c) where does the steam produced go?
   - (d) how long can it be maintained?

5. Explain "motoring" including:

   - (a) under what conditions is it used?
   - (b) why is it necessary?
   - (c) what are the problems and how are they moderated?
   - (d) how long can it be maintained?

6. Why are two sizes of reject valves used on most plants?

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