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## Module 234-3

# THE MAIN STEAM SYSTEM

## OBJECTIVES:

After completing this module you will be able to:

3.1 Describe two general operating practices used in the steam system to minimize each of the following:

a) Thermal stresses; ⇔ *Page 5*

b) Excessive steam pipeline vibration; ⇔ *Page 6*

c) Steam moisture content at the turbine inlet. ⇔ *Pages 7-8*

3.2 Describe two general operating practices used in the steam system to prevent each of the following:

a) Water hammer; ⇔ *Pages 8-9*

b) Steam hammer. ⇔ *Page 9*

3.3 For boiler safety valves:

a) State two important actions that must be taken if the total available relief capacity of the valves is reduced (by the removal of too many valves from service) below the legal requirement; ⇔ *Page 11*

b) Describe two adverse consequences/operating concerns caused by the lifting pressure setting of any one valve being: ⇔ *Pages 11-12*

i) Too high;

ii) Too low;

c) Describe one adverse consequence/operating concern caused by the blowdown setting of any one valve being: ⇔ *Pages 12-13*

i) Too high;

ii) Too low;

d) State the reason for their testing and explain how the testing frequency is determined. ⇔ *Pages 13-14*

3.4 State:

a) Four operating states during which boiler pressure rises and four operating states when it decreases; ⇔ *Pages 16-17*

b) Two functions of boiler pressure control (BPC); ⇔ *Page 17*

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*Pages 17-18* ⇔ c) The parameter normally adjusted by BPC to maintain boiler pressure at its setpoint while operating in:

i) The reactor leading mode;

ii) The reactor lagging mode;

*Pages 19-21* ⇔ d) Three automatic actions in response to each of the following boiler pressure upsets:

i) High boiler pressure;

ii) Low boiler pressure;

*Pages 21-22* ⇔ e) Five operating states when some or all of the steam reject valves control boiler pressure;

*Pages 23-24* ⇔ f) The operating concerns regarding discharging boiler steam by the steam reject valves to:

i) Atmosphere (3);

ii) Condenser (2).

*Page 25* ⇔ 3.5 a) State the effect of varying the turbine steam flow rate on the turbine generator speed and load:

i) When the generator is synchronized with the grid;

ii) When the generator is not synchronized.

*Pages 25-28* ⇔ b) For the two types of turbine governing used in CANDU stations:

i) Throttle governing (Full arc admission);

ii) Nozzle governing (Partial arc admission);

explain how the turbine steam rate is controlled:

– During turbine generator runup;

– When the generator is synchronized.

*Pages 29-30* ⇔ 3.6 a) i) State how turbine steam flow must be changed in response to a reactor trip.

ii) Explain two major operating concerns caused by failure to change the steam flow as required.

*Pages 30-31* ⇔ b) For each turbine steam valve:

i) State its action upon a reactor trip;

ii) Explain the purpose of its action.

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3.7 a) State the general purpose of a turbine trip. ⇔ *Page 31*

b) List four examples of operating conditions that should trigger a turbine trip and, for each of them, state the major hazard of continued operation. ⇔ *Page 31*

c) i) State the major difference between sequential and nonsequential turbine trips. ⇔ *Pages 32-33*

ii) State the reason why sequential trips are preferred.

iii) Give an example of operating conditions that would initiate a nonsequential trip and explain why a sequential trip would be an inappropriate action.

d) For each turbine steam valve: ⇔ *Pages 33-34*

i) State its action upon a turbine trip;

ii) Explain the purpose of its action.

3.8 a) State the major hazard to the turbine generator represented by a load rejection. ⇔ *Page 36*

b) Explain the changes in turbine speed which occur on a load rejection. ⇔ *Pages 35-37*

c) For each turbine steam valve: ⇔ *Pages 37-39*

i) State its action at the onset of a load rejection and as speed is returning to normal;

ii) State the purpose of each of these actions.

3.9 a) List three operating circumstances when turbine steam valves must be tested. ⇔ *Pages 39-40*

b) Explain three reasons why routine on-power tests of these valves must be performed. ⇔ *Pages 40-41*

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# INSTRUCTIONAL TEXT

## INTRODUCTION

In the previous turbine courses, you learned about the structure of the main steam system used in CANDU stations. You also familiarized yourself with the major components of this system and their functions. Based on this general knowledge, this module discusses the following operational aspects:

- Assorted operational problems in the main steam system;
- Some operational problems associated with boiler safety valves;
- Boiler pressure control;
- Turbine steam flow control during turbine runup and power maneuvers;
- Action of turbine steam valves in response to typical unit upsets;
- Steam valve testing.

For easy reference, a simplified pullout diagram showing a typical arrangement of the major steam valves in CANDU stations is attached at the end of the module. Included with the diagram is a glossary of different names used for these valves at different stations. The first name listed for each valve is preferred in these course notes.

The term *turbine steam valves* – frequently used in these notes – encompasses the following valves: ESVs, GVs, IVs, RESVs, RVs and the extraction steam check valves.

## ASSORTED OPERATIONAL PROBLEMS IN THE MAIN STEAM SYSTEM

Serious operational problems, possibly leading to severe equipment damage, can occur in the main steam system if improper operating practices are used. In this section, the following operational problems are discussed:

- Thermal stresses;
- Pipeline vibration;
- Steam wetness at the turbine inlet;
- Water hammer;
- Steam hammer.

We will examine each of these problems and learn the proper general operating practices that are used to prevent or at least minimize it. Note that all these problems, except for the third one, can also occur in auxiliary steam systems such as the reheat system or the steam reject system.

## Thermal stresses

Module 234-11 describes in detail how thermal stresses are produced and what problems they can cause. For the time being just accept that thermal stresses increase with increasing local temperature differences (commonly referred to as **temperature gradients**) within the equipment. At steady power operation, the temperature distribution within the system components (pipes and valves) is relatively uniform. Therefore, thermal stresses are very small. But **when the steam temperature and/or flow changes, large** temperature gradients, and hence **thermal stresses, are produced** in the system components.

The largest thermal stresses can arise during some abnormal operating conditions such as a boiler crash cooldown or a large pipeline break when the steam temperature drops very quickly. **Among the normal operating conditions** that produce increased thermal stresses (ie. load changes, startups, shutdowns), **cold unit startups are most critical.** This is due to the low initial temperature of the system which promotes large temperature gradients and hence, large thermal stresses. In addition, at low temperatures, system components exhibit increased brittleness. This makes them more susceptible to damage from fast rising stresses.

In order to prevent excessive thermal stresses during cold startups, **the system must be heated slowly**. This is achieved by use of the following **general operating practices**:

*⇔ Obj. 3.1 a)*

1. **Raising the boiler steam temperature at the proper rate.**

   During this process, the reactor and HT pumps supply heat, most of which is allowed to remain in the HT system, boilers and steam piping, thereby raising their temperature. The typical warmup rate does not exceed 2.8°C/min and is controlled by rejecting the surplus heat in boiler steam to atmosphere. Note that this controlled heating minimizes thermal stresses not only in the main steam system, but also in the boilers and the HT system. The same applies to many auxiliary steam systems (eg. the reheat system) which branch off the main steam piping.

2. **Proper warming of the turbine steam inlet piping before steam flow is admitted to the turbine.**

   During the initial phase of startup*, the turbine isolating valves are closed. This allows for pre-runup tests of turbine steam valves (such as the governor valves and emergency stop valves) when the turbine is still isolated from the boiler steam. As long as the turbine isolating valves stay closed, the downstream piping remains cool. But when the valves open, boiler steam fills the piping up to the governor valves, which are closed. Since there is no steam flow to the turbine, heating of the piping is relatively slow*.

* Unit startup is discussed in detail in module 234-11.

* Recall that heat transfer to or from a fluid decreases when the fluid flows more slowly.

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## Pipeline vibration

**Steam pipelines are particularly susceptible to vibration.** First, compared with other equipment, they are very flexible due to their length and elastic supports (the latter is needed to accommodate thermal expansion/contraction of the piping). Second, the complexity of a large steam system causes it to have many, closely spaced, natural frequencies. This increases chances for resonance, which can produce high vibration. Given enough time, the vibration can damage components like flange bolts, welded joints, and even the pipe wall. Such problems have been experienced in many steam systems.

In most cases, pipeline vibration is caused by the steam flow itself. This **flow-induced vibration** is caused by turbulences within the steam flow (eg. downstream of a valve or a sharp elbow), and pressure and flow surges occurring in the system (eg. upon a turbine trip or in the event of water hammer). The vibration frequencies excited due to turbulences in the steam flow depend on the steam velocity, and hence the steam flow rate. At some flow rates, the margin to a resonance can be substantially reduced. This explains why pipeline vibration levels can peak at some loads.

This also explains why excessive pipeline vibration can occur during certain **nonstandard operating conditions** that result in an excessive steam flow through some pipelines. For example, operation with one steam pipeline to the HP turbine valved out (eg. due to some control problems with the steam valves installed in this line) can increase the steam velocity in the remaining three lines to a point that their vibration may become too high. In this case, some turbine unloading may be necessary to bring the vibration down to an acceptable level.

Another cause of excessive pipeline vibration is **a faulty pipe hanger or support.** As the pipe support rigidity is reduced, so are the pipe natural frequencies. This can result in resonance at a steam flow at which no pipeline vibration problem is normally experienced.

*Obj. 3.1 b)* ⇔

Prolonged operation with excessive steam piping vibration is prevented by the following **general operating practices**:

1. **Steam pipeline vibration monitoring.**

   In most CANDU stations, no pipeline vibration monitoring instrumentation is installed. Therefore, field inspections/reports are the only way of detecting any abnormal pipeline vibration. In the stations equipped with such instrumentation, an alarm is given in the event of excessive pipeline vibration. This can be verified/supplemented by field inspections.

2. **Elimination of the identified cause(s) of the excessive vibration.**

   For example, the faulty hanger/support should be promptly repaired or the turbine load reduced as mentioned above.

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## Steam wetness at the turbine inlet

You will recall that during normal operating conditions, the typical boilers used in CANDU stations produce nearly saturated steam. This significantly helps in maintaining a very low moisture content of the HP turbine inlet steam. However, before the boiler steam can enter the turbine, it must flow through the long pipelines of the main steam system. During this flow, the steam loses heat. As a result, **some steam condenses**. If not removed, the condensate formed would result in increased wetness* of the turbine steam. In the extreme case, slugs of water could be formed in the lowest points of the system. Driven by the steam flow, they could cause water hammer in the steam system and possibly water induction to the HP turbine, either of which could inflict severe damage. While this extreme case is described in the next section of this module, the following covers the less drastic case.

* Its adverse consequences were already discussed in module 234-1.

To ensure a satisfactory dryness of the HP turbine inlet steam during all operating conditions, the boilers produce very dry steam, and the main steam system is well insulated and has several steam traps and drain valves. The drains and traps are located in the lowest places in the system where the steam condensate tends to accumulate. Operation of this drainage equipment is complicated by the fact that **the rate of steam condensation in the system** varies widely, depending on the piping temperature. The condensation process is **particularly intensive during cold startup** when the piping is initially cold. In addition, whenever the steam flow is very small, it is easy for the condensate to collect in the lowest points of the piping. Note that a large steam flow makes it more difficult as the fast moving steam picks up droplets from the condensate surface.

Malfunction or improper use of the drainage equipment can result either in increased wetness of the steam supplied to the turbine or an undue loss of hot steam through the drain lines. To avoid these problems, the following **general operating practices** are used:

*⇔ Obj. 3.1 c)*

1. **The operation of the steam traps should be periodically monitored during field inspections.**

   This is usually achieved by checking, with a temperature sensor, the drain pipe temperature upstream and downstream of each trap. If the trap operates properly, its upstream pipe should be hot and the downstream pipe should be much cooler. A cool pipe upstream indicates the trap failed closed as the water that has accumulated in the pipe keeps it abnormally cool. Conversely, a hot downstream pipe is indicative of the trap failed open because the hot steam blowing through the trap causes the pipe to be abnormally hot.

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2. **The drain valves – which are normally closed – should be opened during unit operation below a certain turbine load*.**

* Typically, about 5% FP.

   This practice reflects different rates of steam condensation in the system during different operating conditions as explained above. While the **steam traps** installed in the system are capable of removing the relatively small amounts of condensate that forms when the system is hot and the steam flow rate is large, they **cannot accommodate the heavy steam condensation** which occurs **during startup, shutdown, following a turbine trip, etc. Adequate draining** of the steam system during all these operating conditions **requires**, therefore, **the drain valves to be open**. On the other hand, if they stayed open during other operating conditions when little drainage is required in the system, they would unnecessarily remove hot steam from the system, thereby reducing the overall thermal efficiency of the unit.

## Water hammer

Under some abnormal operating conditions, enough water can accumulate in the lowest points of the steam system to form **water slugs**. Driven by fast moving steam, the slugs can cause water hammer in the steam system and possibly water induction to the turbine*. Both water hammer and water induction can do extensive damage.

* Water induction is discussed in module 234-13.

The excessive accumulation of water can be caused by malfunction of the drainage equipment or improper operating practices, eg. warming of the steam system too fast. In addition, large quantities of water can enter the system during a high boiler level excursion. While maintaining good boiler level control during all operating conditions is essential to prevent formation of water slugs in the steam system, the following **general operating practices** are used in the steam system to achieve the same goal:

*Obj. 3.2 a)* ⇔

1. **The drain valves are open when the unit output is below a certain level** (as explained in the previous section).

   As a digression, the same practice is used in the auxiliary steam systems, eg. the extraction steam system. The only difference is that the drain valves in these systems are combined into a few groups. The unit output below which the valves should be open varies from one group to another. This reflects different steam pressure and temperature conditions in these systems.

2. **After a turbine trip on a very high boiler level, steam admission to the turbine is delayed.**

   The purpose of this delay is to give the drain valves enough time to remove any water that might have collected in the steam pipelines during the boiler level excursion. The required delay varies from one station to

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another and may reach up to 1 hour. Needless to say, the original cause of the boiler level excursion must be rectified before the turbine can be restarted.

Though both these operating practices seem to be quite obvious and easy to carry out, their improper execution or even omission has caused several cases of severe water hammer and water induction accidents in many power generating stations in the world, including CANDU units.

## Steam hammer

In the main steam system, steam hammer **can occur in the drain lines if enough condensate has accumulated there and the pressure is rapidly reduced, causing some water to flash to steam**. The flashing process resembles an explosion because it is very fast, and the steam volume can be hundreds or even thousands of times as large as the volume of the water that has flashed. The high pressure waves (surges) that result propagate through the system, causing other steam pockets to collapse. This, in turn, generates low pressure waves which travel through the system, causing some water to flash back to steam. The process of intermittent creation and collapse of steam pockets lasts until the energy of the pressure waves has dissipated, mainly due to friction. In the meantime, the pressure surges can damage equipment – much like water hammer.

**Steam hammer can be prevented by proper operation of the drain valves** as follows: ⇔ *Obj. 3.2 b)*

1. To prevent accumulation of condensate in the piping, the **drain valves should be opened** early enough **during unit startup and unit unloading**.

   If there is hardly any water in the piping upstream of the valves, not much flashing to steam can occur. Hence, steam hammer is prevented.

2. If a drain valve is found failed in the closed position (eg. due to actuator or control logic failure), it **should be opened very slowly**.

   In this case, some condensate is likely to have accumulated upstream of the failed valve. By opening the valve slowly, the initial low pressure surge that can start steam hammer is avoided, and this is why this operating practice can be effective in steam hammer prevention.

Typically, drain valves are motorized and operated remotely from the control room. If the controls/actuator fail, manual operation should be carried out with the above considerations in mind if steam hammer is to be avoided. The same applies to the drain valves used in other systems, eg. the extraction steam system.

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## SUMMARY OF THE KEY CONCEPTS

- To avoid excessive thermal stresses, the main steam system must be heated slowly. This is accomplished by raising the boiler steam temperature at the proper rate and adequate warming of the turbine steam inlet piping before steam is admitted to the turbine.
- Steam pipeline vibration can be minimized by careful monitoring (to detect early abnormal vibration) and prompt corrective actions to eliminate the identified cause(s) of the excessive vibration.
- To minimize the steam wetness at the HP turbine inlet, steam trap operation is monitored periodically, and the drain valves are open whenever the turbine load is below a certain level.
- Water hammer in the main steam system is prevented by proper boiler level control, opening the drain valves whenever the turbine load is low enough, and ensuring a sufficient delay in restarting the turbine after a trip on a very high boiler level.
- Steam hammer in the main steam system is prevented by proper operation of the drain valves. First, they should be opened before large quantities of condensate are allowed to accumulate in the piping. Second, their opening should be slow to prevent a low pressure surge that may cause the condensate to flash to steam, and hence, initiate steam hammer.

*Pages 43-45* ⇔

You can now do **assignment questions 1-4.**

## ASSORTED OPERATIONAL PROBLEMS ASSOCIATED WITH BOILER SAFETY VALVES

In this section you will learn about:

- The effect on unit operation of too many boiler safety valves removed from service;
- Adverse consequences and operating concerns caused by an improper setting of the lifting pressure setpoint or blowdown of a boiler safety valve;
- Periodic testing of these valves.

### Valve unavailability for service

You will recall from previous turbine courses that the major function of the boiler safety valves is to protect the boilers and the associated steam piping from overpressure.

To perform this function adequately, the valves must meet certain legal requirements. One of them defines the minimum flow capacity of the valves. This requirement stipulates that **the safety valves must be able to remove safely (ie. without the steam pressure rising excessively) the steam flow equivalent to the highest reactor power within the trip envelope**. The statement *within the trip envelope* accounts for a possible reactor power transient above the power setpoint. Such a transient can occur during certain upsets (eg. a loss of reactor regulation) leading to a reactor trip. Therefore, in order to provide adequate overpressure protection during unit operation at full power, the boiler safety valves must actually be able to discharge more than 100%* of the full power steam flow.

* Usually, 115-120%.

In most stations, the installed flow capacity of all the boiler safety valves more than meets this requirement. The extra flow capacity makes it possible to remove from service a certain number of the valves (if they leak or fail to reseat) and still be able to continue safe operation at full power.

⇔ *Obj. 3.3 a)*

However, **if too many valves are unavailable for service***, the maximum boiler steam flow must be reduced such that the remaining operable safety valves can still remove it safely. This is achieved by the **following actions**:

* The limit on the number of unavailable valves depends on the station. In the extreme case, all boiler safety valves must be available to allow full power operation.

1. **The reactor trip setpoint** (typically, the high neutron power trip) **must be reduced** to limit the maximum steaming rate within the trip envelope;

2. **The actual reactor power must be decreased** if the above action could result in too small a margin to trip.

In fact, to prevent a reactor trip, it may be necessary to reduce reactor power first, and then the trip setpoint. Regardless of their sequence, both these actions ensure that the flow capacity of the available safety valves will be sufficient to accommodate a possible reactor power transient prior to a high neutron power trip.

In the stations where the boiler safety valves are also used for crash cooldown, additional requirements define the minimum number of valves that must be available. This number is smaller than the number of the safety valves required for adequate overpressure protection while operating at high power. Details are left for the station specific training.

## Improper setting of the lifting pressure setpoint

⇔ *Obj. 3.3 b)*

In order to minimize the probability of safety valve malfunction, its lifting pressure and blowdown must be properly adjusted. Let us now examine **the adverse consequences and operating concerns** caused by improper setting of the lifting pressure of a boiler safety valve:

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1. **Too high a setting:**

   a) If the problem is known, **the faulty valve cannot be credited as available for overpressure protection**. In some case, this can force unit derating as outlined earlier.

   b) If the valve malfunction were not detected prior to an overpressure requiring safety valve operation, **the integrity of the boilers and the associated steam piping might be jeopardized** as the remaining safety valves may be unable to limit the overpressure to a safe level.

2. **Too low a setting:**

   The lifting pressure of the valve would approach the normal boiler pressure. This could result in **unduly frequent operation of the valve and/or possible simmer** (ie. audible passage of steam without appreciable disc lift). The latter could occur at nearly normal boiler pressure due to the valve spring pressing the disc against the seat too lightly.

   a) **If no corrective action** were taken, this could cause:

      i) **Accelerated wear and eventual failure of the valve.** This would increase maintenance costs and may force a unit outage if the valve is leaking steam excessively.

      ii) **Undue loss of hot steam**, resulting in:

         - Reduced overall thermal efficiency;
         - Possible problems with maintaining the generator output;
         - Increased consumption of makeup water;
         - Increased noise.

   * These terms are explained in the next two paragraphs.

   b) If **the valve** were **quickly shimmed or removed from service***, damage could be prevented and the steam loss minimized. But this would render **the valve unavailable** and could force unit derating.

      A **shimmed** safety valve has a shim installed above the valve spring. As the spring compression is increased, the valve lifting pressure setpoint is raised. This can stop simmer, and the valve remains available for crash cooldown (if required in a given station). However, shimming is not considered accurate enough to credit the valve for overpressure protection.

      Total removal of a boiler safety valve from service is typically done by its **gagging**. This is achieved by placing a clamp on the valve stem such that the valve cannot lift.

*Obj. 3.3 c)* ⇔

## Improper blowdown setting

Recall now that safety valve blowdown is defined as the difference between the lifting pressure and the reseating pressure expressed as a percentage of

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the lifting pressure. Its typical value for boiler safety valves is about 3-5%. What it means is that the reseating pressure is 3-5% below the lifting pressure. Improper blowdown setting of a boiler safety valve can cause the following **adverse consequences and operating concerns**:

1. **Too high a blowdown**:

   This means that the reseating pressure is too low. Following its opening on an overpressure transient, the valve would stay open longer than necessary, particularly so in the case of the valve reseating pressure being lower than the normal boiler pressure setpoint. The resultant **undue loss of boiler steam** through the maladjusted valve would have the same consequences as those listed above in point 2 a) ii).

2. **Too low a blowdown**:

   This means that the reseating pressure is too close to the lifting pressure. The operating concern that results is that the difference between the two pressures may be too small to prevent **valve chatter**. The term refers to a series of rapid openings and closings of the valve. Initiated by an overpressure transient, they are fuelled by fluctuations of the steam pressure below the valve disc. The fluctuations are caused mainly by the varying flow through the valve when it is opening or closing.

   Valve chatter **could rapidly** (ie. within seconds) **destroy the valve seat and disc**. The valve would then have to be removed from service with all the attendant adverse consequences. If the valve were left in service, the steam leak through the damaged seat and disc would result in the consequences outlined above.

How do we know that a boiler safety valve is maladjusted? This can be detected during periodical tests of these valves or by analyzing their response to a boiler overpressure transient.

## Testing of boiler safety valves

*⇔ Obj. 3.3 d)*

Like other safety-related systems or components, boiler safety valves operate very rarely. As they remain in the closed position for extended periods of time, chances are increased that they may fail to operate when a need arises. **To ensure that they will open at the correct pressure if required to operate,** we must test them periodically.

The minimum required **testing frequency** that is stated in your station's operating documentation, is **determined by the more restrictive** of the following:

1. **Legal requirements** based on the Boiler and Pressure Vessel Act and administered by the appropriate Pressure Boundary Authority*.

* For example, in Ontario, this is the Ministry of Consumer and Commercial Relations.

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2. The **reliability and availability targets** set out in the quality assurance program used in your station.

   These programs can be much more restrictive than the legal requirements. For example, in some stations, boiler safety valves are also used for crash cooling, and have reliability targets that require more frequent testing than normal legal requirements specify.

If these valves do not meet our reliability/availability targets and legal requirements, corrective actions must be taken. These actions can include increased test frequencies to determine failure rates/times/mechanisms, changes in design, changes to maintenance procedures, etc.

## SUMMARY OF THE KEY CONCEPTS

- For adequate overpressure protection, boiler safety valves must meet certain requirements. One of these requirements stipulates the minimum flow capacity of all these valves.
- Though in a typical CANDU unit, the installed capacity of the boiler safety valves more than meets the legal requirement, the unavailability for service of too many valves forces a reduction in the reactor trip setpoint. Reactor power may also have to be reduced to maintain adequate margin to trip.
- Too high a lifting pressure setting of a boiler safety valve makes this valve unavailable for overpressure protection and – if undetected – may jeopardize the integrity of the boiler and the associated steam piping.
- Too low a lifting pressure setting of a boiler safety valve could result in unduly frequent operation of the valve and/or its simmer. This would cause an undue loss of boiler steam and accelerated wear of the valve. If it were removed from service for adjustments or repairs, its unavailability might force unit derating.
- Too large a blowdown of a boiler safety valve would result in an undue loss of hot boiler steam with all its adverse consequences.
- Too small a blowdown of a boiler safety valve could result in rapid damage to the valve due to chattering. The valve would have to be removed from service for repairs. Prior to this, steam leakage could occur through the damaged valve.
- Boiler safety valves are tested routinely to ensure that they will open at the correct pressure when required to operate. The test frequency meets the more restrictive of the following: the legal requirements administered by the Pressure Boundary Authority, and the reliability/availability targets set out in your station's quality assurance program.

***Pages 45-46*** ⇔

You can now do **assignment questions 5-10.**

# BOILER PRESSURE CONTROL

Boiler performance – so vital to operation of the whole unit – strongly depends on effective control of boiler pressure. In this module, the following aspects of boiler pressure control are addressed:

- Causes of boiler pressure changes;
- Normal boiler pressure control;
- Automatic responses to boiler pressure upsets;
- Operation of the steam reject valves.

## Causes of boiler pressure changes

You will recall that the primary function of the boilers is to transfer heat from the reactor coolant to the boiler water. The produced steam then removes heat from the boilers as it flows out.

For overall unit control, **it is very important to match the heat supply to the boilers with the heat removal from them. When the two balance each other**, the energy stored in the boiler water and steam does not change. Consequently, **boiler pressure and temperature stay constant**. If the heat input to the boiler exceeds the heat output, the surplus heat is being deposited in the boilers, thereby raising its pressure and temperature. The opposite happens when the heat input is below the heat output – in this case, some heat is being withdrawn from the boilers causing the boiler pressure and temperature to drop. These cases are summarized in the table below.

| CASE | EFFECT |
|---|---|
| Heat input = Heat output | p, T stay constant |
| Heat input > Heat output | p, T rise |
| Heat input < Heat output | p, T drop |

**Fig. 3.1. The effect of boiler heat flow balance on boiler pressure (p) and temperature (T).**

During transition periods, **boiler pressure measurements change faster than temperature measurements**. Therefore, to control the heat flow through the boilers, we monitor boiler pressure, and not boiler temperature.

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*Obj. 3.4 a)* ⇔

Certain operating states or upsets disturb the heat flow through the boilers. This causes the boiler pressure to change. Let us first consider the case of **the boiler heat input exceeding the heat output** such that the **boiler pressure rises**. This can happen **during the following operating states and upsets**:

1. **Warming of the boilers and HT system during a cold unit startup**;
2. **Turbine trip or load rejection**;
3. **Unit unloading** (if turbine unloading leads reactor unloading);
4. **Unit loading** (if reactor loading leads turbine loading).

During warming of the boilers and the HT system, boiler pressure rises gradually from atmospheric pressure to 4-5 MPa, depending on the station. During the remaining three operating states (points 2-4 in the above list), only a transient pressure rise occurs. The transient is minimized by corrective actions described later in this section. The largest boiler pressure transient occurs on a turbine trip from full power or a full load rejection. Power manoeuvres listed in points 3 and 4 produce much smaller transients.

Points 3 and 4 are valid under the assumption that a constant boiler pressure setpoint is maintained over the whole reactor power range. But in some CANDU units, the boiler pressure setpoint is ramped down with increasing reactor power. In those units, boiler pressure rises during unit unloading, and decreases during loading as dictated by the pressure setpoint.

The above list is limited to the most typical operating states and upsets. Some other upsets, like a loss of reheat, can cause an increase in boiler pressure, too. In fact, it can be caused by any other upset that produces a surplus of boiler heat input over output.

Similarly, **the following operating states and upsets can cause boiler pressure to drop**:

1. **Cooling of the boilers and the HT system**;
2. **Reactor trip, stepback or setback***;
3. **Unit unloading** (if reactor unloading leads turbine unloading);
4. **Unit loading** (when turbine loading leads reactor loading).

* Recall that a reactor stepback is a rapid drop in reactor power, effected by insertion of control absorbers into the reactor core. A reactor setback is a gradual reduction in reactor power controlled by liquid zone levels.

With respect to the magnitude of boiler pressure changes, this list is quite similar to the previous one. That is, the largest pressure drop occurs during cooling of the boilers and HT system. Other operating conditions listed above result only in a transient pressure drop. The largest transient is caused by a full power reactor trip or a stepback to zero power. A smaller transient is produced due to a reactor setback. Power manoeuvres listed in points 3 and 4 cause even smaller transients.

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Same as before, points 3 and 4 apply to the CANDU stations where a constant boiler pressure setpoint is maintained over the whole reactor power range. Also, the above list is incomplete. A drop in boiler pressure is also caused by any other upset (eg. spurious opening of a boiler safety valve) that makes the boiler heat output exceed the heat input.

It is important to realize that even a small mismatch between the boiler heat input and output, if allowed to last long enough, can eventually cause a large boiler pressure change. In reality, it is counteracted by appropriate corrective actions as described below. These actions mitigate boiler pressure changes such that during some of the above operating states and upsets boiler pressure deviates only very slightly from its setpoint.

## Normal boiler pressure control

**Boiler pressure is normally controlled automatically by** a special computer subroutine called **BPC** (short for Boiler Pressure Control). This subroutine is run all the time by the computer that normally controls the unit operation. **BPC performs two major functions:**

⇔ *Obj. 3.4 b)*

1. **It attempts to maintain boiler pressure at its setpoint.**

   This is achieved by scanning all boiler pressures in regular intervals * and initiating some corrective actions when a pressure error is detected or anticipated. The latter applies, for example, to major unit upsets such as turbine trips when it is obvious that boiler pressure will change. As BPC begins its corrective action right after the upset has occurred (ie. without waiting for boiler pressure to change), the resultant pressure transient is considerably reduced.

   * Typically, every 2 seconds.

2. **It changes the boiler pressure setpoint** during the following operating states:

   a) Warmup and cooldown of the HT system;

   b) Reactor loading and unloading (except for the stations where the boiler pressure setpoint is kept constant over the whole reactor power range).

In order to keep boiler pressure at its setpoint, BPC must try to maintain a proper balance between the boiler heat input and output. This can be achieved by varying either the reactor power (ie. the heat input) or the steam flow out of the boilers (ie. the heat output). This brings us to two **modes of the BPC operation**:

⇔ *Obj. 3.4 c)*

1. **The reactor lagging mode** (also called the turbine leading mode).

   In this mode, boiler pressure is controlled by adjusting the reactor power. When a boiler pressure error (defined as the difference between the actual boiler pressure and the setpoint) is detected, **the BPC adjusts the set-**

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**point to the reactor regulating system.** The system then brings reactor power to the new setpoint. Along with the boiler pressure error, the rate at which the turbine steam flow (and hence, the boiler heat output) is changing is monitored, too. This is achieved by measuring the steam pressure at the HP turbine inlet or close to it*. This extra input allows the BPC to anticipate an upcoming change in boiler pressure and respond to it in advance, thereby minimizing pressure fluctuations.

* Recall from module 234-1 that in the turbine, steam pressure is approximately proportional to load, and thus, the steam flow.

This is the preferred mode of BPC operation in most CANDU stations. Its names reflect the fact that when this mode of control is used, changes in the reactor power lag behind changes in the turbine generator output.

2. **The reactor leading mode** (also called the turbine following mode).

   In this mode, changes in reactor power occur before changes in the boiler steam flow. Reactor power is controlled independently, and **boiler pressure is controlled by adjusting the setpoint to the turbine governing system.** This causes the turbine steam valves to change the boiler steam flow as requested by the BPC. Needless to say, it causes the generator output to change accordingly.

   To enhance boiler pressure control when the BPC operates in this mode, some other parameters (in addition to the boiler pressure error) are used as inputs by the BPC. These typically include the rate at which boiler pressure is changing and the rate at which reactor power is changing. Their use allows the BPC to anticipate the upcoming changes in boiler pressure, and hence minimize pressure transients.

   This is the preferred mode of BPC operation in some CANDU stations. But in most stations, this is the *alternate* mode which is selected when the preferred reactor lagging mode of operation is not suitable. For example, this happens following a reactor trip, stepback or setback when the reactor power is either lost or cannot be manoeuvred due to some operational problem.

## SUMMARY OF THE KEY CONCEPTS

- BPC controls boiler pressure at its setpoint. It also changes the setpoint during some operating states.
- Boiler pressure rises during warmup of the HT system and the boilers. A temporary rise in boiler pressure occurs on a turbine trip or a load rejection. A smaller transient pressure increase is caused by unit unloading in the reactor lagging mode or unit loading in the reactor leading mode. But in the stations where boiler pressure setpoint is ramped down with rising reactor power, unit loading causes boiler pressure to decrease, and unit unloading to rise.

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- Boiler pressure decreases during cooldown of the boilers and the HT system. A temporary decrease in boiler pressure occurs upon a reactor trip, stepback or setback. Unit unloading in the reactor leading mode, or unit loading in the reactor lagging mode also causes a small transient pressure decrease. The last statement applies to the stations where a constant boiler pressure setpoint is maintained.
- In most CANDU stations, BPC can operate in either the reactor lagging mode (which is normally preferred) or the reactor leading mode (the alternate mode). In some CANDU stations, only the latter mode is used.
- While operating in the reactor lagging mode, the normal response of BPC to a boiler pressure error is an appropriate adjustment of the setpoint to the reactor regulating system. The regulating system then changes the reactor power, as requested by BPC.
- In the reactor leading mode, BPC responds to a boiler pressure error by adjusting the setpoint to the turbine governing system. In response to this, the governing system changes the turbine steam flow.

## Automatic responses to increased boiler pressure error

*⇔ Obj. 3.4 d)*

**The control action of BPC**, as described above, **can accommodate only relatively small mismatches in the boiler heat flow**. After all, there are strict limits on how much and how fast the reactor power and the turbine power can be manoeuvred. For example, when an increase in the turbine steam flow is demanded by BPC, the execution of this request is limited (among other factors) by the position of the governor valves – once they are fully open, their further action to fulfill the BPC demand is just impossible. When the unit operates at full power, these valves cannot accommodate a much larger steam flow – their extra flow capacity is usually only a few percent of the full power steam flow.

When any of these limitations renders the normal BPC control action inadequate, the boiler pressure error increases. This eventually causes other, more drastic, automatic actions to occur. They are depicted in Fig. 3.2 which, for simplicity, does not show alarms and annunciations.

As can be seen in this diagram, an excessive boiler pressure results first in **opening of some or all of the steam reject valves**. The valves provide an alternate flow path for boiler steam when the turbine is unavailable (eg. following a turbine trip) or can accept only a very limited flow (eg. during runup). More information about these valves is provided later in this module.

Upon the boiler pressure error reaching a certain level, **the reactor is set back**. This action reduces the boiler heat input, and thus it helps to prevent a further increase in boiler pressure. Of course, upon the reactor setback, BPC reverts to the reactor leading mode if it did not operate in this mode already.

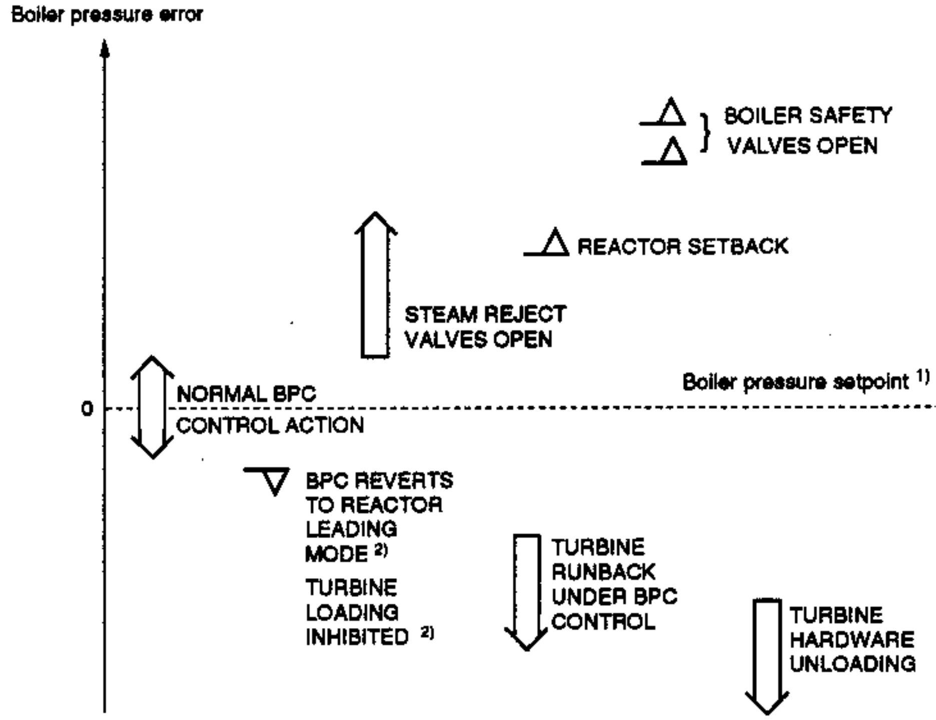


**Fig. 3.2. Major automatic responses to boiler pressure error:**

Notes:

1) In some stations, the setpoint is ramped down with increasing reactor power.
2) Only when BPC is operating in the reactor lagging mode.

When all these actions fail, **the boiler safety valves are the last line of defence against overpressure**. Note that BPC has nothing to do with these valves. Fig. 3.2 shows that the individual safety valves open at somewhat different pressures. This is partly caused by a limited accuracy at which the valve lifting pressure can be adjusted, and partly done on purpose to prevent all the safety valves from simultaneous operation. When different safety valves open at different pressures, the number (and hence the flow capacity) of the operating valves can match better the overpressure transient (mild versus severe). Also, since all the safety valves do not open and close at the same time, flow and pressure surges in the steam system and boilers are reduced, thereby minimizing some operational problems (eg. steam pipeline vibration).

In the reactor lagging mode, when boiler pressure drops excessively below setpoint, **BPC reverts to the reactor leading mode**, with reactor power frozen, and BPC controlling turbine output. Of course, any **further turbine loading is inhibited**. The purpose of this action is to prevent any further drop in boiler pressure. Notice that the excessive boiler pressure error implies that in the reactor lagging mode of operation, the reactor power cannot keep up with the steam load imposed on the boilers, perhaps due to

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loading the turbine too fast. Transfer to the reactor leading mode of BPC operation can solve this problem by limiting the boiler steam demand to a level that is appropriate for boiler pressure control.

If the pressure error is large enough, turbine unloading (commonly referred to as **turbine runback**) is carried out **under control of BPC** which lowers, at a limited rate, the setpoint to the turbine governing system. If this action fails to occur (eg. due to a computer malfunction), allowing a further drop in boiler pressure, the **low boiler pressure unloader*** in the turbine governing system takes over. Directly activated by low boiler pressure, the unloader reduces the turbine steam flow, regardless of the setpoint to the turbine governing system. Because this action does not rely on any runback, it can unload the turbine very quickly. In Fig. 3.2, this action is depicted as **turbine hardware unloading**.

* More information about this unloader is given in module 234-7.

## Operation of the steam reject valves (SRVs)

⇔ *Obj. 3.4 e)*

It is worth emphasizing that the SRVs are **not used for overpressure protection** (which is provided by the boiler safety valves), **but rather for boiler pressure control**. In principle, some or all of the SRVs open whenever boiler pressure rises too much above its setpoint. This can be caused by the actual pressure rising and/or the setpoint dropping. Listed below are four unit operating states and upsets when this happens (recall that they were already discussed earlier in this module):

1. **Controlled cooldown of the HT system and boilers***;
2. **Turbine trip or load rejection**;
3. **Unit unloading** (if turbine unloading leads reactor unloading);
4. **Unit loading** (if reactor loading leads turbine loading).

* Recall that in most CANDU stations, the boiler safety valves (and not the SRVs) are used for crash cooling.

The operating conditions listed in points 2 and 3 are typically followed by **poison prevent operation** during which the SRVs handle all the surplus steam that cannot be accepted by the turbine. The objective of this operation is to allow for keeping the reactor power high enough to prevent reactor poisoning. More information regarding this mode of unit operation can be found in module 234-13.

The above list must be supplemented with one more item that may require some explanation:

5. **Unit startup.**

   Starting up a nuclear reactor is a complex process, even if no constraints are placed on the boiler steam load. Similarly, starting up a large turbine generator is quite a task, even if there were no limits as to the availability of boiler steam.. Therefore during unit startup, it is convenient to maintain the reactor power high enough to slightly exceed the turbine steam demand. Any surplus boiler steam is then handled by the SRVs. This greatly simplifies the startup, because the requirements and limitations imposed on the nuclear side can be satisfied without affecting those present in the conventional side and vice versa.

The same approach is often used while warming up the HT system and the boilers. The reactor power is then kept somewhat above that required to bring about the selected heatup rate and the surplus heat is rejected by the SRVs.

Normally, a certain pressure error must be present (as shown in Fig. 3.2) for these valves to start opening. But there are a few exceptions. For example, during poison prevent operation this error offset is eliminated such that the valves can control the boiler pressure right at its setpoint. Also, upon a turbine trip or load rejection, BPC opens these valves without waiting for any pressure error. This fast action minimizes the resultant pressure transient considerably.

## Types of SRVs

The SRVs used in any CANDU unit are of two different sizes. The smaller valves have a combined capacity of about 5-10% of the full power steam flow. They are used during unit startup and to handle minor pressure transients, whereas more serious transients are accommodated by the larger SRVs.

Depending on the station, **the large SRVs discharge steam to either atmosphere or the turbine condenser** – the latter being the more typical arrangement. In the stations where these valves exhaust to atmosphere, they can handle essentially the whole full power steam flow. This large flow capacity stems from the possible use of these valves for crash cooling. During poison prevent operation, however, these valves normally handle only about 65-70% of the full power flow, with the reactor power reduced appropriately. This minimizes consumption of makeup water, while keeping reactor power high enough to prevent poisoning.

In the other stations, where the large valves exhaust to the condenser, they are commonly referred to as CSDVs which stands for condenser steam discharge (or dump) valves. Their combined capacity is usually limited to about 65-70% of the full power steam flow in order to prevent overloading of the condenser. This limit reflects the fact that compared with the turbine exhaust steam, each kilogram of the steam rejected by these valves possesses more heat because it has not lost any in the turbine. Because of this limit, full reactor power cannot be maintained when these valves operate. On the other hand, the limit is high enough to allow for successful poison prevent operation.

**In all CANDU stations, the smaller SRVs exhaust to atmosphere.** In the stations equipped with CSDVs, the smaller valves are called ASDVs

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which is short for atmospheric steam discharge (or dump) valves. Because the valves exhaust to atmosphere, they can be used even when the condenser is unavailable.

## Operating concerns regarding SRVs

⇔ *Obj. 3.4 f)*

Neither the atmosphere nor the main condenser is a perfect heat sink for the SRVs as far as unit operation is concerned. **In the case of the atmosphere, large losses of steam occur** when the valves open, causing the following operational concerns:

1. Increased consumption of makeup water and hence **increased operating costs.**
2. **The maximum possible duration of poison prevent operation is drastically limited.**

   This is caused by a rapid depletion of the makeup water inventory when reactor power is held at about 65-70% FP. The limit is about 1-1.5 hours unless the other units (in a multiunit station) share their own makeup water inventory. Within this time limit, chances for fixing the original cause of the turbine trip or load rejection that has initiated the poison prevent operation, are reduced. In the extreme case, this may be impossible, forcing a reactor poison outage.
3. Operation in this mode can be a nuisance for the nearby communities (a citizenship concern) because it generates a **loud noise.**

In the stations equipped with **CSDVs**, the following operating concerns exist:

1. **Limited availability and size of the condenser as a heat sink.**

   As opposed to the atmosphere which always exists as an infinite (for all practical purposes) heat sink, the condenser can accept only a limited heat flow and needs a few auxiliary systems to be able to function. Operational problems with any of these systems (eg. loss of the condenser cooling water) may severely restrict the condenser's ability to function and, in the extreme case, may render it completely unavailable. A forced outage due to reactor poisoning would result.

   Operational problems with the CSDVs may have a similar effect. Even if the valves are in perfect condition, their opening can be restricted to prevent damage to some other equipment. For example, recall from the preceding module that these valves are tripped in the closed position upon a very high boiler level.

   In most stations, the flow capacity of the CSDVs is limited to only about 65% of the full power steam flow. Therefore in these stations, the reactor power that can be handled by these valves is more limited than in the

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stations with large atmospheric SRVs. This makes prevention of reactor poisoning more difficult while recovering from a reactor trip or stepback.

2. **Increased risk of damage to the condenser and/or CSDVs.**

   Jets of hot boiler steam being dumped into the condenser can damage its internals if protective measures fail. This is covered in detail in module 234-5.

   As for the CSDVs, prolonged operation promotes their damage due to harsh operating conditions: the valves handle hot steam at very high velocity (due to a large pressure differential across the valves).

## SUMMARY OF THE KEY CONCEPTS

- When the normal control action of BPC is ineffective, an excessive boiler pressure can successively cause the steam reject valves to open, activate a reactor setback, and finally force some or all of the boiler safety valves to open.
- When the boiler pressure drops excessively below the setpoint, BPC reverts to the reactor leading mode and further turbine loading is inhibited. If the pressure dropped even more, turbine unloading would be carried out under control of BPC. Should this fail, dropping boiler pressure would finally result in turbine hardware unloading performed entirely by the turbine governing system (ie. with no BPC input).
- The steam reject valves open to cool the boilers and the HT system, upon a turbine trip, a load rejection or fast turbine unloading (when it leads reactor unloading). The last three events are usually followed by poison prevent operation which imposes a heavy load on the valves. The valves can also operate during reactor loading when it leads turbine loading. In addition, they are also used during unit startup to facilitate the overall unit control.
- The major operating concerns regarding discharging steam to atmosphere by the SRVs are increased cost of makeup water, a severe limitation on the duration of poison prevent operation, and the noise generated.
- Discharging hot boiler steam to the main condenser by the CSDVs increases chances for condenser and/or CSDV damage. The availability and size of the condenser heat sink are also reduced as compared with those of atmosphere. This reduces the chances of preventing reactor poisoning, following a reactor trip or stepback.

*Pages 47-48* ⇔

You can now do **assignment questions 11-18.**

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# TURBINE STEAM FLOW CONTROL DURING RUNUP AND WHEN THE GENERATOR IS SYNCHRONIZED

In this section, you will learn how turbine generator speed and load depend on the turbine steam flow, and how the latter is controlled by the turbine steam valves during normal operating conditions.

## Effects of the turbine steam flow rate on turbine generator speed and load

⇔ *Obj. 3.5 a)*

Recall that one of the major functions of the main steam system is to provide means of controlling the turbine steam flow. It turns out that varying this flow has quite different effects on the turbine speed and load, depending on the generator status.

**When a generator is connected to a large grid** (that is supplied by many other large generators), changes in its output are relatively small when compared to the overall grid load. Therefore, varying the steam flow to one turbine generator does not cause a fast change in the grid frequency. Hence, **the turbine generator speed remains approximately constant.** Even if the steam supply were isolated, the speed would not change (in this case, the generator would be driving the turbine). Since the speed stays constant, **varying the turbine steam flow changes only the generator output.**

Given enough time, any mismatch between the grid load and the generating capacity could eventually change the grid frequency. A special system (grid) control centre prevents this by matching the generating capacity to the electrical load (typically by loading or unloading preselected units, and purchasing power from the interconnected utilities when necessary).

**During turbine runup**, the generator is disconnected from all electrical load. Consequently, **varying the turbine steam flow affects only the turbine generator speed, and the generator load remains zero.**

## Types of turbine governing

⇔ *Obj. 3.5 b)*

The term *turbine governing* refers to the method that is used in a given turbine to control the steam flow and hence, the turbine generator speed and load. In CANDU stations, two types of turbine governing are used:

1. **Throttle governing** (also called **full arc admission**);
2. **Nozzle governing** (also known as **partial arc admission**).

These methods differ with respect to the arrangement of nozzles in the turbine first stage and operation of the governor valves (and, in some stations,

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also the emergency stop valves and intercept valves). Operation of the remaining turbine steam valves (ie. the reheat emergency stop valves and release valves) is not affected.

The arrangement of the turbine steam valves is shown in the pullout diagram at the module end. Note that steam is supplied to the HP turbine by four pipelines in parallel. In each line, one governor valve (GV) and one emergency stop valve (ESV) are installed. Each LP turbine is supplied with steam via two lines in parallel, each equipped with one intercept valve (IV) and, in most stations, one reheat emergency stop valve (RESV).

After this general introduction, let us now discuss each type of governing in more detail.

The principle of **throttle governing** is very simple: the whole flow of turbine steam is throttled (hence, the name of this governing). The throttling is identical in all the steam pipelines that are in parallel. Therefore, the **valves** that are controlling (throttling) the steam flow **operate in unison**: at any given moment, **their openings are** – in principle – **identical**. As a result, the pressure and temperature of the steam supplied via one pipeline do not differ from those in the other lines. Therefore, the individual steam flows are allowed to mix before they enter the turbine first stage. The mixing occurs inside the turbine casing, in the annulus chamber to which the steam admission pipes are connected. Consequently, at any steam flow rate (even when it is very small), all the nozzles in the first stage are supplied with steam. Since steam is admitted all around the turbine inlet arc, this method of governing is also called **full arc admission**.

Throttle governing is used in most CANDU stations. Between these stations, there are some differences regarding the steam valves that are involved in the governing. This is caused by turbine design differences in these stations (different turbine manufacturers and/or the age of the design). Two **major variations** of this method of governing are as follows:

1. In some stations, it is **performed solely by the governor valves** (GVs). They control the steam flow over the whole range of turbine speed (during runup) and load.
2. In other stations, **the GVs control the steam flow only when the turbine speed is close to the synchronous speed***. This occurs during the final stage of turbine runup, not to mention the normal operation. **During the initial phase of runup, the GVs stay fully open, and the steam flow is controlled by the emergency stop valves** (ESVs).

* Above 1650-1750 rpm, depending on the station.

Note that accurate control of a small steam flow by valves that are sized for the full power flow is difficult. To improve it, three methods are used.

First, **in some stations**, only two out of four GVs or ESVs are used during runup, while the other two valves remain closed.

Second, each valve that controls the small steam flow usually has a pilot valve (ie. a smaller disc placed inside the main disc) which throttles the steam flow while the main disc remains shut.

Third, in some stations, **the intercept valves (IVs) assist the GVs in controlling the small steam flow** that occurs **during turbine runup and operation at light loads**. Instead of being performed solely by the GVs, throttling is now distributed between them and the IVs. Therefore, for any given steam flow, the opening of the GVs is increased as compared with the situation when the IVs stay fully open. As a result, the accuracy of controlling the small steam flow is improved. Note that throttling of the IVs is used only when the steam flow is small. At medium and high turbine power, these valves stay fully open.

The principle of **nozzle governing** is to adjust the number of the turbine first stage nozzles that the steam is allowed to flow through. To achieve this, the nozzles are divided into a few groups (typically four). Each group of the nozzles is isolated from the others and supplied via its own pipeline with a GV as shown in Fig. 3.3 below.

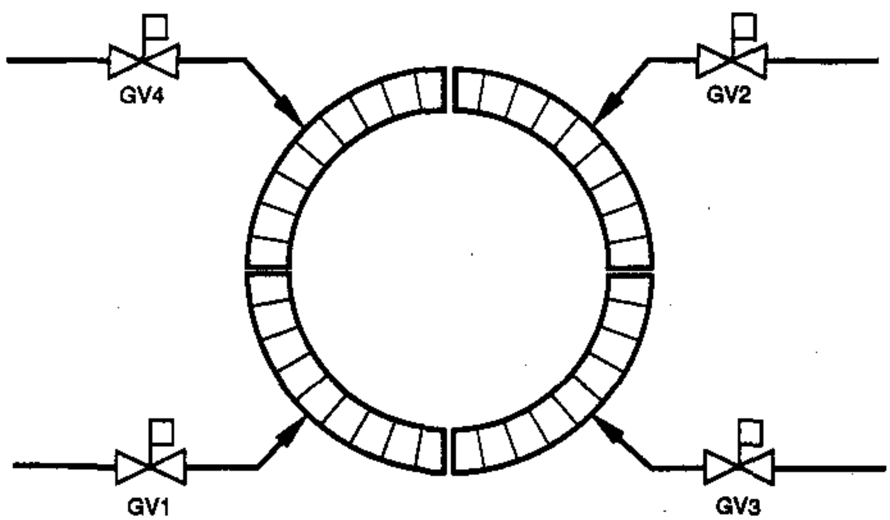


**Fig. 3.3. Nozzle governing - the arrangement of the turbine first stage nozzles and the governor valves (GVs).**

In this method of governing, the ESVs are not used for flow control. In CANDU units that employ this governing, the IVs are not used for flow control either. It is performed solely by **the GVs** which **operate**, in principle, **sequentially**. At very small steam flow rates, only GV1 is controlling, while the other GVs are closed. When GV1 is fully open and the steam demand increases further, GV2 starts opening. This continues until all the GVs are fully open. Note that over a large range of partial loads one

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or more of the GVs are closed, thereby isolating some nozzles in the first stage. This is why this method of governing is also known as **partial arc admission** (steam only enters on a portion of the turbine inlet arc).

The above description of valve operation is simplified and only illustrates the principle of nozzle governing. The actual valve operation is somewhat different to minimize some operational problems. Since this method of governing is used only in a few CANDU units, details are left for the station specific training.

For clarity, it must be stated that in this method of turbine governing, turbine nozzles are divided into groups **only in the first turbine stage**. You realize that once the steam has left the individual groups of nozzles, its pressure equalizes. This is because all the nozzle groups exhaust into the same common area (where the moving blades spin around). Since the inlet pressure to all the nozzles in the second stage (let alone, the other stages downstream) is equal, their separations into individual groups would make no sense.

## SUMMARY OF THE KEY CONCEPTS

- Varying the turbine steam flow during turbine runup changes the turbine speed, while the generator load remains zero.
- When the generator is connected to a large grid, varying the turbine steam flow affects the generator output and the speed remains approximately constant.
- In throttle governing, the turbine steam valves operate in unison, and the turbine first stage nozzles are not divided into separate groups.
- During turbine runup, throttle governing is performed by different valves, depending on the station. In some stations, the GVs are used over the whole speed range. In other stations, the GVs control the flow only when turbine speed is close to 100%. In those stations, the ESVs control the steam flow (with the GVs fully open) at lower turbine speeds.
- In some stations, the IVs assist the GVs in throttling the very small steam flow that occurs during turbine runup and at light loads. This improves the accuracy of flow control.
- In all stations, turbine load is controlled by the GVs.
- In nozzle governing, the turbine first stage nozzles are divided into a few groups, each of them having its own steam supply line. In principle, the GVs operate sequentially. The ESVs and the IVs are not used for flow control.

***Pages 48-49*** ⇔

You can now do **assignment questions 19-21.**

# ACTION OF MAJOR TURBINE STEAM VALVES IN RESPONSE TO TYPICAL UNIT UPSETS

Proper operation of the turbine steam valves in response to various unit upsets is vital because equipment safety – and sometimes personnel safety as well – depend on it. Therefore, it is very important that you know how and why these valves operate during these emergency conditions. In this section, you will learn about action of the turbine steam valves in response to the following upsets:

- Reactor trip;
- Turbine trip;
- Load rejection.

The last two terms are described in more detail. For the turbine trip, you will learn about its general purpose, typical causes and two major types. As for the load rejection, you will find out how it differs from a turbine trip, and how and why turbine speed varies.

## REACTOR TRIP

### Required response regarding the turbine steam flow

*⇔ Obj. 3.6 a)*

On a reactor trip, and particularly when from a high power level, the heat input to the unit is drastically decreased. In response, **the GVs close gradually* to reduce the turbine steam flow** in an attempt **to match** the reduction in **the heat input**.

* The valve action is described in more detail on the next page.

Failure to do this would result in very fast cooling of the boilers and the heat transport (HT) system. The reason is that much more heat would be removed with boiler steam than would be supplied by the reactor and HT pumps. Due to the cooling, the boiler temperature (thus, pressure) and the coolant temperature would drop rapidly. The resultant **coolant shrink** would be so fast and so large that the HT pressurizing system could not prevent the coolant pressure from dropping.

Note that with dropping boiler pressure, the turbine steam flow would be decreasing, thereby reducing the rate of heat removal from the boilers and the HT system. After several minutes, a new thermal equilibrium would be reached where the boiler temperature/pressure and the coolant temperature would stabilize at a low level, and the HT pressurizing system would restore the normal coolant pressure.

Nonetheless, the transient fast drop in the boiler steam and reactor coolant temperature and pressure causes the following **operating concerns**:

1. **Excessively low HT pressure** could result in some of the reactor coolant flashing to steam. The presence of large quantities of vapour in the coolant could have the following adverse consequences:

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a) In the fuel channels – **impaired fuel cooling** could possibly lead to some fuel sheath defects.

b) In the **HT pumps – severe cavitation**, possibly on the verge of vapourlocking, would:

i) Reduce the pump capacity and hence, further **impair fuel cooling**;

ii) Produce **heavy vibration** of the pumps and the HT system pipework which, in the extreme case, could cause their failure.

2. Fast dropping boiler steam and reactor coolant temperatures would result in **large thermal stresses in the HT system, boilers, main steam system and the turbine**. Although acute damage would be very unlikely, the large and fast changing thermal stresses would reduce the equipment life through fatigue. **Extensive nondestructive tests might be required** to confirm the equipment integrity.

*Obj. 3.6 b)* ⇔

## Action of major turbine steam valves on a reactor trip

In order to avoid these consequences, **the turbine steam flow must be reduced** in response to a reactor trip. To minimize the disturbing effect of the trip on boiler pressure, the steam flow should be reduced **at a rate at which the boiler heat input decreases**. Note that although the trip reduces reactor thermal power very quickly, the boilers continue – for several more seconds – receiving the reactor coolant essentially as hot as during normal operation. The delay is caused mainly by the time it takes the coolant to flow from the reactor to the boilers. As a result, the turbine steam flow is not stopped abruptly – instead, it is reduced gradually by the GVs.

* More information on turbine runback is provided in module 234-7.

* Motoring is described in module 234-13.

Normally, this action occurs under control of BPC. When the reactor trips, **BPC** reverts to the reactor leading mode (if it worked in the reactor lagging mode prior to the trip), and **initiates a turbine runback***. Should this fail to occur, the dropping boiler pressure would result in a **turbine hardware unloading** as already outlined in the BPC section of this module. One way or the other, **the GVs are eventually fully closed**, and the unit begins a mode of operation called motoring*.

What about the **other turbine valves**? **In principle**, they all **stay in the same position as prior to the reactor trip**. This facilitates steam readmission to the turbine once the trip has been cleared. The following exceptions apply:

* More information about these valves is provided in module 234-6.

1. **The check valves in the extraction steam pipelines close***;

2. **The IVs close partially** (applies to some stations only).

Recall that, in some stations, the IVs assist the GVs in controlling the turbine steam flow when it is fairly small. In these stations, the opening of the IVs is correlated to that of the GVs such that the IVs are partially

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open when the GVs are closed. This prepares the IVs for assisting the GVs in flow control once some steam is readmitted to the turbine.

Action of the turbine steam valves on a reactor stepback or setbacks is similar, except that it may be slower (in the case of setbacks), and that the GVs may be partially open in their final position (in the case of partial stepbacks and setbacks).

# TURBINE TRIP

## Purpose and typical causes

⇔ *Obj. 3.7 a)*

**The main purpose** of a turbine trip is to prevent, or at least minimize, damage to the turbine generator and/or other equipment (eg. the main transformer) which could very likely occur if operation were continued.

⇔ *Obj. 3.7 b)*

There are many possible **causes of turbine trips**. It may be an operator error or an instrumentation malfunction resulting in a spurious trip. Typically, however, it is a legitimate operational problem. Listed below are several samples:

1. **Loss of lubricating oil pressure.**

   The purpose of the turbine trip is to prevent/minimize damage to all the equipment (mainly the turbine generator bearings) supplied with the oil.

2. **Very high bearing vibration.**

   The objective of the turbine trip is to prevent/minimize damage to the turbine generator internals, bearings, etc. due to excessive vibration.

3. **Very high boiler level.**

   As outlined in the preceding module, this upset promotes damage due to water hammer in the steam pipelines, and water induction in the turbine. The turbine trip aims at their prevention.

4. **Low condenser vacuum.**

   This could result in damage to the last stage(s) of the LP turbine and/or its exhaust hood due to overheating and increased blade vibration*.

5. **Electrical fault** in the generator, main transformer, unit service transformer or the associated equipment.

   For example, a phase-to-phase or phase-to-ground fault can produce extremely large currents capable of inflicting severe damage very quickly.

6. **High turbine overspeed.**

   It jeopardizes the turbine generator integrity, mainly due to large centrifugal stresses. Possible damage to the equipment can be extremely severe*.

* Low vacuum, LP turbine overheating and blade vibration are discussed in more detail in modules 234-4, 234-5, 234-13 and 234-14.

* Details are described in module 234-13.

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## Types of turbine trips

*Obj. 3.7 c)* ⇔

No matter what its cause, **every turbine trip includes two major actions**:

1. **The generator must be disconnected quickly from all its electrical loads** such that possible electrical faults (as mentioned in point 5 above) can be cleared and a turbine rundown can quickly begin.
2. **The turbine steam flow must be stopped quickly** to prevent excessive overspeed when the generator is disconnected from the grid.

This brings us to two different **types of turbine trips**:

1. **Sequential trips.**

   During these trips, the turbine **steam flow is stopped first.** Only when this is confirmed to have happened (typically, by detecting a reverse power flow in the generator, ie. from the grid to the generator), do the generator circuit breakers open.

   Recall that the normal turbine speed is maintained regardless of the steam flow as long as the generator is connected to the grid (assuming its normal frequency). Hence, **the above sequence of the two major actions prevents a turbine overspeed** which could otherwise compound to the original problem that has caused the trip. This is the reason why **sequential trips are preferred.**

2. **Nonsequential trips.**

   During these trips, the **generator circuit breakers open concurrently with or prior to the stopping of the turbine steam flow.** Since they do not prevent an overspeed, nonsequential trips are carried out only when it is absolutely necessary. Their two **major causes** are:

   a) **Electrical faults.**

      Due to very **large fault currents**, severe damage to the affected electrical equipment can occur so fast that there is just **no time to delay the opening of the circuit breakers.** A chance must be taken that the turbine steam valves will operate properly, minimizing the turbine overspeed to a safe level. Though both the major actions are initiated roughly at the same time, opening of the generator circuit breakers is much faster than stopping the turbine steam flow.

   b) **High turbine overspeed.**

      Ignoring severe grid upsets, abnormally high overspeed can happen only when the generator is disconnected from the grid (eg. during a turbine runup or following a load rejection), and some of the turbine steam valves fail to operate as required. Since the generator circuit breakers are already opened when the overspeed trip occurs, this trip is inherently nonsequential.

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Among all turbine upsets, this is the one during which the highest overspeed can occur. While most likely the trip would prevent damage, the fact that overspeed has risen so much would indicate serious malfunction of some turbine steam valves and/or the governing system. The malfunctioning equipment would have to be repaired before continued operation is allowed.

## Action of major turbine steam valves during a turbine trip

⇔ *Obj. 3.7 d)*

Recall that upon any turbine trip, steam supply to the turbine must be stopped quickly. Obviously this means cutting off the boiler steam flow to the HP turbine. But this is not enough. In big turbines, large quantities of steam are inside the HP turbine, moisture separators, reheaters and the interconnecting pipelines. If this steam were allowed to flow through the LP turbines, a large driving torque would be produced.

The extraction steam pipelines and feedheaters are another potential source of steam supply to the turbine. Not only are large quantities of steam present in there, but also the hot condensate inside the feedheaters would flash to steam when subjected to a low pressure. Note that once the main steam flow through the turbine is stopped, the turbine pressure quickly approaches the condenser pressure. The low pressure could draw large quantities of steam from the feedheaters to the turbine where it would produce a driving torque.

Another possible source of steam to the turbine is through many leaking reheater tubes. Live steam, supplied through a large reheater tube leak, can continue to drive the turbine even after the other sources of steam have been cut off.

Whatever its cause, the increased driving torque could result in excessive turbine overspeed (during a nonsequential trip) or increased delay in opening of the generator circuit breakers (during a sequential trip) – both promoting equipment damage. To prevent this, **the following turbine steam valves close quickly upon a turbine trip**:

1. **Emergency stop valves** (ESVs) cut off steam supply to the HP turbine.
2. **Governor valves** (GVs) back up the ESVs and thus increase the reliability of stopping the steam flow to the HP turbine.
3. **Reheat emergency stop valves** (RESVs) stop the steam flow to the LP turbines. Some early CANDU units do not have these valves.
4. **Intercept valves** (IVs) back up the RESVs (if there are any), and hence ensure stopping of the steam flow to the LP turbines.
5. **Check valves in the extraction steam pipelines** prevent a backflow of steam to the turbine.

In addition to the above, **release valves** (RVs), **or their equivalents** as outlined below, **open quickly** to release to the condenser the steam trapped inside the turbine set between the closed GVs and IVs. Note that, due to lack of a net flow, the pressure of the trapped steam tends to equalize. As a result, the HP turbine exhaust pressure can rise above its normal full power level. This could be particularly bad if a malfunction caused some GVs/ESVs to close slower than the IVs/RESVs. **Opening of the RVs** therefore **prevents** the following problems:

a) **Possible overpressure** of the moisture separators, reheaters, the exhaust part of the HP turbine, and interconnecting pipelines;

b) **Increased driving torque** produced by the LP turbines due to failure of some IV(s) to close. This would result in increased overspeed on a nonsequential trip. And during a sequential trip, the generator disconnecting from the grid would be delayed*. In both cases, chances for equipment damage would be increased. This concern applies particularly to the few CANDU units that have no RESVs, because their absence increases greatly the risk of a flow path to the LP turbines being left open during a turbine trip.

* Recall that during a sequential trip, the generator circuit breakers open only when it is confirmed that the turbine steam flow has been stopped.

There are many differences in the RVs used in different stations. The largest flow capacity RVs are installed in the few units that have no RESVs. For the steam trapped inside the turbine set, the large RVs create a preferred, low-resistance flow path to the condenser, thereby decreasing the amount of the steam that would drive the LP turbines due to IV failure. Newer CANDU stations are equipped with RESVs in series with the IVs which greatly increases the reliability of stopping the steam flow to the LP turbines. Therefore, large RVs are not necessary, and either only small RVs or no RVs at all are installed. In the latter case, some other valves (eg. moisture separator drains dump valves), whose primary function is quite different, open upon a turbine trip to release the trapped steam. For better overpressure protection, the RVs or their equivalents are backed up by bursting discs or safety valves.

**The speed at which the turbine steam valves operate is very important** in ensuring effective protection of the equipment when an operational problem calls for a turbine trip. Normally, these valves need about 0.5 seconds to reach their safe position.

## SUMMARY OF THE KEY CONCEPTS

- On a reactor trip, the turbine steam flow is gradually reduced by the GVs (assisted by the IVs, in some stations). This action prevents an excessive drop in the HT system pressure, and a fast drop in the boiler steam and reactor coolant temperatures with all their adverse consequences.

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- The main purpose of a turbine trip is to prevent/minimize damage to the equipment which could likely happen if operation were continued.
- During a sequential turbine trip, the turbine steam flow is stopped first, and then the generator circuit breakers open. This prevents a turbine overspeed and is the reason why sequential trips are preferred.
- During a nonsequential turbine trip, the generator circuit breakers open concurrently with or prior to the action of the turbine steam valves to stop the steam flow. Some overspeed is unavoidable. Two major operating events that result in a nonsequential turbine trip are an excessive turbine overspeed and various electrical faults in the generator or its electrical auxiliaries.
- Upon a turbine trip, most of the turbine steam valves close quickly to stop steam supply to the turbine. The only exceptions are the release valves or their equivalents that open to release the steam trapped inside the turbine set between the closed GVs and IVs.

## LOAD REJECTION

### Differences in comparison with a turbine trip

A load rejection refers to an operational upset when **the generator is quickly disconnected from the grid in response to some acute grid problem**, eg. due to a lightning strike. The two major differences between a load rejection and a turbine trip:

1. **It is the grid, and not the unit, that is having a problem.**

   Therefore, there is no need for a turbine rundown. On the contrary, it would postpone and complicate resynchronization with the grid (once the grid problem has been cleared) because the turbine generator speed would have to be raised first.

2. Although disconnected from the grid, **the generator is still supplying the unit service load.**

   This is done to minimize the risk of a loss of Class IV power. Note that chances of this upset are increased because disconnection of the generator from the grid has already disabled one of the sources of Class IV power.

### Turbine speed transient on a load rejection

Immediately after disconnecting the generator from the grid, turbine generator speed rises rapidly. This happens because a load rejection reduces the generator countertorque instantaneously (to a level that corresponds to the unit service load, which is typically 6-7% FP). The resultant surplus of the turbine driving torque over the reduced generator countertorque causes the *⇔ Obj. 3.8 b)*

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machine to accelerate. The higher the power level prior to the load rejection, the worse the mismatch between the two torques. Consequently, the acceleration increases.

***Obj. 3.8 a)*** ⇔

In the event of a full load rejection, failure to quickly remove the driving torque would result in such a **rapid acceleration** that it would take just **a few seconds** for the speed to reach a level where catastrophic damage could occur. This represents the **major operational hazard by a load rejection**, particularly when from a high initial power level.

***Obj. 3.8 b)*** ⇔ ***Continued***

To prevent excessive overspeed, the turbine steam flow must be quickly stopped. This requires fast operation of the turbine steam valves. If the valve performance is fine, the maximum turbine overspeed is well below the turbine overspeed trip level (the latter is usually about 110-112% of the synchronous speed).

Though the turbine steam valves cut off the steam supply to the turbine very quickly (usually in less than 0.5 second), the steam that is already inside the turbine continues to expand. Therefore, turbine speed keeps rising, and the maximum overspeed is reached a few seconds after the generator breakers have opened.

Once most of the steam inside the turbine has expanded, the retarding torque (produced mainly due to the service load on the generator) predominates and the speed starts dropping. If no steam were readmitted to the turbine, its speed would continue dropping below 100% and the service load would be supplied at a lower and lower frequency. To avoid this, enough steam must be admitted to the turbine to stabilize its speed as close to 100% as possible. This also simplifies resynchronization with the grid when it is ready for it.

Fig. 3.4 below shows two variations of the turbine overspeed transient on a full load rejection.

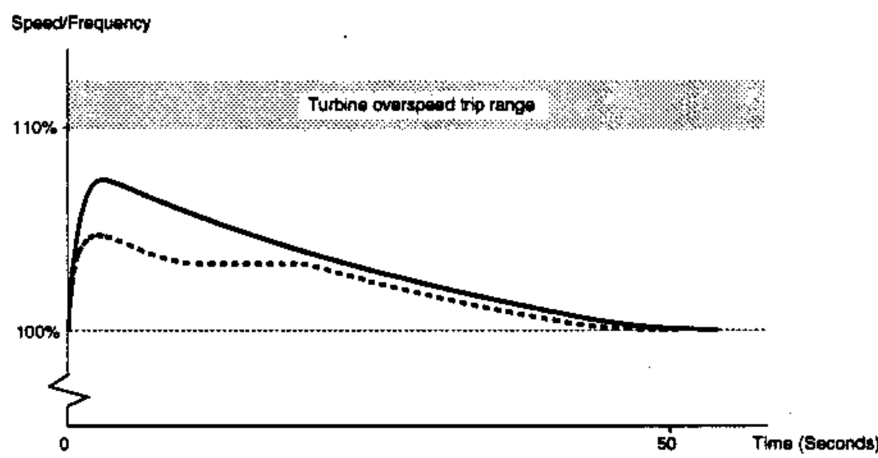


**Fig. 3.4. Typical turbine overspeed transient on a full load rejection.**

——— Older units with slower governing systems;

- - - - - - - Newer units with faster governing systems.

In Fig. 3.4, normal performance of the turbine steam valves is assumed. This is why the overspeed peak is well below the overspeed trip range. Speaking of the overspeed peak, you have probably noticed that its level in the two graphs of Fig. 3.4 is different. This reflects different speeds of turbine steam valve operation in different stations. From the sketch, you can also see that the two transients differ somewhat in their dropping speed phase. This is caused by different operation of the intercept valves in different stations as explained on page 38.

## Action of major turbine steam valves on a load rejection

*⇔ Obj. 3.8 c)*

To summarize the above, action of the turbine steam valves on a load rejection must accomplish two **major goals**:

1. At the onset of the load rejection, the valves must **cut off the steam supply quickly** to prevent an excessive overspeed that would require a turbine overspeed trip.
2. Later on, when the dropping turbine speed approaches 100%, the valves must **readmit** enough **steam** to maintain the normal speed, and thus, supply the unit service load at the 60 Hz frequency.

These two general goals of the valve operation apply to every station. There are, however, some station specific differences regarding the operation of individual valves. This reflects different types of the turbine governing system and different arrangements of the turbine steam valves used in different CANDU stations. For simplicity, the description below ignores the least common cases and assumes that the transient overspeed has not reached the turbine overspeed trip level. Here is how individual turbine steam valves operate during a load rejection:

1. **Emergency stop valves** (ESVs).

   **In most CANDU stations**, the other valves are fast enough to handle full load rejections. Therefore, **the ESVs stay open**. The advantage of this is that when the overspeed transient is over, steam readmission to the turbine is facilitated as these valves do not have to reopen.

2. **Governor valves** (GVs).

   **Initially, they close quickly** to stop the steam flow to the HP turbine, and hence limit the overspeed transient. **When the normal speed is approached, the valves open slightly** to admit enough steam to maintain the normal turbine speed.

3. **Reheat emergency stop valves** (RESVs).

   In all stations where these valves are installed, they **stay open** during load rejections. This facilitates steam readmission to the turbine as mentioned in point 1 above.

4. **Intercept valves** (IVs).

   In all stations, **at the onset of a load rejection, the IVs close quickly** to stop the steam flow to the LP turbines. Recall that in order to limit the transient overspeed satisfactorily, the steam that has passed the closing GVs and is flowing through the HP turbine, moisture separators, reheaters and interconnecting pipelines must be prevented from entering the LP turbines.

   **When the dropping turbine speed approaches 100% and while the GVs are still fully closed, the IVs reopen.** Their opening may be full or partial, slow or fast, depending on the station. Typically, they open only partially*. But in some stations, the IVs open fully to reestablish the normal flow path through the LP turbines.

   * Recall that this is done to assist the GVs in controlling the small steam flow when the generator is supplying the service load.

   The rate at which the IVs reopen also varies from station to station. In the early CANDU stations, where release valves (RVs) are installed, the IVs open quickly. By that time, the steam that was trapped inside the turbine upstream the IVs has been released to the condenser via the RVs. Therefore, opening of the IVs has no effect on the rate at which the turbine speed is dropping (see the solid line graph in Fig. 3.4).

   In the new CANDU stations, no dedicated RVs are installed. Their equivalents are of a relatively small size, and cannot quickly remove the trapped steam. Therefore, a significant quantity of this steam is still present in the turbine, when the IVs start reopening. If released too quickly, this steam would drive the turbine enough to cause it to overspeed again. To prevent it, the IVs reopen slowly. During this process, turbine speed remains approximately constant until most of the trapped steam has been released. Then, turbine speed resumes dropping again (see the dashed line graph in Fig. 3.4).

5. **Release valves** (RVs) or their equivalents.

   **Initially, these valves open quickly** to release to the condenser the steam trapped inside the turbine set between the closed GVs and IVs. This action serves the purposes outlined in the turbine trip section of this module.

   Prompt opening of the RVs also prevents a turbine trip on HP turbine exhaust pressure. Available in most stations, this trip should occur before the pressure reaches a level at which the reheater safety valves or bursting discs (depending on the station) operate. Note that the generator cannot be quickly returned to the grid if such a trip has occurred. Instead, the cause of overpressure would have to be corrected first. This loss of production can be avoided if the RVs operate properly.

   **After the IVs have reopened on dropping turbine speed, the RVs reclose** to establish the normal flow path through the LP turbines. In the stations, where no RVs are installed, their substitutes (eg.

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moisture separator drains dump valves) close and resume their primary function, once steam is readmitted to the turbine.

6. **Check valves in the extraction steam lines.**

   **At the onset of a load rejection, these valves close** to prevent a backflow of steam to the turbine, and hence minimize the transient overspeed. **When steam is readmitted to the turbine, the valve actuators open, but the valves remain closed*** because their discs cannot be lifted by extraction steam at very low pressure**.

* The lost motion linkage between the valves and their actuators is described in module 234-6.

** Recall from module 234-1 how the turbine steam pressure profile changes with load.

## SUMMARY OF THE KEY CONCEPTS

- The major hazard to the turbine generator represented by a load rejection is an excessive overspeed which could result in catastrophic failure.
- The RESVs and, in most stations, the ESVs do not operate on a load rejection because the remaining turbine steam valves are fast enough to handle this upset.
- The main objective of the turbine steam valve action at the onset of a load rejection is to limit the transient overspeed.
- To meet this objective, the GVs, the IVs and the extraction steam check valves close quickly to cut off steam supply to the turbine. In turn, the RVs open to release to the condenser the steam trapped inside the turbine set between the closed GVs and IVs.
- As the dropping speed approaches 100%, the objective of the valve operation is to control the turbine steam flow such that the service load is supplied at the 60 Hz frequency and the generator is ready for resynchronization with the grid.
- To achieve this goal, the GVs open partially. The IVs open partially or fully (depending on the station), and the RVs close. The extraction steam check valves remain closed because the extraction steam pressure is too low to lift their discs.

You can now work on **assignment questions 22-28.**

⇔ *Pages 49-52*

# TURBINE STEAM VALVE TESTING

## Timing of the testing

⇔ *Obj. 3.9 a)*

Recall that the consequences of failure of the turbine steam valves to respond properly to major unit upsets can be very severe. It is therefore crucial that the valves be maintained fully capable of performing their intended functions. To ensure this, valve tests are performed under the following operating circumstances:

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1. **During turbine startup prior to steam admission to the turbine;**
2. **Following any maintenance that might have affected the valve performance;**
3. **At regular intervals** (eg. once a month) **when the unit is running.**

In base load units which run nonstop for long periods (sometimes exceeding one year), these **routine on-power tests** are the ones that are performed most often. During these tests, one valve is tested at a time. This allows the unit to continue running, though with some fluctuations in the generator output.

*Obj. 3.9 b)* ⇔

## Purpose of routine on-power tests of major turbine steam valves

The three major reasons why such tests are periodically performed are:

1. **To discover failed valves** such that they can be repaired or placed in the safe position **before a dangerous multiple valve failure can develop.**

   Note that due to the arrangement of the turbine steam valves, **a single valve failure cannot result in severe damage to the equipment.** This is achieved by placing ESVs and GVs, and similarly RESVs and IVs in series. In each pair, only one valve has to operate to stop the steam flow. Recall that if no RESVs are installed, the large capacity RVs would reduce the adverse consequences of failure of an IV to close. In turn, the RVs (or their substitutes) are backed up by safety valves, or rupture or lifting discs. And finally, failure of a single check valve in the extraction steam piping is not sufficient to produce a catastrophic overspeed.

   However, **certain multiple valve failures** (eg. the ESV and GV in the same line) **are very dangerous.** Such failures could result in serious damage and, in the extreme case, a safety hazard to personnel.

   Of course, any single valve failure increases the risk of a dangerous multiple valve failure. This is why **even a single valve failure is potentially dangerous, particularly if undetected over an extended period of time.** Routine on-power tests minimize this risk.

2. **To prevent an excessive buildup of deposits on valve stems and hydraulic components of the turbine governing system.**

   Recall that **carryover of various salts** and silica in boiler steam promotes their deposition on the steam valve stems. At the same time, corrosion products and/or other **impurities in the hydraulic fluid** used in the turbine governing system have a tendency to collect in tight clearance areas in the hydraulic valve actuators, control and trip relays, etc. If allowed to accumulate excessively, such deposits could slow down the valve operation to a point that their safety function would be compromised, promoting a severe accident. Note that the valves do not have to be totally disabled – it is enough if their operation is just sluggish.

Because **base load units** operate at a steady power level for extended periods of time, their steam valves and associated hydraulic components in the turbine governing system remain in essentially the same position. This creates **excellent conditions for buildup of various deposits**, and has caused numerous valve failures in many stations in the world. This can be prevented by stroking the valves during their routine on-power tests to scrape the thin layer of deposits off. Needless to say, proper purity of the hydraulic fluid and boiler steam must be maintained, too.

3. **To ensure that the unavailability** (Q) **of the turbine steam valves** (ie. the fraction of time they are unavailable to perform their intended functions) **does not exceed the unavailability target** ($Q_T$), ie. $Q \leq Q_T$.

   Recall that $Q = \lambda T / 2$

   where: $\lambda$ = valve failure rate (failure/year);
   T = test intervals (years).

   Routine tests allow for verification of the assumed values of the failure rates ($\lambda$) for various valves. If the actual values are larger than those assumed, a corrective action (more frequent testing and/or design changes) can be taken to ensure that $Q \leq Q_T$.

Failure of a valve to pass a test can have a profound effect on the operation of the unit. In the extreme case, continued operation may not be allowed and the turbine must be shut down for valve repairs. However, the consequences vary widely, depending on the station and the type of the failed valve. The most severe consequences apply to faulty ESVs and GVs. Details are left for the station specific training.

## SUMMARY OF THE KEY CONCEPTS

- Turbine steam valves are tested during turbine startup, following any maintenance that might have affected the valve performance, and routinely when the unit is running.
- Routine on-power tests of the turbine steam valves are performed for three major reasons. First, to discover failed valves before a dangerous multiple valve failure has a chance to develop. Second, an excessive buildup of deposits on the valve stems and in their hydraulics is prevented when the valves are stroked. Finally, the assumed valve failure rate

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is verified, and corrective actions taken if necessary, to ensure that the valve unavailability does not exceed its limit.

***Page 53*** ⇔

You can now do **assignment questions 29-31.**

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## ASSIGNMENT

1. a) Large thermal stresses in the steam system occur (at steady full power operation / when the steam temperature or flow changes).

   b) Excessive thermal stresses in the steam system during cold start-up are prevented by the following operating practices:

      i) ______________________________

      ______________________________

      ii) ______________________________

      ______________________________

2. a) Pipeline vibration levels can change with unit load because

   ______________________________

   ______________________________

   ______________________________

   ______________________________

   ______________________________

   b) In a steam system that suffers no vibration problem during normal operation over the whole power range, excessive pipeline vibration can be experienced due to:

      i) ______________________________

      ______________________________

      ii) ______________________________

      ______________________________

   c) The following general operating practices are used to prevent prolonged operation with excessive steam pipeline vibration:

      i) ______________________________

      ______________________________

      ii) ______________________________

      ______________________________

   d) Turbine unloading may be able to reduce steam pipeline vibration because ______________________________

   ______________________________

   ______________________________

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3. a) The rate of condensate collection in the steam system is particularly high during ____________ because:

   i) ______________________________

   ______________________________

   ii) ______________________________

   ______________________________

   b) The usual method of monitoring steam trap performance is to

   ______________________________

   ______________________________

   Proper operation of the trap is indicated by ______________

   ______________________________

   c) The drain valves in the steam system should be open whenever

   ______________________________

   d) The reason why steam should not be readmitted to the turbine immediately following its trip upon a very high boiler level is

   ______________________________

   ______________________________

   ______________________________

4. a) In the steam system, steam hammer can occur when ________

   ______________________________

   ______________________________

   ______________________________

   b) To prevent steam hammer, the drain valves should be operated as follows:

   i) ______________________________

   ______________________________

   This practice achieves its purpose by ______________

   ______________________________

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ii) ______________________________

______________________________

This practice achieves its purpose by ______________

______________________________

5. a) To provide adequate overpressure protection during all operating conditions, the boiler safety valves must be capable of removing safely the steam flow equivalent to ______________

______________________________

This requirement accounts for ______________

______________________________

______________________________

b) If too many valves are unavailable for overpressure protection, the following actions must be taken:

i) ______________________________

in order to ______________________________

ii) ______________________________

in order to ______________________________

6. a) Safety valve blowdown is defined as ______________

______________________________

______________________________

b) Safety valve simmer is defined as ______________

______________________________

c) Safety valve chatter is defined as ______________

______________________________

7. a) When the lifting pressure of a boiler safety valve is set too high, the following adverse consequences/operating concerns result:

i) ______________________________

______________________________

ii) ______________________________

______________________________

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b) When this setting is too low, it causes the following adverse consequences/operating concerns:

i) If no corrective actions were taken: ________________

________________________________________

________________________________________

________________________________________

________________________________________

ii) If the valve were quickly shimmed or removed from service:

________________________________________

________________________________________

8. a) A blowdown setting of a safety valve that is too high can result in

________________________________________

________________________________________

b) The adverse consequence/operating concern caused by a blowdown setting of a boiler safety valve that is too low is

________________________________________

9. Loss of hot boiler steam through a faulty/malfunctioning boiler safety valve has the following adverse consequences:

a) ________________________________________

b) ________________________________________

c) ________________________________________

d) ________________________________________

10. a) Boiler safety valves are tested routinely in order to __________

________________________________________

________________________________________

b) Their testing frequency is determined by the more restrictive of the following:

i) ________________________________________

________________________________________

ii) ________________________________________

________________________________________

11. Major functions of the BPC program are:

    a) ______________________________

    b) ______________________________

12. The BPC program adjusts the boiler pressure setpoint during the following unit operating states:

    a) ______________________________

    b) ______________________________

13. Under the assumption of a constant boiler pressure setpoint over the whole reactor power range, boiler pressure changes as follows during each of the following operating states:

| Operating state | Boiler pressure |
|---|---|
| Cooling of the boilers and the HT system | (drops / rises) |
| Load rejection | (drops / rises) |
| Reactor trip, stepback or setback | (drops / rises) |
| Unit loading in the reactor lagging mode | (drops / rises) |
| Unit loading in the reactor leading mode | (drops / rises) |
| Turbine trip | (drops / rises) |
| Unit unloading in the reactor lagging mode | (drops / rises) |
| Unit unloading in the reactor leading mode | (drops / rises) |
| Warming of the boilers and the HT system | (drops / rises) |

14. To maintain boiler pressure at its setpoint, BPC adjusts the following parameter:

    a) ______________________________

    when the unit operates in the reactor lagging mode.

    b) ______________________________

    when the unit operates in the reactor leading mode.

15. Suppose that a CANDU unit is operating in the reactor leading mode at full power when the reheat steam is suddenly cut off in response to reheater problems.

    a) Boiler pressure would initially (drop / rise) as a result of this upset.

    b) BPC would attempt to return boiler pressure to its setpoint by

    ______________________________

    ______________________________

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c) This action may be unsuccessful due to ________________

________________________________________

In this case, BPC would ________________________

16. Listed in the order of increasing boiler pressure error, the following actions (other than normal control action of BPC) occur in response to:

a) Too high boiler pressure:

i) ________________________________

ii) ________________________________

iii) ________________________________

b) Too low boiler pressure:

i) ________________________________

________________________________

ii) ________________________________

iii) ________________________________

17. In the stations where all the SRVs discharge steam to atmosphere:

a) The duration of poison prevent operation is limited by

________________________________________

b) Two other operating concerns caused by discharging boiler steam to atmosphere are:

i) ________________________________

________________________________

ii) ________________________________

________________________________

18. Two concerns associated with operation of the CSDVs are:

a) ________________________________________

b) ________________________________________

19. The effect of increasing steam flow on the turbine speed and generator output is as follows:

a) During runup: ________________________________

b) When the generator is connected to a large grid: ____________

________________________________________

20. a) In throttle governing, the first stage nozzles (are / are not) divided into individual groups and the GVs operate (in unison / sequentially).

    b) In nozzle governing, the first stage nozzles (are / are not) divided into individual groups and the GVs operate (in unison / sequentially).

21. The turbine steam flow is controlled by the following valves:

| Turbine Status | Throttle Governing | Nozzle Governing |
|---|---|---|
| Runup | | |
| Synchronized | | |

22. Failure to reduce the turbine steam flow in response to a reactor trip causes the following adverse consequences/operating concerns:

    a) Due to an excessively low HT system pressure:

       i) ______________________________

       ______________________________

       ______________________________

       ii) ______________________________

       ______________________________

       ______________________________

    b) Due to the fast dropping boiler steam and reactor coolant temperatures:

       ______________________________

       ______________________________

       ______________________________

23. a) On a reactor trip, the steam flow is (gradually / rapidly) reduced by the ______________ valves.

    b) In some stations, this action is accompanied by the __________ valves which close (fully / partially). The purpose of this is:

       ______________________________

       ______________________________

    c) In addition, the extraction steam check valves (close / open).

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24. a) The general purpose of a turbine trip is ____________________

________________________________________

________________________________________

________________________________________

b) A turbine trip can be caused by operating events such as:

| Event | Hazard if operation continued |
|---|---|
| | |
| | |
| | |
| | |

25. a) Every turbine trip includes two major actions:

i) ________________________________

in order to ________________________________

________________________________

ii) ________________________________

in order to ________________________________

________________________________

b) The difference between sequential and nonsequential turbine trips is ________________________________

________________________________________

________________________________________

________________________________________

________________________________________

c) A sequential turbine trip would not be the correct response to an electrical fault in the generator or its auxiliaries because

________________________________________

________________________________________

________________________________________

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26. Upon a turbine trip, the turbine valves operate as follows:

| Valves | Action | Purpose |
|---|---|---|
| ESVs | | |
| GVs | | |
| RESVs | | |
| IVs | | |
| RVs* | | |
| Extr.stm. check valves | | |

* Or their equivalents.

27. The major hazard to the turbine generator represented by a load rejection is ________________________________________

____________________________________________________

28. a) The major differences between a load rejection and a turbine trip are:

i) ____________________________________________

____________________________________________

ii) ____________________________________________

____________________________________________

NOTES & REFERENCES

b) At the onset of a load rejection, the turbine valves typically operate as follows:

| Valves | Action | Purpose |
|---|---|---|
| GVs | | |
| ESVs | | |
| IVs | | |
| RESVs | | |
| RVs* | | |
| Extr.stm. check valves | | |

* Or their equivalents.

c) When the dropping turbine speed approaches 100%, the turbine valves typically operate as follows:

| Valves | Action | Purpose |
|---|---|---|
| GVs | | |
| ESVs | | |
| IVs | | |
| RESVs | | |
| RVs* | | |
| Extr.stm. NRV actuators | | |

* Or their equivalents.

NOTES & REFERENCES

29. Turbine steam valves must be tested under the following circumstances:

a) ______________________________

______________________________

b) ______________________________

______________________________

c) ______________________________

______________________________

30. Routine on-power tests of the turbine steam valves must be performed in order to:

a) ______________________________

______________________________

______________________________

b) ______________________________

______________________________

______________________________

c) ______________________________

______________________________

______________________________

31. a) Failure of a single turbine steam valve to operate as intended during a major unit upset (can / cannot) cause severe damage to the equipment and create a safety hazard to the personnel.

b) In base load units, the tendency for buildup of deposits on the turbine steam valve stems and in their hydraulics (is / is not) a serious problem because ______________________________

______________________________

c) Some of the major turbine steam valves do not have to be tested if their operational performance record is satisfactory (false / true).

Before you proceed to the next module, **review the objectives** and make sure that you have not overlooked any important issue.

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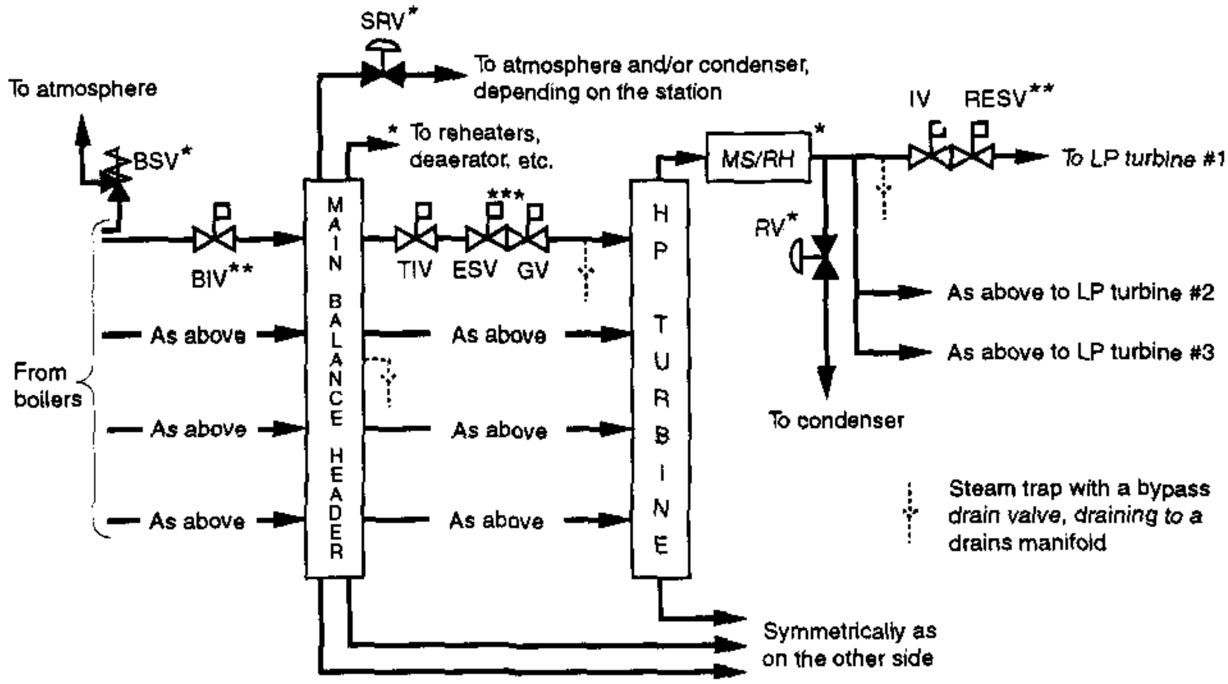


**Fig. 3.5. Simplified arrangement of the major steam valves in a typical CANDU unit:**

MS/RH = moisture separators and reheaters. For valve acronyms see the glossary.

* The exact number and location of this equipment depend on the station and may differ from those shown.

** Not in all stations.

*** Strainers are placed inside the valve casing.

## GLOSSARY OF VALVE NAMES

BIV = Boiler Isolating Valves (Steam Main Isolating Valves, Main Steam Isolating Valves);

BSV = Boiler Safety Valves (Boiler Safety Relief Valves, Main Steam Safety Relief Valves, Main Steam Safety Valves, Steam Generator Safety Valves);

ESV = Emergency Stop Valves (Main Stop Valves);

GV = Governor Valves (Control Valves, Main Control Valves);

IV = Intercept Valves (Intercept Control Valves);

RESV = Reheat Emergency Stop Valves (Intercept Stop Valves, Intermediate Stop Valves);

RV = Release Valves (Reheat Release Valves);

SRV = Steam Reject Valves (Atmospheric Steam Discharge Valves, Atmospheric Steam Dump Valves, Condenser Steam Discharge Valves, Condenser Steam Dump Valves);

TIV = Turbine Isolating Valves (Boiler Stop Valves, Steam Isolating Valves).