NOTES & REFERENCES

Module 234-13

SPECIAL MODES OF OPERATION AND MAJOR ACCIDENTS

OBJECTIVES:

After completing this module you will be able to:

13.1 a) Name and describe the mode of turbine generator operation that usually follows a reactor trip and may also follow a reactor stepback or setback. ⇔ *Pages 2-3*

b) For this mode of operation: ⇔ *Pages 3-5*

- i) Describe how boiler pressure is controlled;
- ii) Describe how feedwater heating is provided;
- iii) Explain three main advantages as compared with tripping the turbine in response to the reactor upset;
- iv) Explain four adverse consequences/operating concerns that may be caused by prolonged operation in this mode;
- v) Explain three factors that may limit its duration.

13.2 a) Name and describe the mode of unit operation that usually follows a turbine trip or a load rejection. ⇔ *Page 6*

b) For this mode of operation: ⇔ *Pages 6-7*

- i) Describe how boiler pressure is controlled;
- ii) Describe how feedwater heating is provided;
- iii) Explain three adverse consequences/operating concerns it causes;
- iv) Explain three factors that may limit its duration.

13.3 a) Describe five ways in which excessive overspeed can damage a turbine generator. ⇔ *Pages 8-11*

b) Describe six general operating practices used to protect the turbine generator from excessive overspeed. ⇔ *Page 11*

c) State five precautions that must be taken prior to and/or during actual overspeed testing of the emergency overspeed trip mechanism in order to prevent an overspeed accident. ⇔ *Pages 11-12*

NOTES & REFERENCES

13.4 For water induction to the turbine:

Pages 13-14⇔ a) Describe two sources of water;

Pages 14-16⇔ b) Describe three major ways in which it can damage the turbine;

Pages 16-17⇔ c) Describe three general operating practices used to prevent it;

Pages 17-18⇔ d) Explain three reasons why during turbine startup:

  i) The possibility of water induction is higher than during normal operation;

  ii) Damage to the turbine due to water induction may be particularly severe;

Page 18⇔ e) State its two typical indications;

Pages 18-19⇔ f) i) State two circumstances under which the turbine must be tripped in response to water induction;

Page 19⇔ ii) Explain two reasons why, when water induction is detected and the turbine is on load, it is generally better to continue running unless high vibration or another serious condition requires tripping;

Pages 19-20⇔ iii) State four conditions which must be met prior to restarting a turbine following an event when water induction has forced shutting it down.

* * *

INSTRUCTIONAL TEXT

INTRODUCTION

In this module, two special modes of operation are discussed: motoring and poison prevent operation. Also described are two major accidents: turbine generator overspeed and water induction to the turbine.

MOTORING

In this section, you will learn what motoring is, when and why it is carried out, what adverse consequences and operating concerns it causes, and what factors limit its duration.

Obj. 13.1 a) ⇔ Motoring is the mode of turbine generator operation during which the generator acts as a synchronous motor (hence the name of this operation), driving the turbine at the normal speed. Naturally, this takes energy from the grid*.

* At a rate of about 1-2% of the generator full power.

For motoring to happen, the generator must be connected to the grid (ie. the turbine generator and its auxiliaries must be fine), the grid must be able to supply the required energy (ie. no grid problems), and the turbine steam flow must be too small to maintain the normal turbine speed on its own. In most cases, the turbine steam flow is stopped (ie. the GVs are closed), and only a small flow of motoring cooling steam is admitted (in some stations).

If the above conditions are met, motoring **follows a reactor trip**. Otherwise, motoring is impossible and the turbine generator is tripped. This happens, for instance, when the reactor trip is caused by a loss of Class IV power*.

Motoring **may also follow** two other types of reactor upsets: **stepbacks** and **setbacks**. Recall that in response to either upset, the turbine steam flow is decreased. In the extreme case, the flow can be reduced enough to cause motoring. For the same reason, motoring also follows full or nearly full turbine runback (while shutting down the turbine or in response to some turbine generator problems).

⇔ *Obj. 13.1 b) i)*

During motoring, **boiler pressure is controlled by the steam reject (discharge) valves**. They handle the surplus boiler steam that is over and above all the other steam loads: motoring cooling steam (if any), gland sealing steam, air ejector driving steam (if any) and DA heating steam. The valves are used for boiler pressure control because other means of control are unavailable. For example, following one of the above reactor upsets, reactor power cannot be maneuvered (due to reactor problems), and the GVs are closed to minimize HP turbine cooling by significantly throttled steam. And in the case of motoring caused by large turbine runback, the GVs are busy executing the runback, and reactor unloading lags behind and is limited*, thereby necessitating the use of the steam reject valves.

⇔ *Obj. 13.1 b) ii)*

Since turbine extraction steam is unavailable during motoring, the LP and HP feedheaters are inoperative, and all the **feedwater heating** takes place in the DA supplied with throttled boiler steam. Because the feedwater flow is very small, the recirculation lines of the running BFPs are opened. The pump heat contributes to feedwater heating in the DA, and thus reduces the demand on boiler steam needed to maintain the proper DA pressure.

⇔ *Obj. 13.1 b) iii)*

Of course, in response to a reactor trip or a large stepback or setback, the turbine could be tripped. But motoring is a better response. Why? During motoring, the turbine generator remains connected to the grid and therefore, **a rundown, runup and resynchronization** with the grid **are avoided**. This results in the following **major advantages:**

1. **Faster return of the generator capacity to the grid.**

   First of all, chances for preventing a poison outage are improved. You will recall that a forced poison outage occurs if, following a reactor trip from full power, the reactor is not reloaded within about 40-45 minutes. Because reloading is a complex multistage process which takes time (the

* Recall that on loss of Class IV power, the generator trips on loss of excitation (in most stations) and/or the turbine trips on loss of vacuum.

* Recall that a high boiler pressure error can cause a reactor setback. The lowest reactor power that this action can effect is about 2 %FP.

shutoff rods must be withdrawn, then the absorber rods must be withdrawn, etc.), it must begin much earlier. This does not leave much time for diagnosing and fixing the reactor problem.

Since during motoring the turbine generator remains connected to the grid, the operator does not need to monitor its rundown, reset the turbine trip, and monitor the runup and resynchronization with the grid. As the operator can focus on the reactor problem, chances are increased that reactor reloading will begin early enough to prevent poisoning.

Second, since the generator is connected to the grid, the generator load follows the reactor load immediately. Note that if the turbine were tripped, generator loading would have to be delayed until runup and resynchronization have been completed. Meanwhile, the steam reject system would have to operate to accommodate the increasing reactor power. You will recall that steam rejection to atmosphere or the main condenser causes some adverse consequences/operating concerns, too.

2. **Reduced thermal cycling, and hence prolonged life, of the HP turbine.**

   Motoring eliminates turbine runup and resynchronization during which the hot HP turbine would be cooled with steam whose temperature would be much lower due to throttling by the steam admission valves (GSVs/ESVs, depending on the station). The cooled turbine would be then heated during loading which would complete a thermal cycle.

3. **Avoidance of potentially risky operating conditions that could result in machine damage.**

   These include:

   - Increased turbine generator vibration levels due to passing through critical speed ranges during turbine rundown and subsequent runup;
   - Incorrect synchronization (eg. out-of-phase);
   - Failure of turbine oil pumps to start as required during turbine rundown.

Obj. 13.1 b) iv) ⇔

However, motoring causes some **adverse consequences/operating concerns**, too. One problem that may develop is **overheating of the LP turbine exhaust**. Recall that during motoring, the LP turbine exhaust is subjected to heating caused by increased windage losses in the last stages. In these stages, the long blades, moving at their full velocity, churn the steam whose flow is drastically reduced (and can even be zero if the motoring cooling steam is unavailable). The small flow results in a very poor flow pattern in these stages and cannot carry away all the frictional heat that is produced due to the windage losses. This leads to elevated temperatures of the LP turbine exhaust.

Nevertheless, this heating of the LP turbine exhaust does not cause troubles if high condenser vacuum is maintained and the exhaust cooling system (exhaust hood sprays and, in most stations, motoring cooling steam) is operating properly. Otherwise, the turbine exhaust can get too hot*, particularly in the case of prolonged motoring.

* Possible turbine damage is described in module 234-4.

While the exhaust overheating can be prevented by adequate cooling of the turbine, prolonged operation of water sprays in the exhaust hood may result in **erosion of the unprotected trailing edge** of the moving blades in the last stage*.

* This is explained in module 234-4.

In addition, the very turbulent steam flow pattern is likely to result in **increased levels of blade vibration**, particularly in the last stage. This type of vibration, referred to as *stall flutter* or ***aerodynamic buffeting***, is described in the next module.

Finally, recall that **motoring consumes energy** (which costs) from the grid – about 1-2% of the generator full power*. For example, for a 900 MWe unit, it is about 10-20 MW, and may be more if windage losses in the turbine are increased due to poor condenser vacuum.

* You do not have to memorize this number.

⇔ *Obj. 13.1 b) v)*

The **duration of motoring** may be limited by a few factors. **First**, motoring ends as soon as the reactor problem is cleared and reactor power raised to a level at which enough boiler steam is produced to load the turbine generator.

Second, motoring is terminated, once it has become clear that reactor poisoning cannot be prevented. In this situation, motoring will not contribute to faster return of the generator capacity to the grid because the unit will be down for at least two days, whether motoring is continued or not. Thus, the major advantage of motoring is lost, while the adverse consequences are still present. As it does not pay to continue motoring, the turbine is tripped.

Third, problems with maintaining adequate condenser vacuum or malfunction of the LP turbine exhaust cooling sprays or motoring cooling steam may result in turbine overheating. The overheating may be sufficient to cause the LP turbine exhaust temperature, bearing vibration and/or axial differential expansion to force a turbine trip.

SUMMARY OF THE KEY CONCEPTS

- Following a reactor trip or a stepback/setback to a very low power level, the turbine generator operates in the motoring mode, provided that the turbine generator, its auxiliaries and the grid are available.
- During motoring, the generator acts as a synchronous motor, taking electrical power from the grid and driving the turbine at synchronous speed.

- Compared with tripping the turbine, motoring allows faster recovery of the generator capacity to the grid. It also reduces thermal cycling of the HP turbine and avoids potentially risky operating conditions (eg. synchronization) that could result in machine damage.
- Operating concerns caused by prolonged motoring are: potential for overheating of the LP turbine exhaust, erosion of the last stage blades, increased levels of blade vibrations, and the cost of energy spent to drive the turbine.
- During motoring, boiler pressure is controlled by the steam reject valves. Feedwater heating is provided in the deaerator supplied with throttled boiler steam.
- Motoring ends as soon as reactor loading produces enough steam to drive the turbine. On the other hand, motoring is terminated when it is clear that reactor poisoning cannot be prevented. Problems with the LP turbine exhaust cooling (due to poor condenser vacuum or malfunction of the exhaust cooling system) can also force a turbine trip.

POISON PREVENT OPERATION

In this section, you will learn:

- When the unit operates in the poison prevent mode;
- How during this operation boiler pressure is controlled, and how boiler feedwater is heated;
- What adverse consequences/operating concerns poison prevent operation causes, and
- What factors limit its duration.

Obj. 13.2 a) ⇔

Poison prevent operation may follow a turbine trip, a load rejection, or a significant turbine runback or unloading, provided that the reactor and its auxiliaries are fine. Otherwise, eg. upon a loss of class IV power, the reactor trips as well.

During poison prevent operation, turbine generator power is either zero (in the case of a turbine trip) or about 6-7% FP (for a load rejection). At the same time, reactor power is maintained high enough to prevent reactor poisoning. For the most typical case of full power operation prior to the upset, reactor power is reduced to about 65-70% FP.

Obj. 13.2 b) i) ⇔

From the above, you can see that in the poison prevent mode of unit operation, the boilers can produce much more steam than the turbine can accept. For **boiler pressure control**, the surplus boiler steam is discharged either to the condenser or atmosphere, and its flow is controlled by the SRVs or CSDVs, depending on the station.

Obj. 13.2 b) ii) ⇔

You will recall that during poison prevent operation, turbine extraction steam is unavailable for **feedheating** because there is very little, if any, steam flowing through the turbine. Thus, the whole feedheating is performed solely in the deaerator, using throttled boiler steam as a heat source.

⇔ Obj. 13.2 b) iii)

While the ability to prevent a forced poison outage is the advantage and the whole purpose of this mode of unit operation, it also has a few **adverse consequences and operating concerns***:

- Discharging steam to atmosphere or the main condenser, as the case may be in different stations, has its own operational disadvantages;
- Due to loss of normal feedheating, there are increased chances of an excessive ΔT at the boiler preheater inlet;
- Energy is wasted, as the reactor fuel is being used without supplying electrical energy to the grid.

* The first two of the listed points are described in modules 234-3 and 234-6, respectively.

⇔ Obj. 13.2 b) iv)

There are three factors that affect the **duration** of poison prevent operation. **First**, this mode of operation ends when the turbine generator load is restored to a level at which no more boiler steam is being rejected. Of course, prior to the turbine generator reloading, the grid or turbine generator problem, that initiated the poison prevent operation, must be rectified.

Second, poison prevent operation is terminated (ie. the reactor is shut down) when it has become clear that fixing the turbine generator/grid problem will take more time than the duration of a poison outage.

Third, the availability of the steam reject system (for proper boiler pressure control) and the condensate and boiler feed systems (for secure supplies of boiler feedwater necessary for reactor cooling) is another factor. For example, recall from the earlier modules that some operational problems (such as poor condenser vacuum) may render the CSDVs unavailable*. Or, in the stations using large atmospheric SRVs, the makeup water inventory may be depleted. In either case, poison prevent operation would have to be terminated, resulting in a forced poison outage.

* More details are given in module 234-5.

SUMMARY OF THE KEY CONCEPTS

- Following a turbine trip or a load rejection, the unit operates in the poison prevent mode, provided that the reactor and its auxiliaries are fine.
- During poison prevent operation, the turbine generator power is limited, by turbine generator or grid problems, to 0-7% FP. The reactor power is maintained at a level high enough (usually, about 65-70% FP) to prevent reactor poisoning.
- Boiler pressure is controlled by discharging the surplus boiler steam to atmosphere or the condenser, depending on the station. Virtually all feedwater heating occurs in the deaerator, using throttled boiler steam as a heat source.

NOTES & REFERENCES

- Poison prevent operation ends when the turbine generator is reloaded to such a level that the steam reject system does not need to operate any more. This mode of operation also ends when the steam reject system or the boiler feed or condensate systems become unavailable.

Pages 23-26 ⇔

You can now answer the **assignment questions 1-7.**

TURBINE GENERATOR OVERSPEED

The term *turbine generator overspeed* refers to an operating condition during which turbine speed exceeds rated speed while the generator is disconnected from the grid. This condition should not be confused with *overfrequency operation* during which the machine is synchronized with the grid whose abnormal frequency exceeds 60 Hz due to some upset.

You will recall from the earlier modules that turbine generator overspeed occurs on **a load rejection or a nonsequential turbine trip**. With the turbine steam valves and the governing system operating properly, the maximum overspeed is just a few percent above the synchronous speed. However, much higher levels of overspeed can occur when the turbine steam valves fail to stop the steam flow quickly enough. This dangerous situation can be caused by a variety of reasons such as deposits on valve stems or corrosion of trip relays in the turbine governing system.

Overspeed also occurs during **actual overspeed tests** of the turbine emergency overspeed governor. This time, speed is raised to about 110-112% at which level the overspeed governor should operate. But, some operating difficulties (eg. field-to-control room communication problems) may lead to a higher overspeed.

Among various accidents directly related to the turbine generator, excessive overspeed is most **dangerous**. In the extreme case, it can cause catastrophic damage of the machine and many nearby systems, while creating an acute safety hazard to the personnel. This and other, less dramatic, forms of damage due to excessive overspeed are described in the next section.

In turn, the last section covers the general operating practices that are used to protect the machine from excessive overspeed.

Obj. 13.3 a) ⇔

Hazards of excessive overspeed

When a turbine generator overspeeds, the centrifugal stresses rise sharply*. If the overspeed is excessive, some turbine generator parts become overstressed: they can loosen, deform plastically or, even worse, break off or rupture.

For a given overspeed, some components are more stressed than others, and therefore they are primary candidates for failure. In most cases, these are the large blade wheels and the long moving blades in the LP turbines.

* Recall that centrifugal stresses rise in proportion to the square of the machine speed. For example, at a speed of 110%, the stresses are $(1.1)^2 = 1.21$ of their level at the synchronous speed.

These are followed by the generator rotor and the HP turbine rotor and blades. Hence, it is usually one of the largest blade wheels and the long moving blades of the LP turbines that are most likely to fail during an overspeed incident.

However, any turbine component may fail at an unusually low overspeed, if that component has already been weakened through erosion, corrosion, fatigue, etc. In the extreme case, such a component may fail even at the normal turbine speed, though chances of it are very remote. In practice, chances of such failure are greatly reduced by operating the machine in a way which minimizes the weakening mechanisms. Also, periodic inspections are performed to detect weakened parts such that they can be repaired/ replaced before failure occurs.

The following are the major ways in which an excessive overspeed can damage a turbine generator:

1. **A large blade wheel in an LP turbine may rupture or a long moving blade(s) may break off.**

   This is the most dangerous type of overspeed damage because the turbine casing, which is relatively thin, is too weak to hold fragments of the ruptured wheel or the broken off blade(s) inside. Instead, due to their mass and high velocity, the large fragments have enough kinetic energy to penetrate the casing. Once outside the casing, these ***turbine missiles*** – as they are commonly referred to – can:

   - Kill or injure personnel;
   - Damage steam piping which creates another acute safety hazard, jeopardizes reactor cooling via the boilers, and promotes common failures due to the presence of large quantities of steam and hot water in the turbine hall;
   - Destroy other equipment such as oil lines (causing oil fire hazard), instrumentation lines and cable runs (causing power supply and control problems), condenser tubes (causing condenser flooding), etc.

   Usually, before they penetrate the turbine casing, the ruptured wheel's fragments damage the turbine shaft substantially. In the extreme case, the shaft can break up, releasing the remaining blade wheels. They cause disintegration of the whole LP turbine casing and end up as additional turbine missiles.

   Even if the shaft is not broken up, its deformation generates very high vibrations* and extremely large loads on the shaft bearings and couplings. As a result, these components and turbine internals (seals, blades, etc.) can be destroyed. The high vibration can also damage the adjacent turbines and the generator. In the generator, the hydrogen seals are likely to fail, causing a hydrogen and oil leak* and possibly fire.

* Turbine generator vibration is covered in more detail in the next module.

* Recall that turbine lube oil is supplied to the generator hydrogen seals.

2. **A part of the generator rotor may rupture or become loose.**

   Though in the extreme case the whole rotor may rupture, it is the end retaining rings (bells) and the rotor winding wedges that are the most likely parts to rupture or become loose. The resultant unbalance can produce very high vibrations that may destroy the hydrogen seals (creating a hydrogen and oil fire hazard) and the generator bearings and couplings. Damage can also propagate to the adjacent LP turbine(s).

   The generator stator can experience some damage, too. However, unlike the LP turbine casings, the generator casing is strong enough to confine the damaged rotor inside. Thus, no missiles are created.

3. **A rotor component (other than those listed in point 1) may break off or rupture.**

   For example, a piece of a blade or blade shrouding may break off, or an HP turbine blade wheel may rupture. To fail before the largest and most heavily stressed LP turbine blade wheels and moving blades, such a component must be weakened, eg. due to stress corrosion cracking. As mentioned earlier, such failure can happen at an unusually low overspeed, depending on the extent of the component deterioration.

   In any case, the failed part does not have enough kinetic energy to pierce the turbine casing. The reason: either the part is relatively small (eg. a blade fragment) or, in the HP turbine, the casing is thick enough. Thus, there is no danger of turbine missiles.

   The initial failure is usually accompanied by secondary damage, often substantial, to other parts of the machine. For example, downstream parts of the turbine may suffer impact damage when they get hit by the broken component or its fragments driven by the steam. Or, the increased rotor unbalance – caused by the initial failure – may raise machine vibration to a damaging level.

4. **A rotor component may deform plastically.**

   Primary candidates for such failure are the heavily stressed discs and moving blades in the LP turbine. Their elongation can result in severe machine damage due to rubbing and high vibration.

   For this type of damage to occur, the overspeed must reach a level at which the tensile stress exceeds the yield point and yet remains below the ultimate tensile stress. Overspeed of such magnitude can happen if the turbine steam valves have closed too slowly or if some of them have failed to close completely.

5. **Speed may rise to a critical speed range and remain there long enough to cause damage through very high vibration.**

   This type of damage can happen when the turbine steam flow, though greatly reduced, is not stopped entirely due to failure of some steam valves to close completely.

NOTES & REFERENCES

The lowest critical speed (that is above the synchronous speed) of the turbine generator rotor is so low* that the centrifugal forces are too small to cause any rotor part to break off or rupture (assuming that the turbine generator is in good mechanical condition). But due to a resonance, vibration can quickly rise to a damaging level. Note that damage can happen very quickly (several seconds) if the vibration levels prior to the overspeed incident were already high.

* In most machines, this critical speed is about 120% of the synchronous speed.

General operating practices used to protect the turbine generator from excessive overspeed

⇔ *Obj. 13.3 b)*

In the preceding module, you learned about one general operating practice whose purpose is to protect the machine from excessive overspeed: ie. except for specific emergency conditions, **the turbine is first unloaded and then tripped** rather than tripped directly when still at load. This prevents overspeed due to failure of some turbine valves combined with premature opening of the generator circuit breakers (eg. due to failure of the turbine sequential trip logic).

To ensure that the reheater steam supply is not a source of driving steam to the turbine, the reheater tube bundles are tested periodically for leaks, either on or off line. Failed tubes, in conjunction with passing steam valves on a turbine trip, could provide driving steam to the turbine.

The other operating practices that are listed below contribute to overspeed prevention by ensuring reliable operation of the turbine steam valves in response to a load rejection or a turbine trip. How these practices achieve it is described in detail in the training materials whose references are given in the margin.

- Satisfactory **purity of the hydraulic fluid** in the turbine governing system is maintained*.
- Satisfactory **purity of boiler steam** is maintained**.
- **Periodic tests of turbine steam valves** are performed***
- **Periodic tests of the turbine governing system** are performed.

  In these tests, emphasis is placed on the tripping system components, and particularly, on the emergency overspeed governor. You will recall that this governor is subjected to two types of tests: on-power tests and actual overspeed tests.

* Module 234-7.

** Module 234-2 and course 224 (Chemistry)

*** Module 234-3.

⇔ *Obj. 13.3 c)*

The latter type of testing is potentially dangerous because the machine is subjected to overspeed up to 12% above the synchronous speed. In fact, a higher overspeed can occur, should the test get out of control. To prevent an overspeed accident, the following **major precautions** are taken prior to and/or during such tests:

- Turbine steam valves should be tested prior to the actual overspeed test to confirm their availability;
- On-power test of the emergency overspeed governor should be performed to check the governor's performance when the turbine speed is still maintained by the grid;
- At least two independent methods of monitoring the turbine speed should be used;
- Good communication must be maintained between the field and the control room personnel conducting the test, and it must be clear under what conditions the test will be terminated. The personnel must not rely on the emergency governor to limit the overspeed (after all, the governor may be faulty – this is why we test it).
- During a cold startup, the actual overspeed should be delayed by a few hours to allow the rotor to warm up thoroughly. This relieves thermal stresses and ensures the whole rotor is at a temperature high enough for the material to be ductile.

SUMMARY OF THE KEY CONCEPTS

- The most dangerous overspeed accident is when a large LP turbine disc ruptures or a long moving blade breaks off, destroying the turbine casing and creating turbine missiles. The missiles are an acute safety hazard and can do extensive damage outside the turbine casing.
- Excessive overspeed can damage the generator rotor through parts breaking off or becoming loose. The resultant vibration may destroy the generator hydrogen seals, bearings and couplings, and damage the generator casing.
- Due to overspeed, a turbine part (other than a large LP turbine disc or a long moving blade) may break off or rupture. Usually, this causes extensive damage to other turbine parts. However, no turbine missiles are created because the broken component does not have enough kinetic energy to pierce the turbine casing.
- Overspeed can also cause plastic deformation of a rotor part such as a large LP turbine disc with long moving blades. This can result in severe damage due to rubbing and very high vibration.
- Overspeed can produce damaging vibration when turbine speed rises to a critical speed range and remains there long enough.
- To protect the turbine from excessive overspeed, proper purity of the boiler steam and the hydraulic fluid in the governing system are maintained. Turbine steam valves and the governing system are periodically tested. When shutting down the turbine generator, the machine is first unloaded and then tripped, rather than being tripped at load. To prevent

reheater supply steam from driving the turbine, reheaters should be periodically tested for tube leaks.

- To prevent an overspeed accident, a few precautions are taken prior to and/or during the actual overspeed testing. Turbine steam valves and the emergency overspeed governor are tested on-power to confirm their availability. At least two independent methods of speed monitoring are used. Adequate communication between all the personnel involved in the test is maintained, and the overspeed governor is not relied upon to limit the overspeed. During a cold startup, the overspeed test is delayed a few hours to allow the rotor to warm up thoroughly.

You can now answer the **assignment questions 8-14.**

⇔ ***Pages 26-29***

WATER INDUCTION

Water damage to steam turbines can be divided into two categories:

a) Chronic damage due to erosion, corrosion and deposits by wet turbine steam in which water exists as fine mist;

b) Acute – at times catastrophic – damage due to ingress of large quantities of water.

The first type of damage is covered in modules 234-1 and 234-2 where wet turbine steam and carryover in boiler steam are discussed. These chronic problems are not considered to be water induction.

The term *water induction* refers to the case where a **large quantity of water** (usually, in a form of slugs) has entered the turbine. In this section, you will learn about major sources of water, major ways in which it can damage the turbine, and the general operating practices that are used to prevent a water induction accident. You will also learn why during turbine startup chances of water induction are increased, as is the potential severity of damage it can cause. Finally, you will learn what the typical indications of water induction are, and what to do when they are received.

Major sources of water

⇔ ***Obj. 13.4 a)***

During a water induction accident, water can enter the turbine in a few different ways as follows:

1. **Via the turbine steam admission piping.**

   Water can accumulate in the lowest points of these lines to an extent that it interferes with the steam flow. As a result, one or more slugs of water is formed and driven, very quickly, by the steam. The most likely causes of water accumulation in the pipelines are improper drainage, too fast warming during startup or a very high boiler level excursion. A less likely cause is failure of reheater drains level control, resulting in the drains backing up all the way to the main steam balance header.

In the stations where moisture separators have their own drain tanks, their flooding can result in water induction to the LP turbines.

2. **Via extraction steam piping.**

   The pipelines can get flooded with water due to a large feedheater tube leak or malfunction of feedheater level controls. Inadequate drainage of these lines can be another cause. In the stations where the reheater first stage is supplied with HP turbine extraction steam, failure of this stage drains level control can result in flooding of the steam piping, leading to water induction to the HP turbine.

Operational experience shows that extraction steam piping is the most frequent source of water in turbine water induction accidents. One contributing factor is the large number of feedheaters of which any one can be a source of water.

The typical point of water entry to the turbine is the casing bottom. This is where the extraction steam piping and some main steam piping are connected. Even though some main steam piping is connected to the casing top half, that point of water entry is less likely because water is much heavier than steam. This localized, asymmetrical water ingress to the turbine can have a large effect on thermal damage to the turbine as described below.

Obj. 13.4 b) ⇔

Turbine damage mechanisms

Water induction can damage the turbine in three principle ways:

1. **Impact damage.**

   Turbine internals can deform, crack or break off when they get hit by slugs of water. The long, heavily stressed moving blades in the last stages of the LP turbines are particularly susceptible to this type of damage. Other internals such as fixed blades, diaphragms and discs are less likely to suffer severe damage.

2. **Thermal damage.**

   Water which contacts hot turbine internals can cause **severe quenching**, particularly when the water temperature is significantly below the turbine metal temperature. This can happen, for example, in the superheated region of the LP turbine. Another example is water induced into the HP turbine inlet during startup or at light loads when a large pressure drop occurs across the ESVs/GVs. You will recall that such throttling turns hot saturated water into very wet and cool steam.

   Less intensive cooling occurs when the water and metal temperatures are similar. But even if they were the same, the metal temperature would decrease due to isolation of the metal from the steam flow by the induced water.

In the case of severe quenching, the induced thermal stresses can be so large that they can cause component **cracking**. At lower stress levels, permanent or elastic **distortion** of the quenched component can occur. Thermal deformations of the casing (usually in form of hogging, since the most likely point of water entry is the casing bottom) are very likely to cause rubbing damage to turbine seals, blades (see Fig. 14.1) and possibly bearings. The rubbing stationary components can also cut grooves in the shaft surface. In the extreme case, the rotor can permanently bow due to large thermal stresses produced by frictional heating at the site of rubbing.

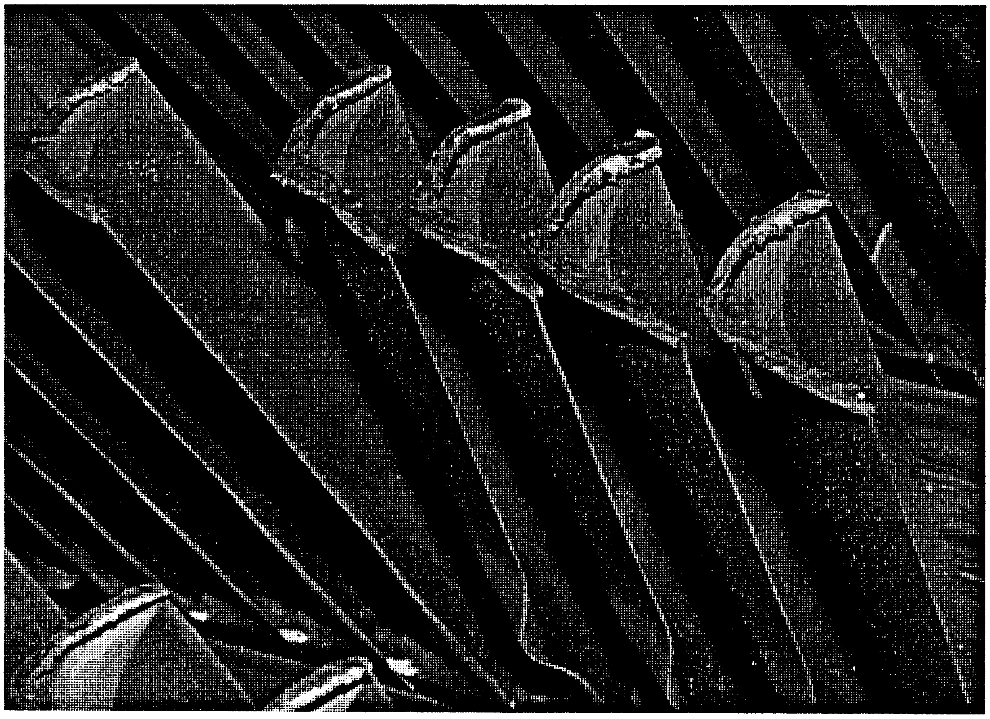

Fig. 13.1. Rubbing damage to HP turbine moving blades due to casing distortion caused by water induction.

3. **Thrust bearing failure.**

When a severe incident occurs, large quantities of water can block some blade passages, hindering the steam flow through the turbine. The resultant abnormal pressure profile in the machine, combined with the impact forces generated during collisions of water slugs with moving blades, can produce an **axial thrust** that **can be several times normal**. Under such an overload, the thrust bearing can fail immediately.

In all cases, the initial damage may be accompanied by **secondary** effects that can **damage** other components. For example, damage described in the first two points above may cause very high vibration that can damage bearings, foundation, oil lines, etc. And failure of the thrust bearing can result in severe axial rubbing in the turbine.

The severity of damage that induced water can inflict depends on factors such as the quantity and temperature of the water, the point of entry, the initial turbine metal temperature and turbine speed. In mild cases, all that happens is increased vibration levels, which may or may not force a turbine trip. But in severe cases, damage may be extensive and put the machine out of service for a few months.

Operational experience shows that in many cases, where the turbine has tripped (eg. on high vibration) as a result of a water induction incident, the extent of **damage has been greatly increased by attempts to return the turbine to service too quickly**. High production pressure and the mistaken belief that a bowed turbine rotor would straighten more quickly at high turbine speed were the typical reasons behind this incorrect action. Later on in this section, you will learn about the conditions upon which turbine startup may be allowed after a water induction incident.

Obj. 13.4 c) ⇔

General operating practices used to prevent water induction

In general, prevention of water induction to the turbine relies on prevention of water accumulation in the main steam, extraction steam and reheater steam piping. In addition, care is taken to ensure that the relevant instrumentation equipment which provides indication, control and protection is in good operating condition. More specifically, the following general operating practices are used to prevent water induction to the turbine:

1. **Prompt response to high/very high boiler, feedheater drains and reheater drains level alarms.**

   Any of these alarms indicates an increased risk of water induction to the turbine. To minimize the risk, the automatic actions* must be monitored and performed manually if they failed to occur.

   Also, if the turbine has tripped in response to a very high boiler level, the machine should not be restarted until the specified time (up to one hour) has elapsed. Recall that this precaution is taken to give the drain valves in the main steam piping enough time to remove any water that might have entered the piping during the boiler level excursion.

2. **Drain valves in the steam piping must stay open when the unit output is below a certain level.**

   This action prevents accumulation of steam condensate in the lowest points of the piping to an extent that water slugs could be formed.

* These actions are described in modules 234-2, 234-4 and 234-6.

Proper operation of these valves is particularly important during cold unit startups when the rate of steam condensation in the piping reaches its maximum.

3. **Periodic tests of components associated with water induction protection.**

   Examples of these components are high level switches in the boilers or check valves in the extraction steam piping. Periodical testing of these components ensures their high availability*.

* Details can be found in module 234-3.

SUMMARY OF THE KEY CONCEPTS

- Water can enter the turbine via the steam admission or extraction piping. In the piping, water can accumulate due to faulty boiler, feedheater drains, or reheater drains level control. Inadequate piping drainage or feedheater tube failure are other typical causes. The most common point of water entry to the turbine is the casing bottom.
- Water induced to the turbine can damage its internals through impact and/or severe quenching. The thrust bearing may be overloaded and fail too. In all cases, the initial damage is often accompanied by secondary damage, eg. due to very high vibration.
- Water induction is prevented by prompt response to high/very high level alarms in the boilers, feedheaters and reheaters. Drain valves in the steam piping should stay open when turbine load drops below a certain limit. Components associated with water induction protection are periodically tested to ensure their high availability.

Water induction during turbine startup

⇔ Obj. 13.4 d)

Though water induction can happen during steady-state operation, the risk of an induction incident is substantially increased during transient operating conditions: startup, trips and large load swings. These conditions disturb control of the boiler, feedheater drains, and reheater drains levels. This increases chances of a high level excursion.

Among these conditions, turbine startup is particularly bad as far as **increased risk** of water induction to the turbine is concerned. **First**, during cold startup, steam condensation in the cold piping is very intensive. Combined with failure of the drain valves or premature steam admission to the turbine when the piping has not been fully drained, it may result in water induction to the HP turbine. **Second**, at light loads, boiler and deaerator level control* reverts to the single-element mode which increases chances of a high level excursion. **Third**, during the preceding shutdown, a level controller may have been miscalibrated, resulting in abnormally high levels during startup. In fact, this was one of the root causes of a severe water induction accident in a CANDU unit several years ago.

* In early CANDU units, single-element DA level control is used at all loads.

NOTES & REFERENCES

Not only is water induction more likely to occur during turbine startup, but also **damage** to the turbine can be **particularly severe** for the following reasons:

- The induced water can result in **severe quenching** of the turbine. Recall that due to a large pressure drop across the ESVs/GVs, hot boiler steam condensate turns into very wet and cool steam when it passes through these valves. At high turbine loads, quenching is less severe because the pressure drop is smaller.
- Some parts of the turbine can be relatively cool, thereby increasing chances of a **brittle failure.**
- Water induction **can coincide with passing through a critical speed range.** This combination can easily produce damaging vibration.

Obj. 13.4 e) ⇔

Indications of water induction

Water induction can be suspected to be in progress when one or both of the following indications are present:

1. **Abnormally high level in a boiler, feedheater, reheater or moisture separator*, combined with a sudden increase in vibration levels, abnormal ADE or axial shaft position.**

   In stations where the HP turbine rotor eccentricity is monitored during normal operation*, increased vibration levels (if occurring in the HP turbine) are likely accompanied by abnormally high eccentricity.

2. **Abnormally high top-to-bottom ΔT in the turbine.**

   This indication reflects the fact that water entering the turbine casing bottom is cooling it. Because this is the preferred point of water entry to the turbine, this indication is very likely to detect water induction. However, in most stations, this indication is not available.

* Applies to the stations where moisture separators have their own drains tanks.

* Recall that in most stations, the eccentricity indication is not available once the turbine speed exceeds a certain level.

Note that when any one of these indications is present, water induction is a probable, but not the only possible, cause. For example, high vibration can result from many other problems (as described in the next section of this module). So can abnormal ADE or shaft axial position. In turn, a high top-to-bottom ΔT can be caused by wet thermal insulation at the casing bottom (due to a steam leak). And as usual, faulty instrumentation can be responsible for a spurious indication.

Obj. 13.4 f) i) ⇔

Actions in response to water induction to the turbine

When an indication of water induction to the turbine is received, the turbine may have to be tripped or its operation can be continued. The decision is based on the type of indication and turbine speed. Generally, **the turbine must be tripped** in either of the following circumstances:

- The water induction has resulted in unacceptably high vibration, axial differential expansion, shaft axial position, HP turbine rotor eccentricity (if its indication is available) or another turbine supervisory parameter. In these circumstances, the turbine must be tripped to prevent/minimize damage.
- An abnormally high top-to-bottom ΔT in the turbine is detected during runup below or within the lowest critical speed range. In this case, the turbine must be tripped, even if the turbine supervisory parameters are satisfactory. This action minimizes chances of damage due to possible undetected rubbing (at low turbine speed) or high resonant vibration (if the runup were continued). As for rubbing at low turbine speeds, recall that bearing vibrations cannot be relied upon to detect it. And the HP turbine rotor eccentricity (even if its indication is still available) cannot detect rubbing in the LP turbines.

⇔ Obj. 13.4 f) ii)

However, it is a different situation where a high top-to-bottom ΔT is detected **when the machine is carrying load or when speed is above the lowest critical speed range**. In this situation, **as long as the turbine supervisory parameters are fine**, it is generally better to **continue running** (at a constant steam flow) for the following reasons:

1. Maintaining the steam flow (particularly when it is large) through the turbine is beneficial because:
    - The induced water can be removed more quickly, thereby minimizing transient quenching of the turbine;
    - Any component distorted elastically by the quenching will restraighten more quickly when heated by the steam.
2. Coasting down through the critical speed ranges, where vibration levels can rise sharply, is prevented.

Naturally, the source of water must be isolated immediately and the appropriate drain valves opened. Also, the root cause of the water induction must be rectified to prevent its recurrence. The turbine condition should be monitored particularly closely, and the machine tripped immediately if any turbine supervisory parameter has reached an unacceptable level or were approaching it quickly.

Turbine restarting following a trip forced by water induction

⇔ Obj. 13.4 f) iii)

Assuming that there is no obvious damage to the turbine due to the water induction, the machine can be restarted if the following conditions are met:

1. **The original cause of water ingress has been rectified and all the other potential sources of water induction are under control** (ie. all boiler, feedheater and reheater levels are fine, and the drain valves in steam piping are opened).

NOTES & REFERENCES

The next three conditions address thermal deformations of the turbine casing and rotor that the water induction incident is likely to have caused.

2. **Turbine casing temperatures have equalized,** ie. the casings have straightened out.

   In the units where the turbine instrumentation allows for monitoring of the top-to-bottom turbine casing ΔTs, this condition can easily be checked. For the turbine to be ready for startup, the ΔTs must be within their limit. Otherwise, even if the rotor were straight, the humped casing would likely cause rubbing and high vibration if runup were attempted.

   In the stations where the ΔT indications are not available, the condition is met by keeping the turbine on turning gear for a specified period of time*.

   * Up to 24 hours.

3. **The HP turbine rotor eccentricity is normal.**

   Recall that this condition prevents rubbing and very high vibration during turbine runup.

   While this parameter is checked before every turbine runup, the water induction incident makes this check particularly important. The reason: the induced water might cause a large (in the extreme case, permanent) thermal bow of the rotor due to heavy rubbing.

4. **Axial differential expansions are normal.**

   Again, this condition must be met to prevent rubbing and high vibration during runup. And the water induction incident may, through quenching, brought some of these expansions to an abnormally high level.

With some luck, the last three conditions can be met, given enough time of turbine operation on turning gear. Otherwise, turbine inspection and repairs are required.

It is worth stressing that **under no circumstances should the turbine be started up if any one of these conditions is not met.** As mentioned earlier, operational experience shows that such a startup is bound to fail and can only increase turbine damage.

Note that the above list of four conditions does not include those (like satisfactory condenser vacuum) that must be met during any turbine startup and which have no or very little connection with water induction.

SUMMARY OF THE KEY CONCEPTS

- During turbine startup, the risk of water induction to the turbine is increased for the following three reasons. First, large amounts of condensate are formed in steam piping. Second, boiler and DA level control reverts to the single-element mode which increases chances of a high level excursion. Finally, a level controller can be malfunctioning due to incorrect maintenance performed during the preceding shutdown.

- Water induction occurring during turbine startup can cause particularly severe damage. For one thing, the large pressure drop across the ESVs/GVs turns hot boiler steam condensate into very wet and cool steam which quenches the turbine quickly. Water induction can coincide with passing through a critical speed range, resulting in damaging vibration. And some parts of the turbine may still be fairly cool, increasing chances of their brittle failure.
- Water induction is indicated, with a good probability, by a high top-to-bottom ΔT in the turbine. Also, when abnormally high level in a boiler, feedheater, moisture separator or reheater is combined with a sudden increase in vibration levels, abnormal ADE or axial shaft position, water induction is the likely cause.
- The turbine must be tripped immediately when water induction has resulted in a turbine supervisory parameter exceeding its safe limit. Even when the turbine supervisory parameters are fine, the same action should be taken if water induction is detected (through a high top-to-bottom turbine casing ΔT) during turbine runup below or within the lowest critical speed range.
- In the remaining circumstances, it is generally better to keep running at a steady steam flow for two reasons. First, the steam flow can remove the induced water faster, and any component distorted by quenching can restraighten more quickly when heated by the steam. Second, the turbine will not have to run down through the critical speeds.
- If a turbine were tripped as a result of water induction, the machine can be restarted only when the following conditions are met: all potential sources of water induction are under control, turbine casing temperature has equalized, and the HP turbine rotor eccentricity and all axial differential expansions are normal.

You can now answer **assignment questions 15-23.**

⇔ Pages 30-33

NOTES & REFERENCES

ASSIGNMENT

1. a) During motoring:

i) The turbine generator operates as follows:

____

____

ii) Boiler pressure is controlled by ____________________

____

iii) Feedheating is provided by ____________________

____

____

b) Motoring usually follows the following upsets:

i) ____

ii) ____

iii) ____

provided that __________________________________

2. a) The major advantages of motoring as compared with tripping the turbine in response to any of the above upsets are:

i) ____

____

ii) ____

____

iii) ____

____

b) Motoring allows faster return of the generator capacity to the grid because:

i) ____

____

____

____

____

NOTES & REFERENCES

ii) ____

____

____

____

____

c) Motoring reduces thermal cycling of the (HP / LP) turbine because

____

____

____

____

____

d) Motoring allows to avoid potentially risky operating conditions such as ____

____

3. a) Motoring causes heating of the LP turbine exhaust because ____

____

____

____

b) This heating does not result in excessive exhaust temperatures provided that:

i) ____

ii) ____

c) Prolonged motoring can result in erosion of the trailing edge of the moving blades in the last stage because ________________

____

____

____

____

d) The other two disadvantages of motoring are:

i) ______________________________

____

ii) ______________________________

____

4. The duration of motoring is determined by the following factors:

a) ______________________________

____

____

____

b) ______________________________

____

____

____

c) ______________________________

____

____

____

5. a) Following a turbine trip or a load rejection, the unit begins ______________ operation, provided that ______________ remain available.

b) During this mode of operation:

i) Reactor power is maintained at about _______ %FP (for the typical case of full power operation prior to the upset) in order to prevent ______________

ii) Boiler pressure is controlled by ______________

____

iii) Feedwater heating is provided in ______________

____

6. Poison prevent operation causes the following operating concerns:

   a) ____

   ____

   ____

   b) ____

   ____

   ____

   c) ____

   ____

   ____

7. The duration of poison prevent operation is limited by the following factors:

   a) ____

   ____

   ____

   b) ____

   ____

   ____

   c) ____

   ____

   ____

8. a) Turbine generator overspeed occurs during:

      i) ____

      ii) ____

      iii) ____

   b) During overspeed, centrifugal stresses in the rotating components increase (at the same rate as / faster than / slower than) the turbine generator speed.

   c) In most turbine generators, the components that are most likely to fail during an overspeed incident are ____________________

   ____________________ because ____________________

9. Excessive overspeed can damage a turbine generator in the following ways:

   a) ______________________________

   b) ______________________________

   c) ______________________________

   d) ______________________________

   e) ______________________________

10. a) Turbine missiles are ______________________________

    b) The major risks created by turbine missiles are:

       i) ______________________________

       ii) ______________________________

       iii) ______________________________

    c) In addition, turbine bearings, couplings and internals can be destroyed due to very high __________________. The generator hydrogen seals (are / are not) also likely to fail in this way.

11. a) Rupture or loosening of a part of the generator rotor can result in the following damage:

    ____

b) Such failure (can / cannot) produce turbine missiles because

____

____

12. When a rotor component (other than a large LP turbine disc or moving blade) breaks off or ruptures, the initial failure is often accompanied by secondary damage to other parts of the machine. Examples of such damage are:

____

or ______________________________

____

13. The following general operating practices are used to protect the turbine generator from excessive overspeed:

a) ______________________________

____

This practice provides overspeed protection by ____________

____

____

b) ______________________________

____

This practice provides overspeed protection by ____________

____

____

c) ______________________________

____

This practice provides overspeed protection by ____________

____

____

d) ______________________________

____

This practice provides overspeed protection by ____________

____

____

e) ____

____

This practice provides overspeed protection by ____________

____

____

f) ____

____

This practice provides overspeed protection by ____________

____

____

4. The following precautions should be taken prior to and/or during actual overspeed testing of the emergency overspeed trip governor in order to prevent an overspeed accident:

a) ____

____

____

b) ____

____

____

c) ____

____

____

d) ____

____

____

e) ____

____

____

15. Major sources of water involved in a water induction accident are:

    a) ______________________________ where water can accumulate due to ______________________________

    ____

    b) ______________________________ where water can accumulate due to ______________________________

    ____

16. a) The most frequent source of water induction to the turbine is

    ____

    b) The typical point of water entry to the turbine is ____________

    ____

17. Water induction can damage the turbine in the following major ways:

    a) ______________________________

    ____

    ____

    ____

    b) ______________________________

    ____

    ____

    ____

    c) ______________________________

    ____

    ____

    ____

    In all cases, the initial damage can be accompanied by secondary damage to other components due to ______________________________

    ____

18. a) Water induction always results in severe damage to the turbine. (False / true)

b) Operational experience shows that in the case where water induction forced a turbine trip (usually, on very high vibration), the severity of damage can be greatly increased by:

____

19. The following general operating practices are used to prevent water induction to the turbine:

a) ____

____

b) ____

____

c) ____

____

20. During turbine startup:

a) Chances for water induction are (decreased / increased) as compared with normal operation because:

i) ____________________________________

____

ii) ____________________________________

____

iii) ____________________________________

____

b) Damage to the turbine can be particularly severe because:

i) ____________________________________

____

____

ii) ____________________________________

____

____

iii) ____________________________________

____

____

21. a) Typical indications of water induction to the turbine are:

i) ______________________________

____

____

ii) ______________________________

____

____

b) When any of these indications is present, water induction is the sure cause. (False / true)

c) When any of these indications is received, the turbine must always be tripped for protection. (False / true)

22. a) Suppose that a high top-to-bottom ΔT in the turbine is detected during runup below passing through the lowest critical speed range. You checked the turbine supervisory parameters and they are fine.

i) Would you trip the turbine? (No / yes)

ii) Why?

____

____

____

____

____

b) Suppose that a similar situation has occurred when the turbine is carrying load or its runup is nearly complete.

i) Would you trip the turbine in this case? (No / yes)

ii) Why?

____

____

____

____

____

____

____

23. Consider a case where a water induction incident forced a turbine trip due to very high vibration. Assuming no obvious damage to the turbine, which conditions would you be particularly careful to check prior to restarting the machine?

    a) Condition: ______________________________

    Reason for checking: ______________________________

    ____

    ____

    b) Condition: ______________________________

    Reason for checking: ______________________________

    ____

    ____

    c) Condition: ______________________________

    Reason for checking: ______________________________

    ____

    ____

    d) Condition: ______________________________

    Reason for checking: ______________________________

    ____

    ____

Before you move on to the next module, **review the objectives** and make sure that you can meet their requirements.

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