Electrical Equipment - Course 230.2

GENERATORS: PART 6

NON-INFINITE BUS OPERATION

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1. OBJECTIVE

The student must be able to:

1. Define a non-infinite bus.
2. Explain how a generator behaves when it is loaded onto a non-infinite bus. The actions of the governor and AVR must also be described.
3. Explain the safety precautions that must be observed when generators are:

    (a) excited,
    (b) loaded,
    (c) unloaded.

2. INTRODUCTION

The previous lesson considered generator loading when the terminal voltage and frequency were fixed by the infinite bus. This section examines the behavior of a generator when it is loaded onto a non-infinite bus.

By definition, a non-infinite bus (sometimes called a finite bus) does not operate with constant voltage and frequency.

When a **large** generator, is loaded onto a system, the system may not behave as an infinite bus. It is *normally assumed that when a generator has a capacity of* **greater than 5%** of the system size, then with respect to this generator, the system does not behave as an infinite bus. For example, when an 800 MW generator is loaded onto a grid having a capacity of 10,000 MW, the system voltage and frequency can vary and the system will behave as a non-infinite bus.

This lesson also considers the action of the Automatic Voltage Regulator (AVR), keeping the voltage constant and the governor controlling the frequency.

3. GOVERNOR ACTION

3.1 Governor Characteristics

Governors are provided with a drooping characteristic, ie, when the turbine speed or generator frequency falls, the governor will signal the governor valves (throttles) to open. This will allow more steam to enter the turbine and the turbine will produce more power.

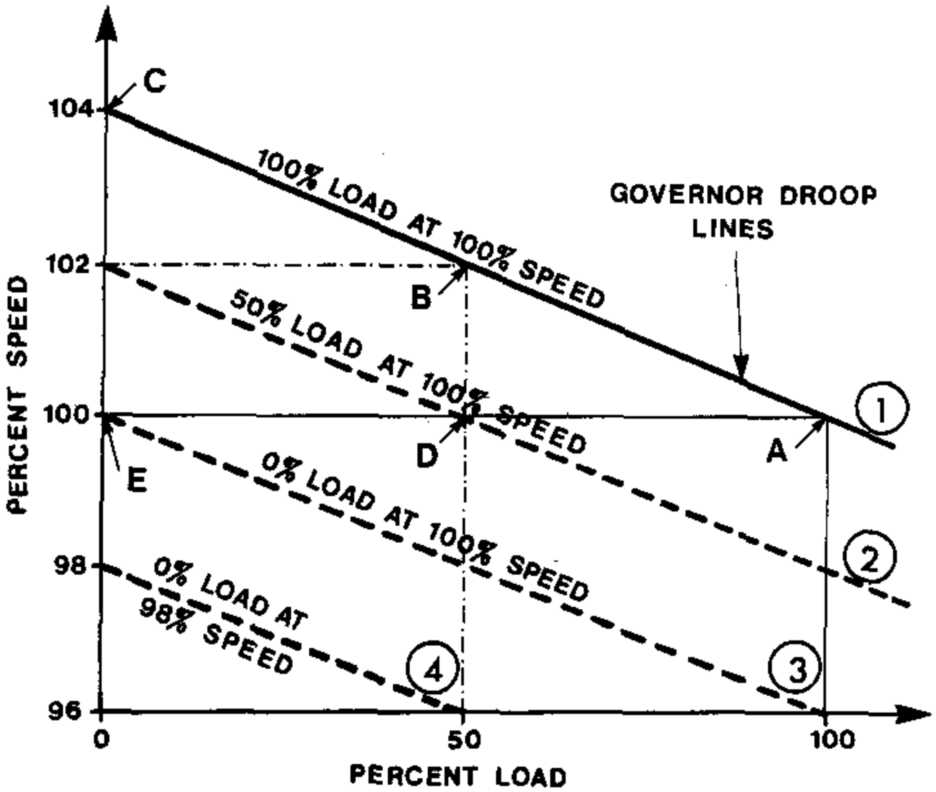

Figure 1: Diagram showing droop characteristic of a turbine governor.

Figure 1 shows four of the droop lines for a governor having a 4% droop or slope. The following examples will illustrate the significance of these droop lines.

Example 1:

The turbine is operating on curve 1 at point 'A', producing 100% load at 100% speed. If for any reason the load frequency rises by 2%, the turbine-generator speed will also rise by 2%. The governor will sense this rise and the governor will partly close the throttle valves. The turbine will then operate at point 'B' where it will give 50% power output. A 4% system frequency speed rise to 104% will, by governor action, automatically fully close the governor valves. The turbine will now operate at point 'C'.

Example 2:

The turbine is operating at point 'D' curve 2, producing 50% load at 100% speed. If the operator wishes to decrease output from 50% load to 0% load, he will lower the governor droop line by operating the speeder gear. In doing this, the operator will be changing the characteristic from the #2 to the #3 droop line.

When the turbine is at 0% load and 100% speed, it will be operating on #3 line at point 'E'. In this example, it is assumed that the system frequency remains the same (60 Hz) and the output from this generator drops to 0% load.

3.2 Frequency Variation, Output Voltage and Power

The speed of a turbine generator, when operating on a given 4% droop line, can only vary a maximum of 4%, between no load and full load. The output voltage V_T for a given level of excitation will also vary by only 4%, (V_T proportional to speed). When the voltage V_T increases, the load consumes more active power output (P) from the generator. (It is assumed there is sufficient steam available.) When V_T falls the load consumes less active power output. This is because:

$$P = \frac{V_T^2}{R}$$

R is the resistance of the load and is assumed to remain constant.

For example, if the speed and hence output voltage rises by 1%, then the power produced by the generator and consumed by the load will rise by $(101\%)^2$, ie, approximately 2%. This example shows, that for normal changes (less than 1%) in frequency from the standard 60 Hz, the change in active power consumed by a load (and given out from a generator) is small. In this case, the excitation is assumed to be constant. In practice, a voltage regulator keeps the terminal voltage constant, see section 4 of this lesson.

3.3 Summary

Turbine-generators, having governors with 4% droop characteristic will:

(a) for a given governor setting (droop line), decrease load if the system frequency rises. Conversely, if the frequency falls, the output will attempt to rise. The output is limited by power of prime mover and heat source.

(b) for a given speed (frequency), decrease load (MW output) if the setting (droop line) is lowered. Conversely, if the setting is raised, the output will increase.

(c) require operator action to raise or lower the droop line.

(d) from the electrical point of view, cause small changes to the generator's active power output.

4. AVR ACTION

4.1 Operation With The AVR In Service

Automatic voltage regulators (AVR's), control the terminal voltage of a generator by **altering the level of excitation.** An AVR, at a given voltage setting, keeps the terminal voltage constant from no load to full load. There is no droop characteristic as on a governor. Consequently, apart from *the very short time, typically .25 sec, required* for the AVR to respond and correct a change in terminal voltage, the terminal voltage of an AVR-controlled generator is taken to be constant.

4.2 Operation With the AVR Out of Service

If a generator is operated on the grid system with its AVR on "manual" instead of "auto", due to an AVR fault for example, dangerous operating conditions can occur. Consider the following three cases:

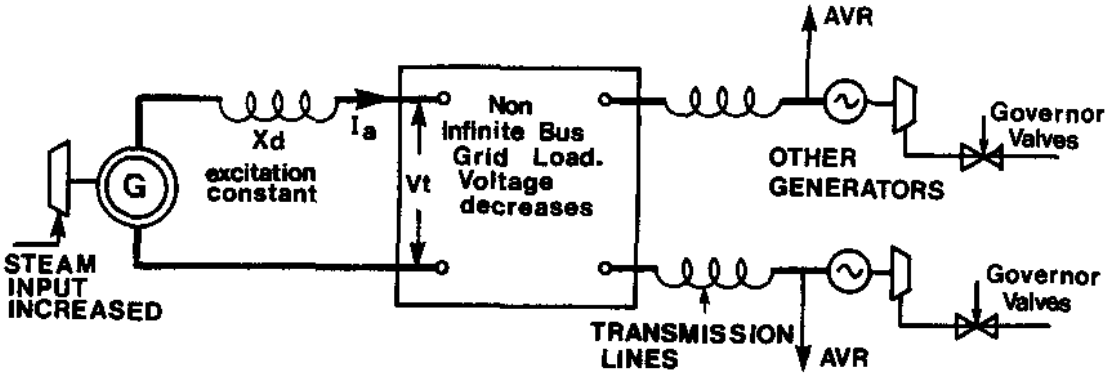

Figure 2: Generator feeding a non-infinite bus grid load: Generator output increased: excitation constant.

Case 1

The generator (with fixed excitation) is on no load connected to a non-infinite bus. **The MW load is increased.** See Figure 2.

(a) The increase in load will produce an increase in I_a and a corresponding increase in armature reaction.

(b) The rotor flux is constant due to fixed excitation. Due to increased armature reaction because of increased load, it follows that the terminal voltage will fall.

(c) The increase in armature reaction, with a constant level of rotor flux, will cause the load angle δ to increase. The load angle can easily be made to exceed the 90° steady state stability limit. **Pole slipping may result.**

(d) The fall in terminal voltage will **reduce the non-infinite bus voltage.** The amount by which the system voltage will fall is largely dependent upon other generators on the system having AVR's which have the ability to correct this voltage drop. It will also depend on the relative transmission line lengths between *generators and the load. Figure 2 shows the* operational conditions. This situation is most likely to occur where the generation is remote from the load. An example of this is at Bruce where the main loads are distant from the generating station.

Case 2

The generator (with fixed excitation) is on full load supplying a non-infinite bus. **The generator output is then reduced.** The following occurs:

(a) The decrease in generator output will produce a decrease in load current I_a and a corresponding decrease in armature reaction.

(b) Load angle δ decreases. This is **not** dangerous as the generator is more stable, ie, it is more secure on the system.

(c) As the armature reaction decreases, the generatore becomes overexcited and **the terminal voltage will rise.** The amount the system voltage rises is again dependent upon other generators on the system having AVR's with the ability to correct this voltage change. It will also depend upon lines lengths and the load. Figure 3 shows the operational conditions.

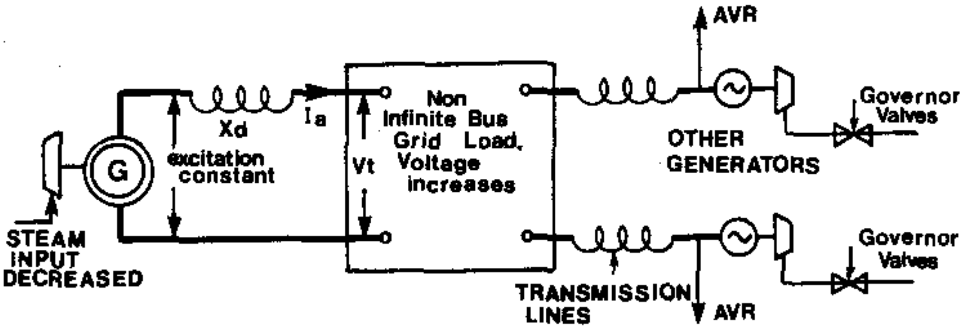

Figure 3: *Generator feeding finite bus grid load.* Generator output decreased: excitation constant.

Case 3

A generator's main output breaker may trip, due to faults which can occur at any instant. The trip can occur when the level of excitation is above that required at no load. When this occurs, the field current must be immediately reduced. With the AVR out of service, this reduction must be done manually. Failure to do this reduction immediately will **cause the output voltage to greatly exceed its rated value** and damage may result. This damage can take the form of insulation failure or over-fluxing which is described in the next lesson.

ASSIGNMENT

1. Explain using a labelled diagram, what is meant by the term "governor droop".

2. The governor on a turbine-generator has a 4% droop. The generator is initially operating at half load and the frequency is 60 Hz. What will be the new operating load if:

   (a) the frequency rises to 61 Hz.
   (b) the frequency falls to 58 Hz.

   (Assume reactor power will follow the power demanded by the turbine.)

3. When a generator terminal voltage changes for a given AVR setting, will the AVR correct the terminal voltage to the original value, a lower value or a higher value? Explain.

4. (a) A 800 MW generator is rapidly loaded onto a 5000 MW system. Explain what will happen to the system's voltage and frequency.

   Assume (i) the AVR's and governors of all generators are in service, and (ii) the generators supply their loads via long lines.

   (b) After being fully loaded, the output breaker trips and the generator is left feeding its auxiliary load of 50 MW. Explain what will happen to the frequency and voltage of:

   (i) the generator
   (ii) the system.

5. *(a) Explain why it is bad practice to operate a generator* with its AVR out of service when the generator is being:

   (i) loaded
   (ii) unloaded.

   (b) A generator is on load with its AVR out of service. The output breaker trips. Briefly explain how the voltage rating of the generator can be exceeded.

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