Electrical Equipment - Course 230.2

GENERATORS: PART 8

LOADING

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1. INTRODUCTION

On completion of this lesson the trainee will be able to:

1. Explain how a small generator or generators behave when they are loaded onto:
   - (a) a dead bus.
   - (b) live bus which is isolated from the system.
   - (c) live bus which is connected to the system.
2. Explain how a large generator behaves when it:
   - (a) suffers load rejection.
   - (b) suffers a partial load rejection and then operates supplying an "island".
3. Explain how re-synchronizing of an "island" is done.

2. INTRODUCTION

The previous three lessons dealt with a generator operating under normal conditions supplying

- isolated loads
- an infinite bus
- a finite bus load.

This lesson explains the effects produced when small generators, eg, combustion turbine powered generators supply a:

- dead bus
- live bus which is isolated from the system
- live bus which is connected to the system.

The lesson also explains the effects which are produced when a **large** generator or generators

- suffers load rejection
- suffers partial load rejection and then operates supplying an "island".

3. LOADING OF **SMALL** GENERATORS

When small generators of 25 MW or less (Class III combustion turbines for example) are loaded, they have similar characteristics to larger generators, ie, their excitation and governor systems behave in a similar manner to those of large machines. Large generators are rarely required to energize dead buses or supply a system which is isolated from the rest of the grid. On the other hand, small generators, for example combustion turbines, have to supply emergency power to energize a dead Class III bus. They then have to supply this bus, *often in conjunction with* other Class III combustion turbines, until the Class III bus can be paralleled with the grid.

3.1 *Small Generator Energizing a Dead Bus*

In generating stations, combustion turbine and diesel driven generators supply the emergency power to the Class 3 system. Following the loss of Class 4, Class 3 requires the combustion turbines driven generators to start up, their output breakers closing and the generators supplying the isolated Class 3 system.

When the generator output breaker closes, there is no load or almost no load on the local system. If the bus is small for example the Class III bus on its own, little problem occurs. But if the bus is large or there are several unloaded buses being supplied together, the capacitance of these buses may cause the terminal voltage to rise considerably. If the AVR is in service, it will control the voltage. If **manual** excitation is used, the terminal voltage and hence **excitation will have to be carefully controlled.**

This is the reason why generators are never connected to long open circuit lines. The capacitance provided by a long open circuited line can easily cause a generator's terminal voltage to rise to a dangerous level. Long open circuit lines are *energized from a live bus.*

3.2 Small Generators Supplying an Isolated Live Bus

In this case, it is assumed that the isolated live bus is already being supplied by one or more running generators. When another small generator is synchronized and loaded onto this bus, the bus will not behave as an infinite bus.

When large loads, (especially large motors) are switched onto an isolated live bus, there will be considerable voltage and frequency "swings". It is therefore good practice to load an isolated generator in stages and not to apply several large loads simultaneously.

The following examples illustrate the prime mover, generator and load behavior, when combustion turbines, singly or in parallel are used to supply class III.

Example 1

Figure 1 shows a typical situation where a generator, G2, is operating on full load supplying a common bus. A second, similar, generator, G1, is then loaded onto the bus. G1 and G2 are driven by similar combustion turbines having governors with similar droop characteristics, see Figure 1.

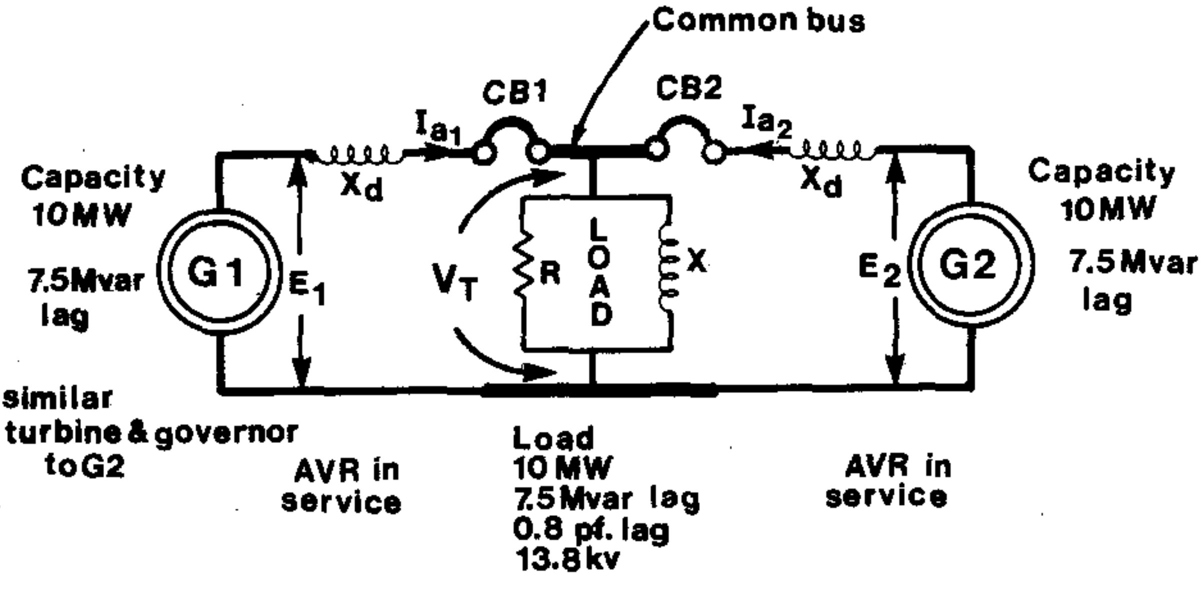


Figure 1: Two generator feeding an isolated system load. G1 loaded onto bus. AVR's in service.

Initially the load of 10 MW and 7.5 Mvar is supplied by G2 through CB2. If G1 is now synchronized to the common bus and loaded with its AVR in service, the following will happen:

(a) As generator G1 produces more active power, its output current will increase proportionally. It is assumed that the characteristic of the AVR will ensure the common bus voltage is held constant and the operating power factor of the generator will also remain constant.

(b) The amount of **generation** on the system now **exceeds** the **load.** Consequently, the frequency and speed of both generators will rise. The *governor* of G2 will sense this speed rise and "back off", thus reducing the output of G2. Without an alteration of G2's governor droop line height, (see lesson *230.21-3, section 3), both generators will* continue to operate at speed and frequency, which is slightly higher than before. The AVR's will hold the voltage constant and ensure both generators supply the same amount of reactive power to the load. Note, it may be necessary for the operator to balance the var output of the two generators, by AVR adjustments. The load will consume the same amount of active and reactive power. There may be a **slight** increase in active power consumption due to the extra speed, ie, motors operating at a higher speed will provide more shaft power thereby consuming more electrical power.

Example 2

This example considers the same two generators described in Example 1. In this case both generators are equally sharing the same 10 MW, 7.5 Mvar load. Both AVR's initially on "auto", are selected to "Manual". The excitation of G1 is increased, the excitation of G2 remains the same, see Figure 2.

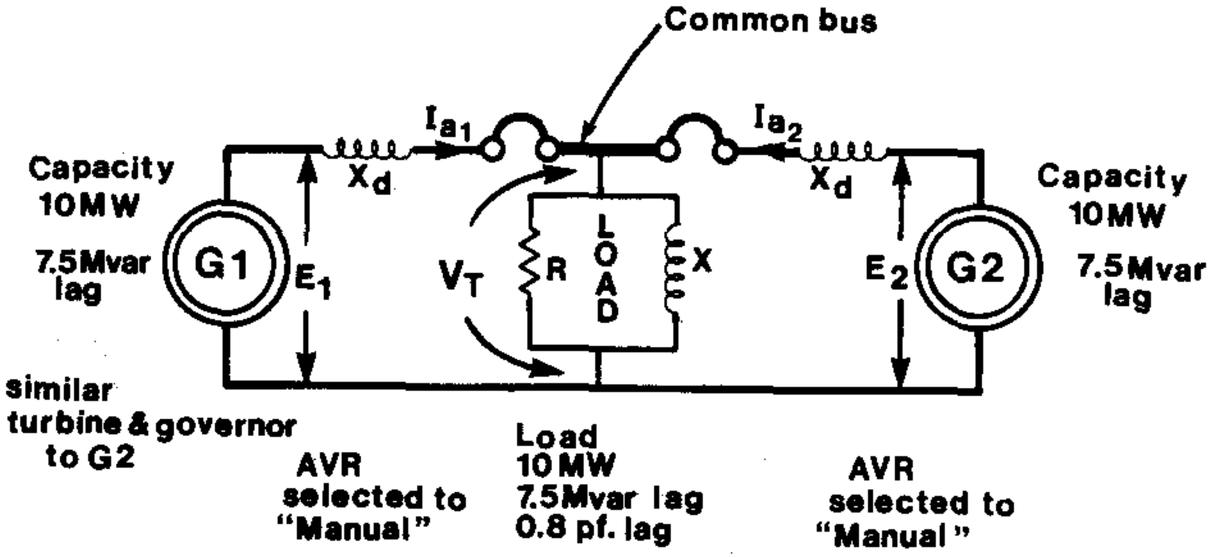


Figure 2: Two generator supplying an isolated bus, excitation on G1 increased. AVR's on Manual.

When the excitation on G1 is increased, the following will happen:

(a) Increasing the excitation on G1 will cause it *to produce a greater field flux. This greater* flux will produce a larger value of E_1. This higher value of E_1 will cause the terminal voltage V_T to rise, Figure 3 shows the induced voltages, the internal voltage drops within the two generators and the common terminal *(and load)* voltage V_T.

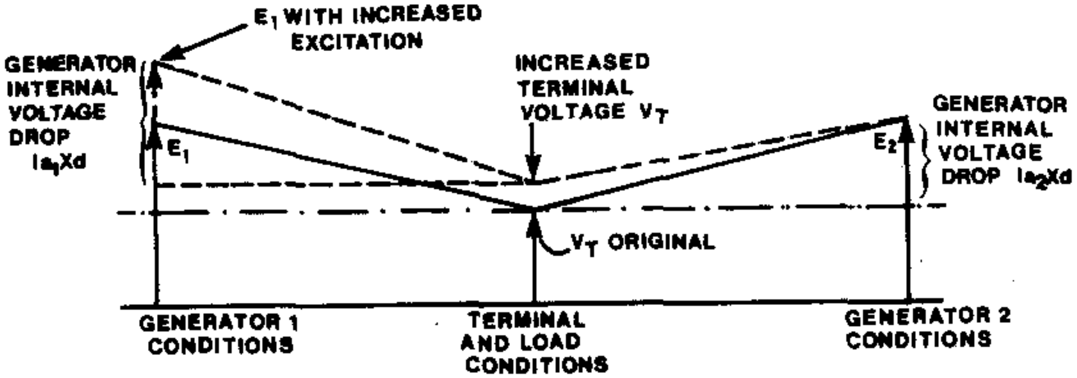


Figure 3: Diagram showing how V_T rises with increased excitation on G1. Note, this diagram is a scalar representation of the voltages.

(b) Because V_T rises, the load will be supplied at higher voltage. It should be remembered that active power P and reactive power Q are dependent upon:

$$P = \frac{V_T^2}{R} \quad \text{and} \quad Q = \frac{V_T^2}{X}$$

Where R is the load resistance and X the load reactance, see Figure 2.

With V_T rising, both P, (MW) and Q, (Mvar) will rise in proportion. This assumes the values of R and X do not vary. As the MW **consumed** by the load is now greater than the MW **produced** by the generators, the speed and frequency of both generators and the load will fall. The governors will sense this speed drop and open the governor valves of their respective turbines. The speed will then rise and steady outjust below the original. The speed difference is due to the slope or droop characteristic of the governor.

The load will now be consuming slightly more MW (due to the voltage increase) and slightly more Mvar (again due to the voltage increase). The power factor of G1 will become more lagging (because it is **overexcited** with respect to the terminal voltage V_T).

The power factor of G2 will become less lagging or possibly leading because it is **underexcited** with respect to the higher value of V_T. The power factor of the **load** will remain constant due to the proportional increase in MW and Mvar. There may be a very slight variation due to the effect of the lower frequency on the load reactance. This difference would, in all probability, not be measurable by normal panel instrumentation.

Example 3

Again, the same two generators described in Example 1 are considered. Initially, both generators are equally sharing the same MW and Mvar load. Both AVR's are selected to "Manual". The power input to G1 is increased by increasing the speeder gear setting which increases the governor setting. The governor setting of G2 is not altered. See Figure 4.

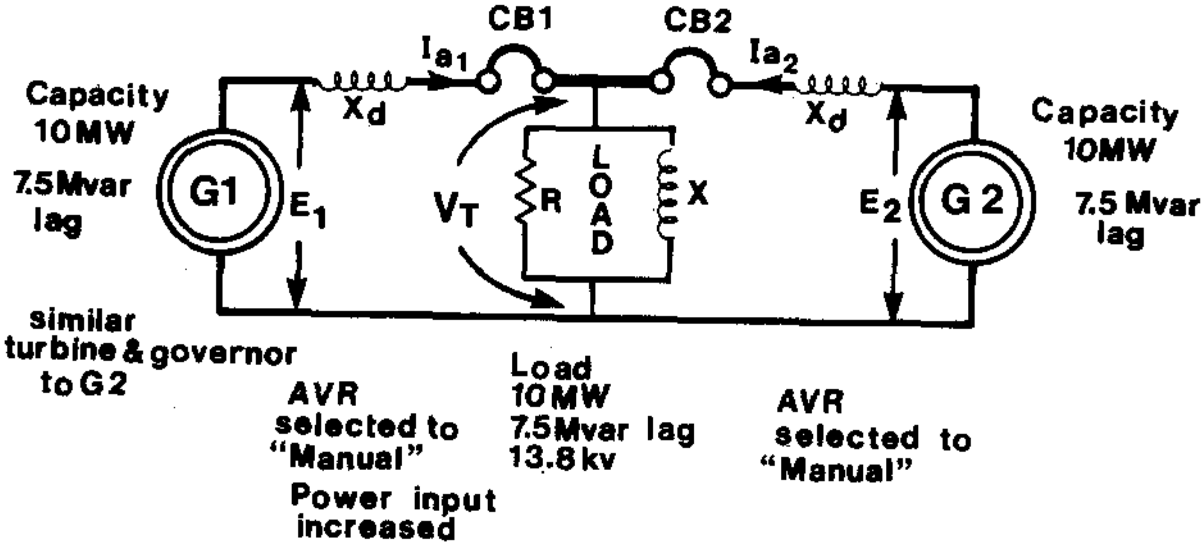


Figure 4: Two generators feeding an isolated system load. G1 output increased AVR's on manual.

When G1 is loaded, the following will happen:

(a) The power output from G1 will increase and the power **produced** by the two generators will now be **greater** than the power **consumed** by the load. This will cause the speed and frequency to rise. The governor on G2 will sense this rise and close in the throttles on G2.

The speed of both generators will then balance out at a level slightly higher than the original speed. Figure 5 shows how the load and speed (frequency) have balanced out on G1 and G2.

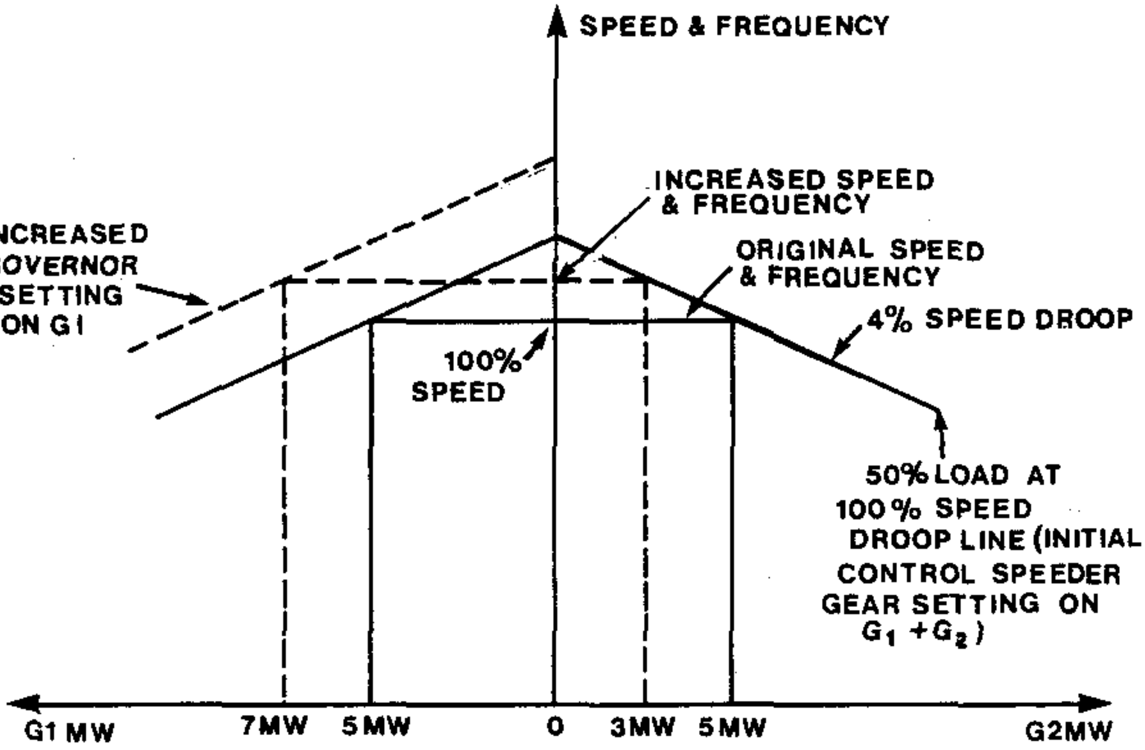


Figure 5: Diagram showing how load on G1 and G2 and the speed and frequency balance out.

(b) Because of the slight speed rise (approximately 1%) the voltage will also rise by approximately 1%. This will cause a rise of approximately 2% in the power consumed by the load, ie,

$$P = \frac{(1.01\ V_T)^2}{R} = \frac{1.02\ V_T}{R}$$

The increase in voltage will cause a corresponding rise in reactive power consumption.

(c) Generator 1 is now producing more power and current. The armature reaction will be larger and the generator will therefore be **underexcited** for the higher load. Its power factor will therefore become **more leading.**

Generator 2 is now producing **less** power and current. The armature reaction will be less and the generator will therefore be overexcited for the lower load. Its power factor will therefore become **more** lagging.

The power factor of the **load**, because the active and reactive power remain in the same ratio, will be constant. There may be a slight variation due to the effect of the higher frequency.

3.3 Loading a Small Generator onto a Live Bus Which is Connected to the System

Providing a small generator has a capacity of less than 5% of the system, the small generator can be assumed to be operating on an infinite bus. The operation of a generator on an infinite bus has already been detailed in lesson 230.21-2.

4.0 LOAD REJECTION ON LARGE GENERATORS

Generators supplying the Ontario Hydro and other systems, can at any instant, trip or be tripped from the system.

Each main generator at a nuclear generating station typically supplies 94% of its output to the grid and 6% to its unit service load. Taking the case of a Bruce 'A' generator operating at 750 MW, it will be supplying 48 MW to its unit service load and 702 MW to the grid.

4.1 Loss of Load Due to Main Output Breaker Tripping

Before the generator main output breaker trips, the generator is receiving 750 MW of shaft power from the turbine, and is sending 702 MW to the grid and 48 MW to its unit service load. Immediately after the main output breaker trips, the generator will only have the auxiliary load of 48 MW. Because the power input to the generator is vastly greater than the output, the turbine-generator will immediately start to accelerate. The governor will sense the increase in speed and quickly act to close the governor valves. Due to the governor slope or droop characteristic, (4% speed droop), and since there is an almost total load rejection, the speed will rise by almost 4%. The speed will stabilize at approximately 1860 rpm (62.0 Hz) and the voltage will be held to its original value by the action of the AVR.

Provided steam is available, (ie, the reactor does not poison out or even if poison out occurs, reactor will produce approximately 3% full power steam for at least 1 hour), the generator will continue to supply 48 MW at 18.5 kV at 62.8 Hz. The operator will have to alter the governor speeder setting to bring the generator output back to 60 Hz for satisfactory operation of the unit service load.

4.2 Loss of Load Due to Remote Load Breakers Tripping

Generators feeding their load through long transmission lines can loose their load due to the breakers opening at the remote ends of the transmission lines, see Figure 6. The situation can easily occur in the Bruce Area where the main load centres are far from the generation area. A large storm can cause many lines to trip and leave the station with an "island" of only the "local load" of 400 - 500 MW instead of the 3000 MW previously supplied. This local lead will consist of the unit services loads plus the load of the surrounding area which has not been tripped as a result of the storm.

Under this condition, the AVR's will control the voltage, and the governors will control the frequency at a level above 60 Hz. Operator action will be necessary to lower the governor speeder settings to bring the frequency to 60 Hz.

Reconnecting an **island** of generation and load to the rest of the system is extremely important. *The "island" will be out of synchronism with the* rest of the system. The re-synchronizing of the "island" to the rest of system, will have to be done remotely from the generating station and this *will involve the personnel at a remote switchyard.* It will also involve co-operation of the personnel at the generating station who will have to control frequency, voltage and phase angle during synchronizing.

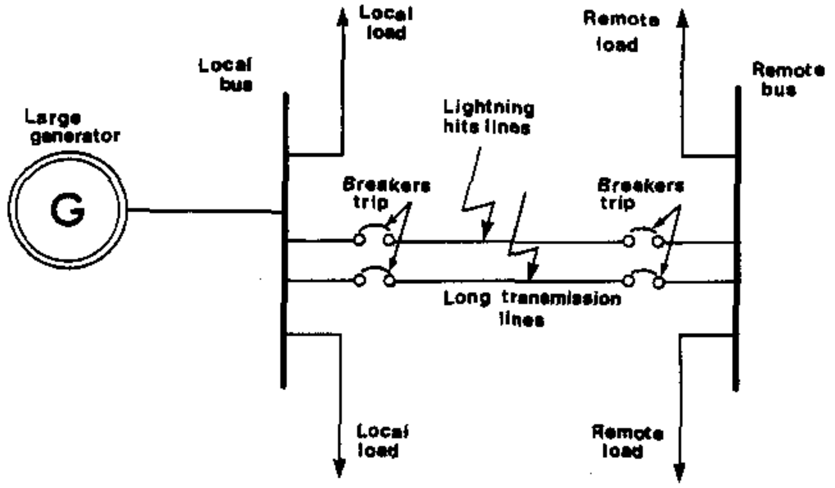


Figure 6: Generator supplying local load and remote bus via long transmission lines.

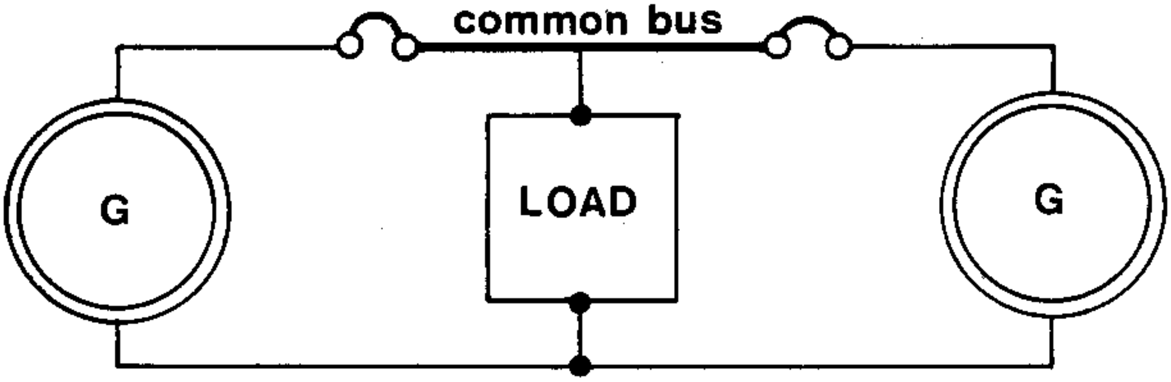
ASSIGNMENT

1. Explain why the AVR of a small generator (combustion turbine) should be in service when:

   (a) the generator energizes a dead bus.

   (b) load is applied to this bus (after it has been energized).

2. Two similar 16 MW, .8 pf combustion turbine driven generators G1 and G2 are arranged to supply a common bus, which feeds a load. See diagram.



   The load of 16 MW, 12 Mvar is supplied by G2. Explain how the bus voltage and frequency will vary when generator G1 is loaded onto the system. The AVR's are in service and the governor setting of G2 is not altered.

3. How are the adjustments made in load sharing between similar turbine generators operating in parallel. State what precautions would be taken to keep the frequency exactly constant when you are loading a large generator onto a system.

4. Two similar 16 MW .8 pf combustion turbine driven generators G1 and G2 are arranged to supply a common bus which feeds a load. This load of 16 MW at .8 pf lag is equally carried by both generators.

   The excitation on G1 is increased, the excitation on G2 is kept constant by putting the AVR on "Manual". Explain how the following will vary:

   (a) Bus voltage.
   (b) Bus MW load.
   (c) Bus frequency.
   (d) pf of G1.
   (e) pf of G2.
   (f) pf of the load.

5. Two similar 16 MW .8 pf combustion turbine driven generators G1 and G2 are arranged to supply a common bus which feeds a load. This load of 16 MW at .8 pf lag is equally carried by both generators. The AVR's are in service. Generator G1 output breaker opens. Explain how the following will vary:

   (a) Bus voltage.
   (b) Bus frequency.
   (c) Frequency of G1.
   (d) Bus MW load.
   (e) Field current on G1.
   (f) Field current on G2.
   (g) pf of G2.
   (h) pf of the load.

6. Two similar 16 MW, .8 pf combustion turbine driven generators G1 and G2 are arranged to supply a common bus which feeds a load. This load of 16 MW at 1.0 pf is equally carried by both generators. Both generators have their AVR's selected to "Manual". The governor setting on G1 is increased until G1 produces 12 MW. Explain how the following will vary:

   (a) Bus voltage.
   (b) Bus frequency.
   (c) Load on G2.
   (d) Load on bus.
   (e) pf and var output of G1.
   (f) pf and var output of G2.
   (g) pf and var consumption of load.

7. Explain what will happen and the actions the operator should take to control the frequency of a large generator when:

   (a) The generator main output breaker opens and only local load remains connected.

   (b) The breakers open at the end of the transmission lines leaving a large generator supplying an "island" which has a consumption of half the normal generator output.

8. State the problems which can occur when re-synchronizing an "island". Assume the re-synchronizing has to be done at a point remote from the generating station.

9. Two identical 100 MW generators, G1 and G2 driven by identical turbines having the same droop settings and characteristics on their governors equally share an isolated load of 100 MW, 1.0 pf. The steam flow to the G1 is then increased until it produces 60 MW.

   With the AVR's and governors in service, explain how each of the following would vary:

   (a) Frequency.
   (b) Terminal Voltage.
   (c) Power factor of each generator.
   (d) Reactive Power output from each generator.
   (e) Load Power.

   What difference(s) in the above would occur if the:

   (f) AVR on Generator 1 was out of service.
   (g) AVR on Generator 2 was out of service.
   (h) Both AVR's were out of service.

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