Turbine, Generator & Auxiliaries - Course 234

GOVERNOR OPERATION

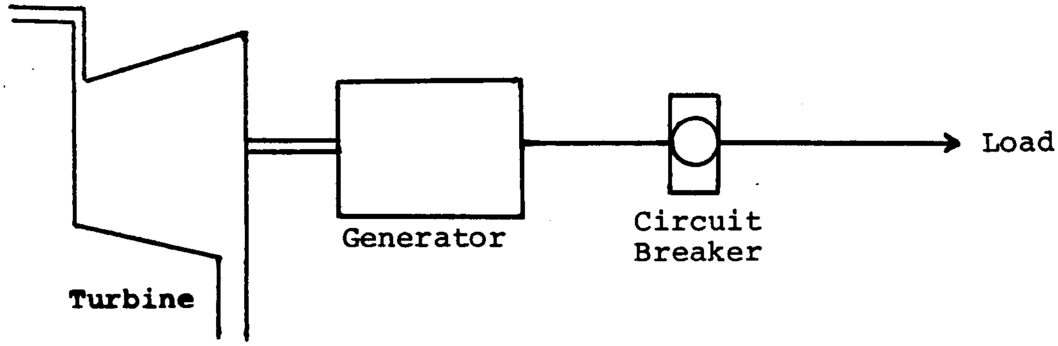


Figure 4.1

Figure 4.1 shows a single turbine driving an ac generator which is supplying a load. Heat energy in the steam passing through the turbine is converted into shaft mechanical power. In the generator this shaft mechanical power is converted to electrical power which then flows to the load where this power is consumed. The turbine is producing a mechanical torque on the shaft. If something were not producing a countertorque of equal magnitude, the rotational speed on the shaft would be increasing. As it turns out the generator, in the process of generating electrical power, exerts this countertorque on the shaft. The countertorque developed by the generator is directly proportional to two quantities:

1. the magnetic field flux of the generator (ϕ), and
2. the load current flowing out of the generator to the load (I),

$$\text{or } T = K\phi I$$

where K = constant of proportionality.

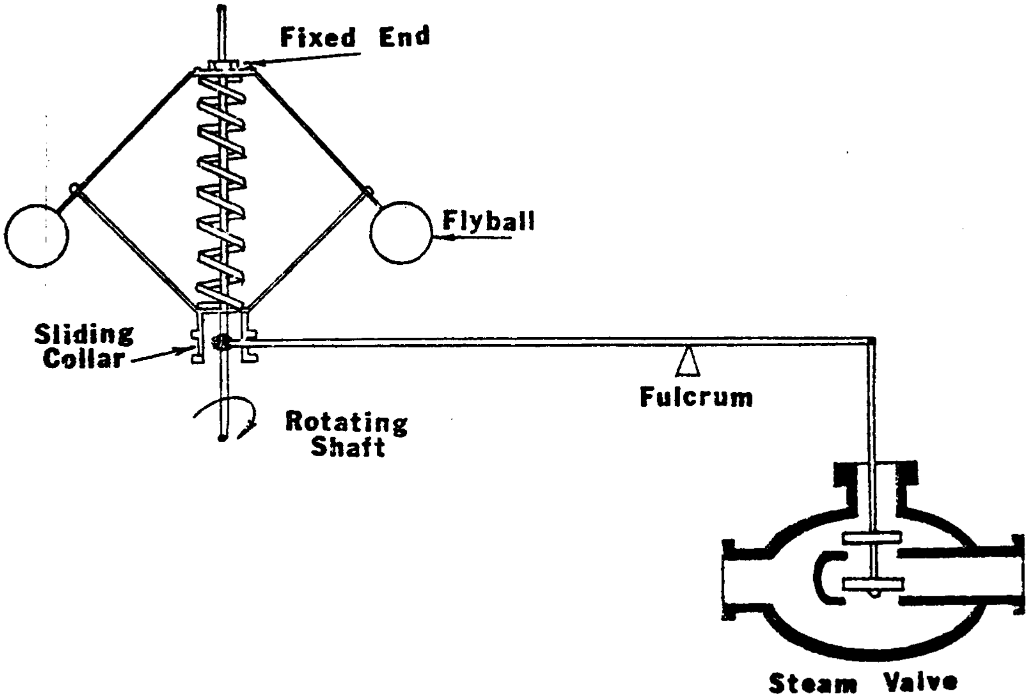
At a constant speed, the mechanical torque produced by steam flowing through the turbine is exactly balanced by this countertorque of the generator.

If the load current flowing from the generator is increased because additional load equipment is energized, the countertorque obviously increases.

$$\overset{\uparrow}{T} = K\overset{\rightarrow}{\phi}\overset{\uparrow}{I}$$

This creates an imbalance between turbine torque and generator countertorque (countertorque is now greater than turbine torque) and the turbine begins to slow down. Clearly, if the turbine is to return to its original speed the turbine torque must be increased by increasing the steam flow to the turbine.

This problem is partially alleviated through the use of the simple governor, shown in Figure 4.2.



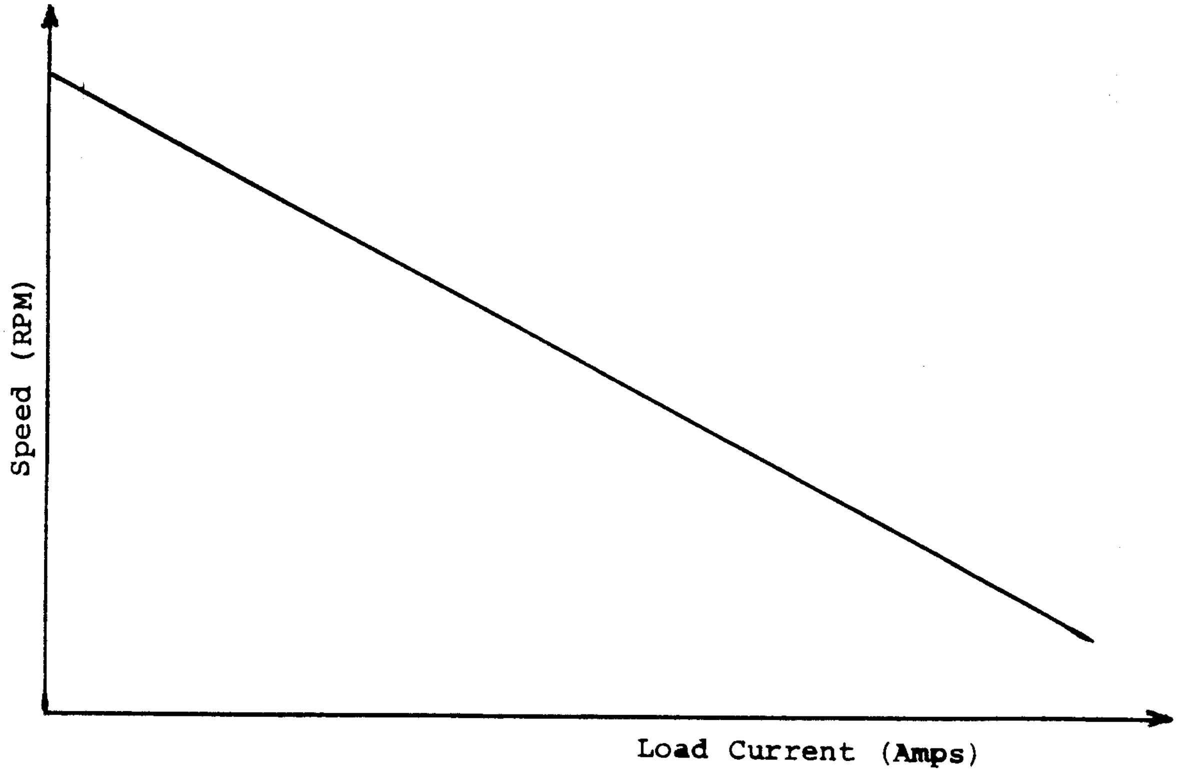
Simple Flyball Governor

Figure 4.2

The flyballs in the governor are driven off the turbine shaft. As turbine speed increases, the centrifugal force acting on the flyballs throws them out against spring tension. As turbine speed decreases, the centrifugal force decreases and the spring pulls the flyballs together. The flyballs are connected to a collar which is free to move. As the flyballs move out (indicating the turbine is speeding up), the collar moves to the left and, acting through the lever, shuts the governor valve. As the turbine speed decreases, the flyballs are pulled in, the collar moves to the right and the governor valve opens, admitting more steam.

With this type of simple flyball governor, the turbine can partially compensate for an increase in generator load. If the load current increases, generator torque ($T = K\phi I$) increases and the turbine slows down. As this happens, the flyballs move in, open the governor steam valve and admit more steam. This increases turbine torque until it is equal to generator counter-torque. At this point speed stabilizes and the flyballs assume a constant position (spring tension balanced by centrifugal force).

The disadvantage of this simple flyball governor is that there is only one speed (flyball position) corresponding to a particular governor valve position. The result is that to increase the steam flow to the turbine, the speed must decrease. If the speed returned to the initial value, the flyballs would return to their initial position. If this occurred, the governor valve would return to its initial position and the steam flow would return to the initial value. Thus, with a simple flyball governor, a particular load can only be achieved at a particular speed. This is shown in Figure 4.3.



Load Versus Speed for a Simple Flyball Governor

Figure 4.3

Since generator output frequency is directly proportional to turbine/generator RPM, this characteristic causes several problems. If the output frequency is not held constant, motors will run at non-constant speeds, load impedances will change and load currents and voltages will vary. For any reliable, practical load distribution system, a constant frequency is essential.

It is possible to construct a constant speed governor which, although somewhat more complicated than the simple flyball governor, overcomes the disadvantage of having an output frequency which varies with generator load current. With the constant speed or isochronous governor the response to a load increase is as follows:

1. load current increases,
2. generator countertorque increases,
3. turbine/generator slows down,
4. governor senses speed drop (flyballs move in),
5. governor opens upon the governor steam valve,
6. more steam is admitted to the turbine,
7. speed returns to the initial speed with turbine power equal to the new generator power.

With a decrease in load, the governor responds in the opposite way:

1. load current decreases,
2. generator countertorque decreases,
3. turbine/generator speeds up,
4. governor senses speed increase (flyballs move out),
5. governor shuts down on the governor steam valve,
6. less steam is admitted to the turbine,
7. speed returns to the initial speed with turbine power equal to the new generator power.

Of course, the Ontario Hydro electrical grid is not individual turbine/generators supplying their own loads, but rather a large number of generators operating in parallel with each other. The operation of many turbine/generators operating in parallel makes the governing somewhat more complex.

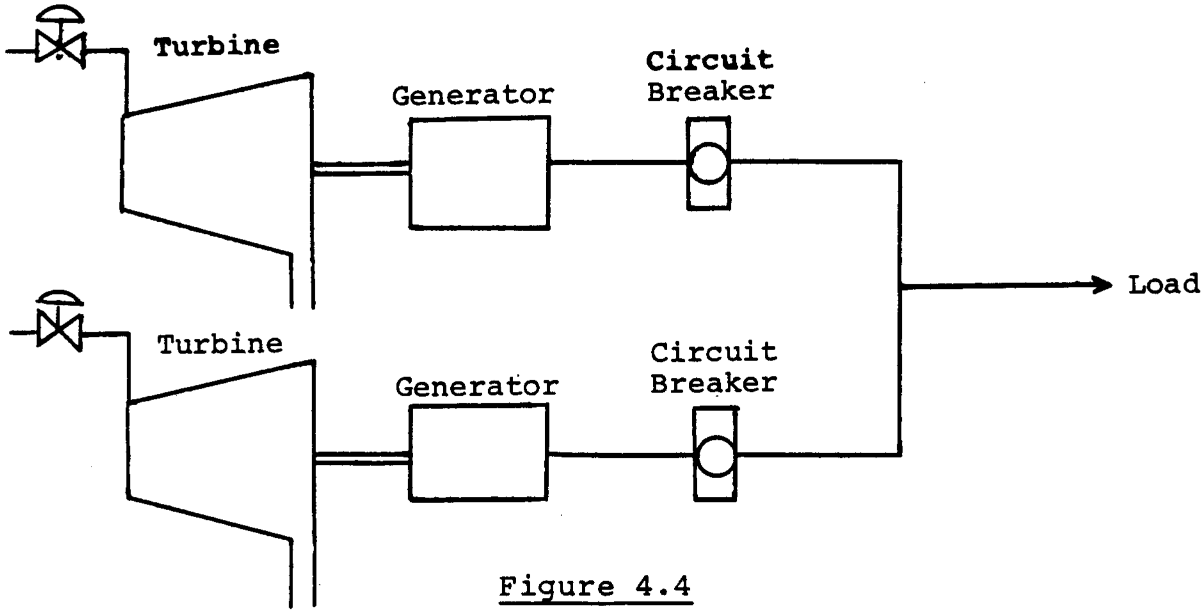


Figure 4.4

Figure 4.4 shows two ac generators operating in parallel supplying a load.

When two or more generators are electrically connected they must operate at the same frequency. If one speeds up, the others must speed up with it; they cannot do otherwise as long as they remain electrically connected. Under normal circumstances, two generators in parallel can no more operate at different frequencies than the wheels of a car can turn at different speeds. In Figure 4.4, the two generators are operating at the same frequency supplying the load. They share the real electrical load in proportion to the turbine mechanical shaft power of each turbine.

If the load increases, the countertorque ($T = K\phi I$) of both generators increases and both generators slow down. Since they are operating in parallel, the two generators must maintain equal frequencies and both slow down equally. Both governors will sense the speed decrease and begin opening up on their respective governor steam valves to return the speed to its initial value. However, if one governor is faster acting it will increase the steam supply to its turbine faster than the other governor will.

Since the generator frequencies must be equal, as the faster-acting governor returns its turbine to the initial speed, its generator will literally "pull" the speed of the other generator up with it. In addition, the turbine with the faster acting governor will pick up a disproportionate share of the load increase. In fact, when two turbine/

generators with constant speed governors are operating in parallel, there is no guarantee that one generator will not pick up all of the load increase. If the total electrical load decreases, the reverse will happen and the faster acting governor will shed its load faster. This is clearly an unstable situation. Although the generators will always return to their initial speed (both have constant speed governors), there will be a constant shifting of real electrical loads between the generators. If many generators were operating in parallel, this constant shifting of real loads between generators would be comical if it were not so hazardous to the stability of the grid.

To prevent this from happening, governors are not designed to be constant speed from no load to full load. Rather each governor is designed to have a small speed droop. That is, as the load is increased, the governor will not return the turbine speed to its initial value but rather to a speed slightly below the initial value. This speed droop is a design characteristic of the governor and is typically between 1% and 5% of full load speed.

$$\text{Speed Droop} = \frac{N_{FL} - N_{NL}}{N_{FL}}$$

where: N_{FL} = full load speed

N_{NL} = no load speed

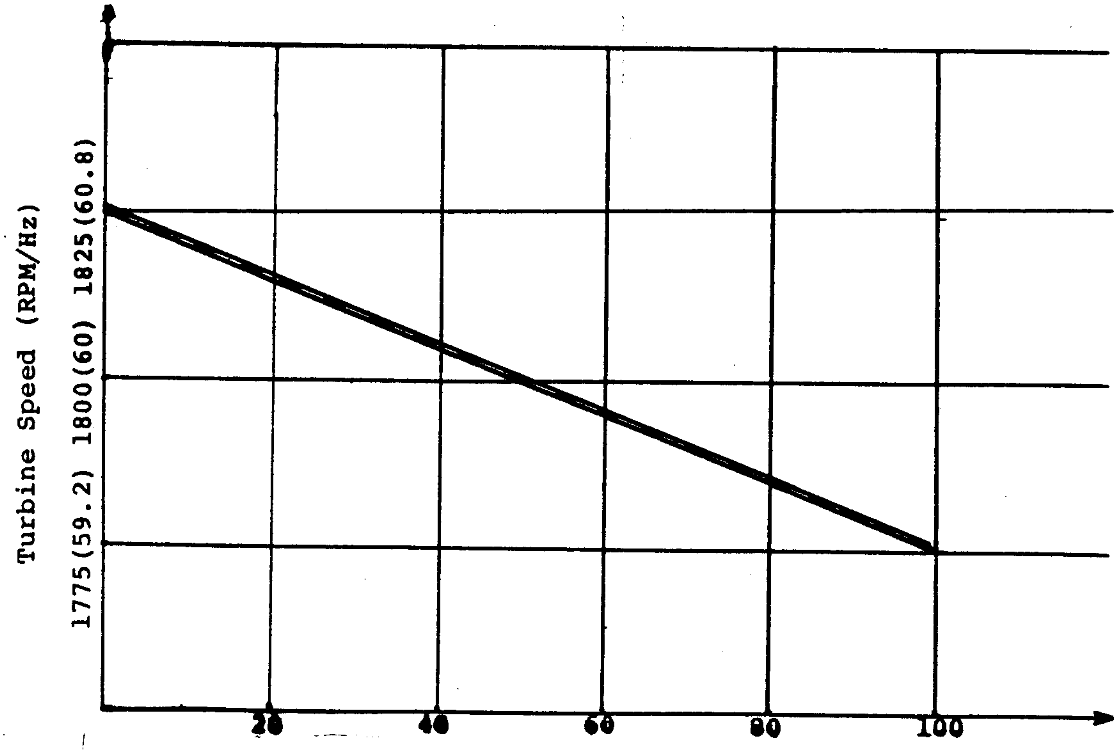


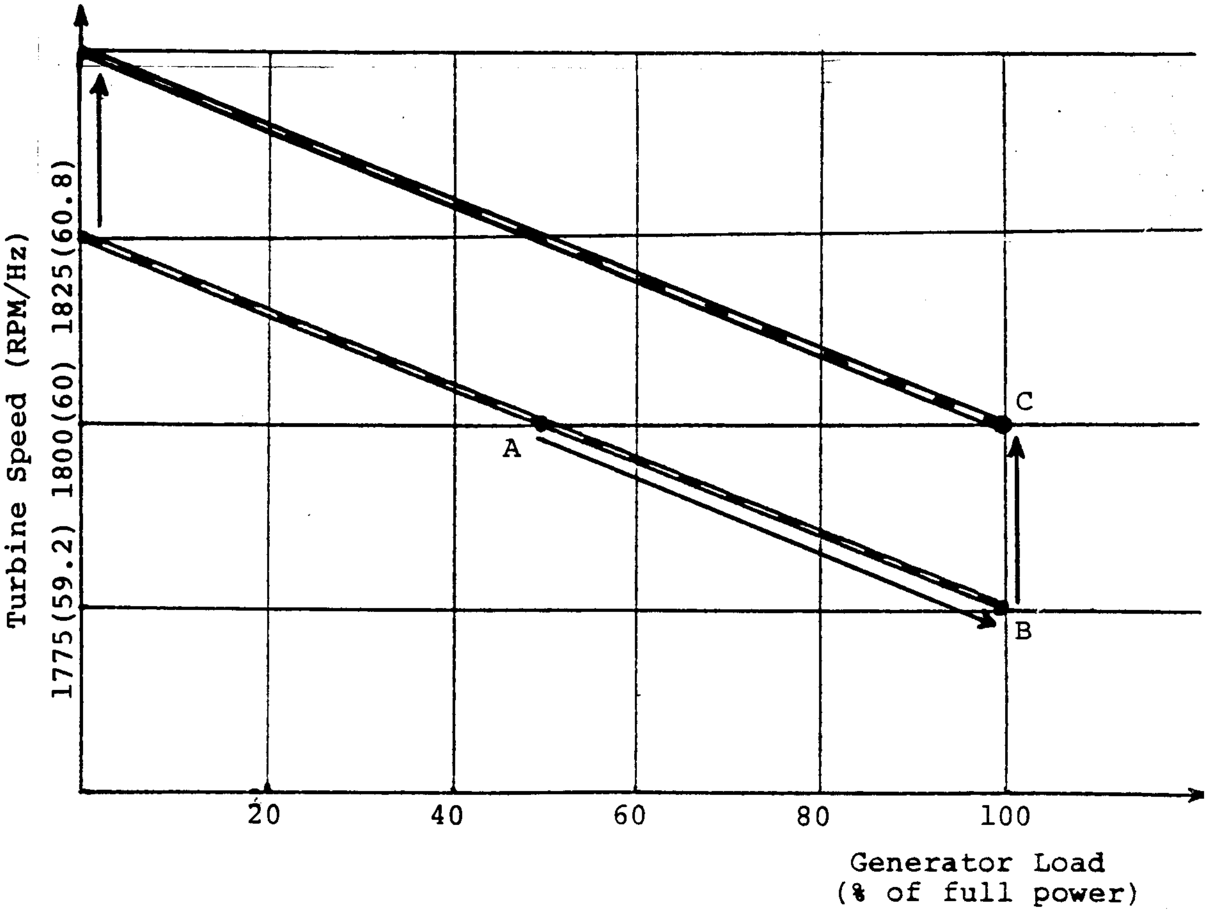
Figure 4.5

Figure 4.5 shows a typical speed versus load curve for a turbine with a governor having speed droop. Consider such a turbine individually supplying a load. If the load increases, the governor will increase the steam supply to meet the additional power demand; however, when speed is stabilized, it will be at a slightly lower speed than it was initially. It would appear at first glance that we are back to the problem of the simple flyball governor. However, the governor is constructed to allow the raising or lowering of the speed droop curve through a device called a <u>speeder gear</u>. The effect of a load increase is shown in Figure 4.6 as follows:

(a) load increases from 50% to 100% of full load,

(b) the governor restores the speed to that dictated by the speed droop curve or 1775 RPM (A to B),

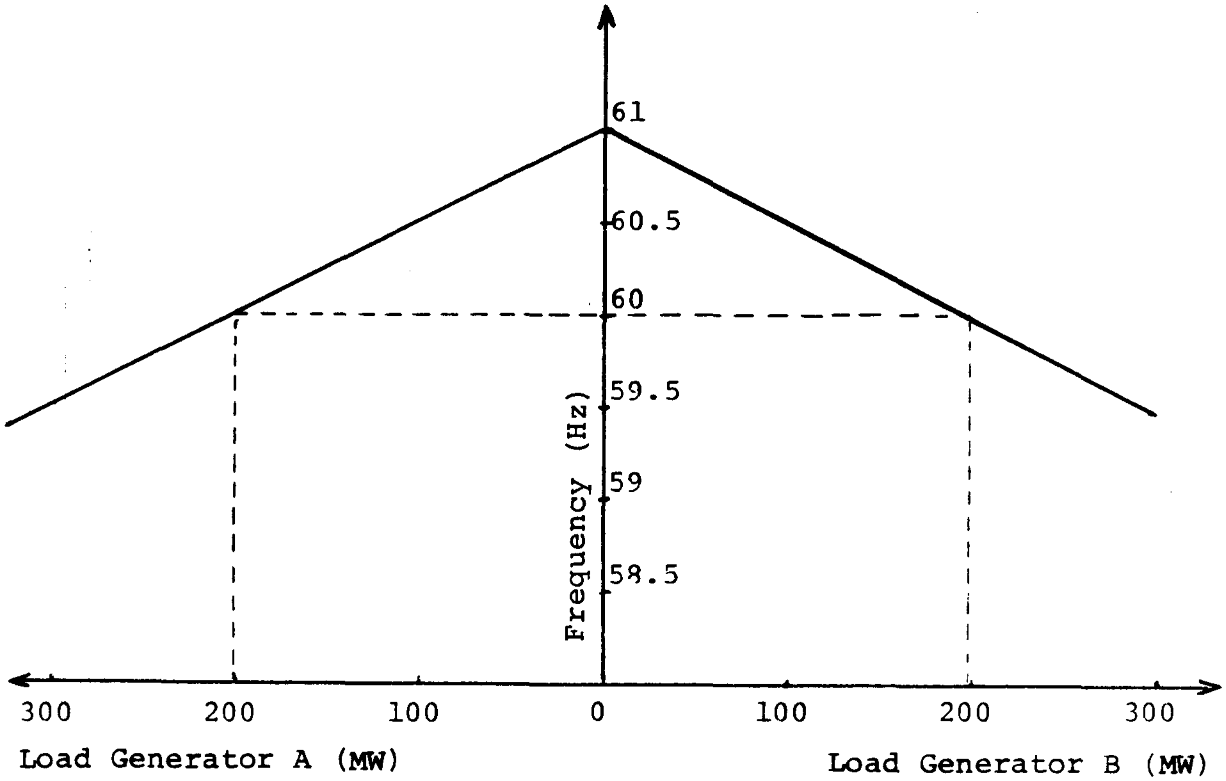
(c) through the speeder gear the speed droop curve is raised (either by the operator or automatically) so that the turbine supplies 100% of full load at 1800 RPM (B to C).



Effect of Load Change

Figure 4.6

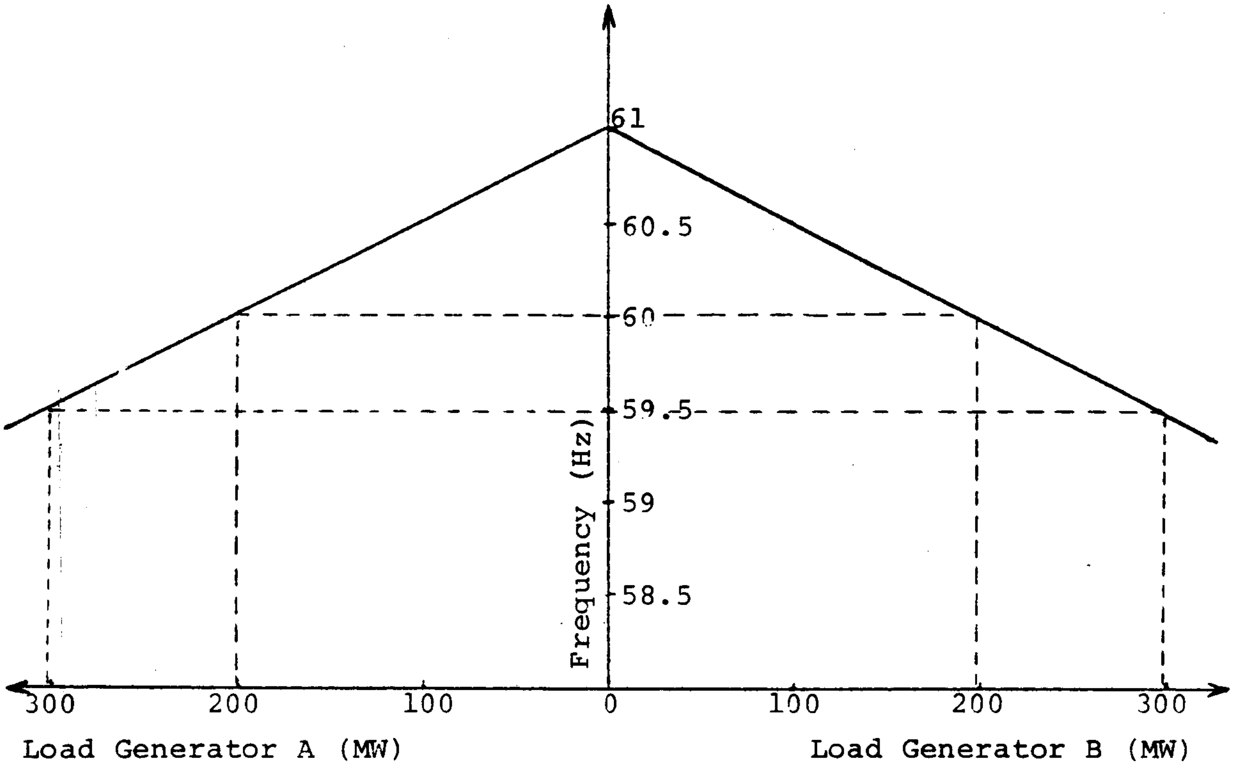
It should be noted that to change the operating point from B to C, what was done in effect was raise the no-load speed from 1825 to 1850 rpm (no-load frequency from 60.8 to 61.6 Hz). Although the governor senses and controls turbine speed, since turbine speed is directly proportional to frequency, it is common to visualize the governor as controlling frequency. When generators are operating in parallel the speed droop of their respective turbine governors eliminates the instability caused by the constant speed governor. Figure 4.7 shows the speed droop curves for two turbine generators equally sharing a 400 MW load at 60 Hz.



Two Turbine/Generator Sharing a 400 MW Load

Figure 4.7

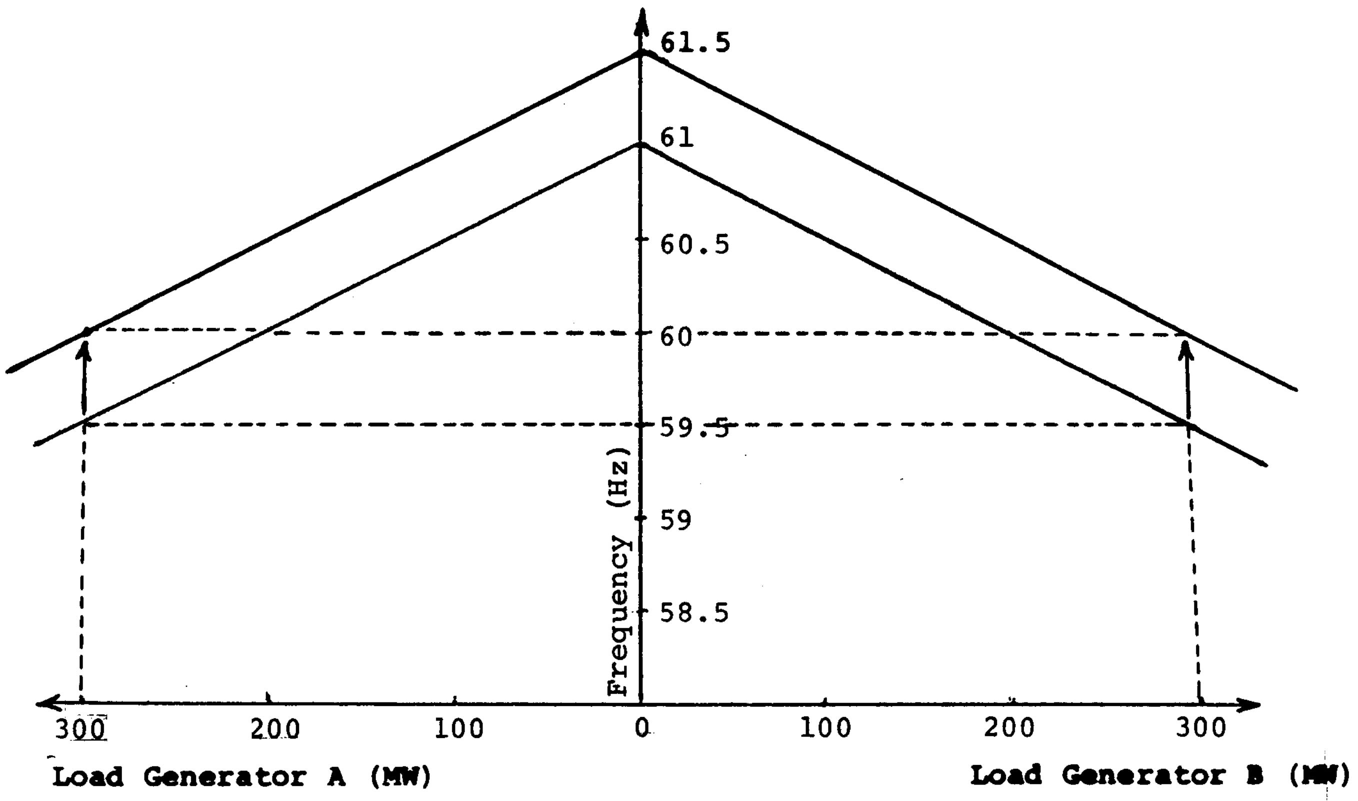
The total load is increased to 600 MW by energizing more loads. Recalling that the two generators must remain at the same frequency, you will note that there is only one point at which these two generators can share 600 MW and that is at a frequency of 59.5 Hz. Furthermore at 59.5 Hz the generators must be equally sharing the load.



Load Increase from 400 to 600 MW

Figure 4.8

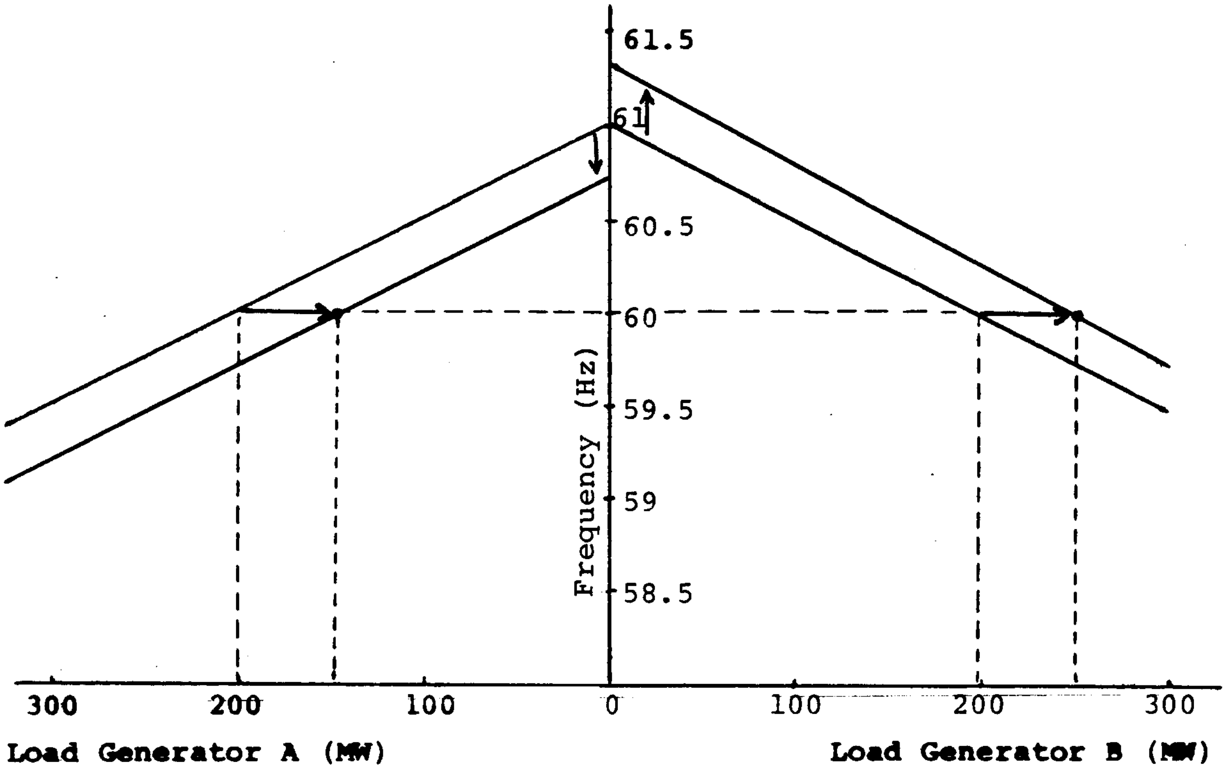
To return the output frequency to 60 Hz the speeder gear would be used to raise both speed droop curves so that the two generators can supply 300 MW each at 60 Hz. To accomplish this the speeder gear increased the no-load speed from 61 Hz to 61.5 Hz (Figure 4.9).



Restoration of Frequency Following a Load Change

Figure 4.9

With the two units operating in parallel equally sharing a 400 MW load at 60 Hz, suppose it is desired to change the load distribution between the two generators. The load of generator A is to be lowered from 200 MW to 150 MW, while the load of generator B is to be increased from 200 MW to 250 MW. Figure 4.10 shows how this is accomplished. The speed droop curve of generator A is lowered, which means for a given frequency (60 Hz) the turbine will call for less steam and the generator load will drop. Simultaneously, the speed droop curve of generator B is raised, which implies that the turbine will call for more steam and generator load will increase. Placing the speeder gear of generator A in the "lower speed" position lowered the no-load speed and lowered the real generator output. Placing the speeder gear of generator B in the "raise speed" position raised the no-load speed and raised the real generator output. However, since both generators were in parallel they could not operate at different frequencies and, provided the operator is careful when he redistributes the load, the common frequency will be 60 Hz.



Varying Load Distribution

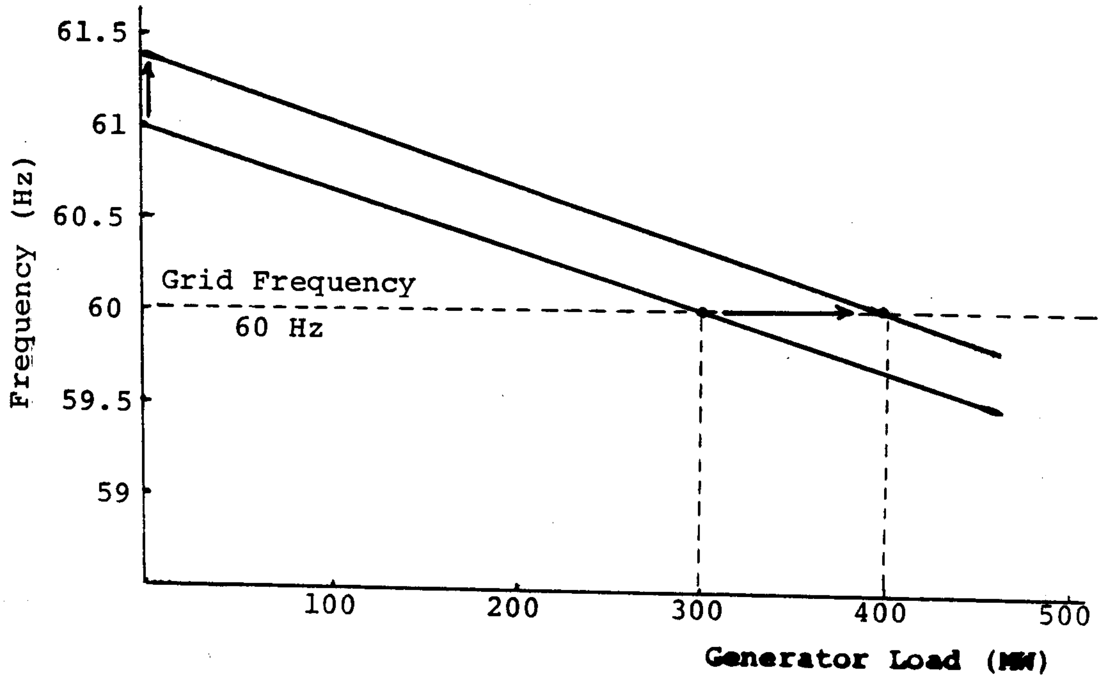
Figure 4.10

The operation of a turbine generator in parallel with the hydro grid is quite similar to the preceding example with a couple of notable exceptions:

1. The hydro grid is large enough that during normal operation the frequency of the grid is constant for all practical purposes. That is when the grid is functioning normally, the frequency cannot be changed by a single generator.

2. The decrease in frequency of the grid for an additional load being energized is much too small to be seen by a governor. That is when the little old lady in Maynooth turns on her stove, the drop in grid frequency (say from 60 Hz to 59.9999999 Hz) is too small to be seen by the governors in the generating stations and the generators cannot automatically pick up this load.

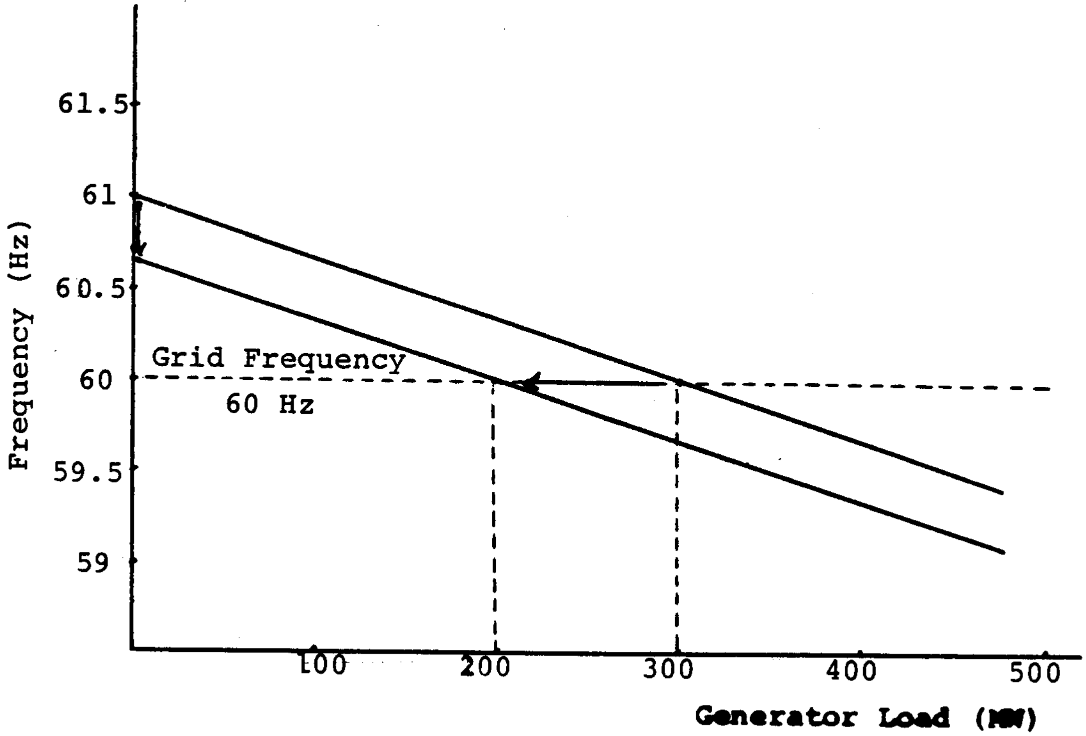
A generator supplying power to the Hydro grid can neither change the grid frequency to any appreciable extent nor sense minor changes in grid frequency. A control centre which can detect small frequency changes must be used to direct turbine generator loading and unloading.



Increasing Generator Load

Figure 4.11

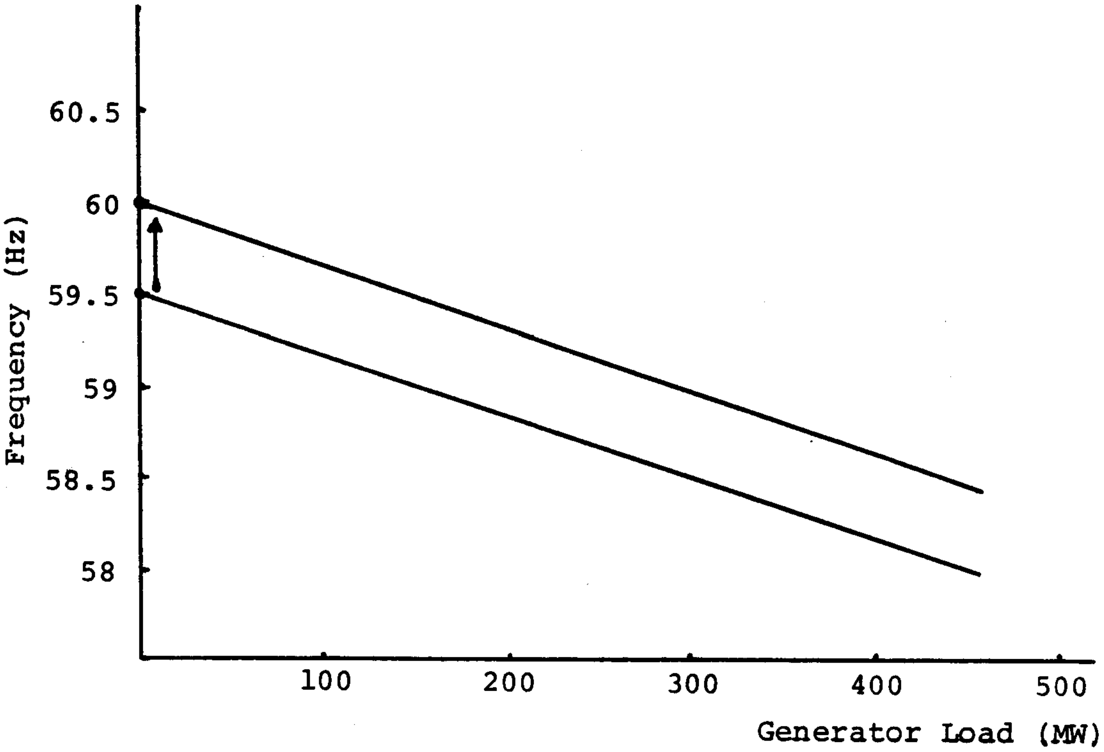
To increase the output of a turbine generator, the speeder gear is moved in the "raise speed" direction, the speed droop curve is raised and the load increases while the frequency remains at 60 Hz (Figure 4.11). To decrease the output of a turbine generator, the speeder gear is moved in the "lower speed" direction, the speed droop curve is lowered and the load decreases while the frequency remains at 60 Hz (Figure 4.12).



Decreasing Generator Load

Figure 4.12

When the turbine generator is not connected to the grid and is supplying no load current, there is no generator countertorque ($T = K\phi I$) to balance the torque produced by the steam in the turbine. The only force acting against the turbine torque is the friction and windage of the turbine and generator. If the speeder gear is moved in the "raise speed" direction when the generator is not synchronized to the grid, the speed droop curve will be shifted upward and the turbine will respond to match the speed determined by the new curve (Figure 4.13). Since the generator is carrying no load, the new, higher speed will be the no-load speed for the new speed droop curve. This higher speed will require a greater steam flow since the friction and windage losses are increased. It should be appreciated, however, that the friction and windage losses are quite small when compared with generator maximum load, and the amount of steam required to raise the turbine speed when the unit is unloaded and unsynchronized is quite small.



Increasing Speed on Generator
Which is not Synchronized to Grid

Figure 4.13

Under normal conditions, the function of the governor can be summarized as being to keep the turbine/generator at the proper load and frequency as determined by the speed droop curve. The operator may change the operative point by moving the speed droop curve. It is then the role of the governor to insure the unit stays there.

As an example of what has been said in this lesson, we will consider the action of the governor during startup, loading and a load rejection.

Startup

You will recall that when the generator is not connected to the grid, the governor will adjust the steam flow to maintain the speed corresponding to the no-load point on the speed droop curve. However, the speeder gear by design is unable to lower the speed droop curve below a no-load speed of about 1650 - 1700 rpm for an 1800 rpm machine. When the speed is below 1650 rpm the governor is trying to bring the speed back up to 1650 rpm, thus the governor steam valves are fully open.

The turbine, therefore, is brought up to 1650 rpm by throttling steam flow with the emergency stop valves. As the turbine speed approaches 1650 rpm, the governor steam valves gradually close until at 1650 rpm they should be passing only enough steam to control the speed at that value. When this happens we speak of the turbine as "coming on the governor" because the governor is capable of controlling the speed at the no-load speed of the speed droop curve. At this point the emergency stop valves can be fully opened.

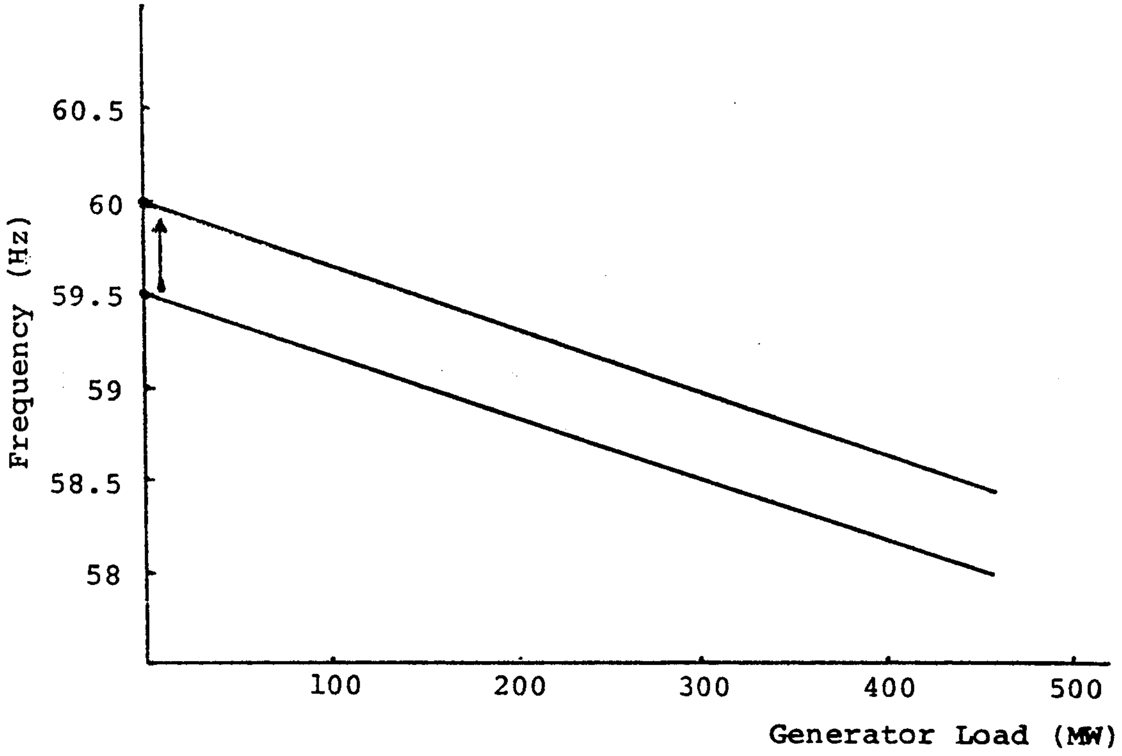
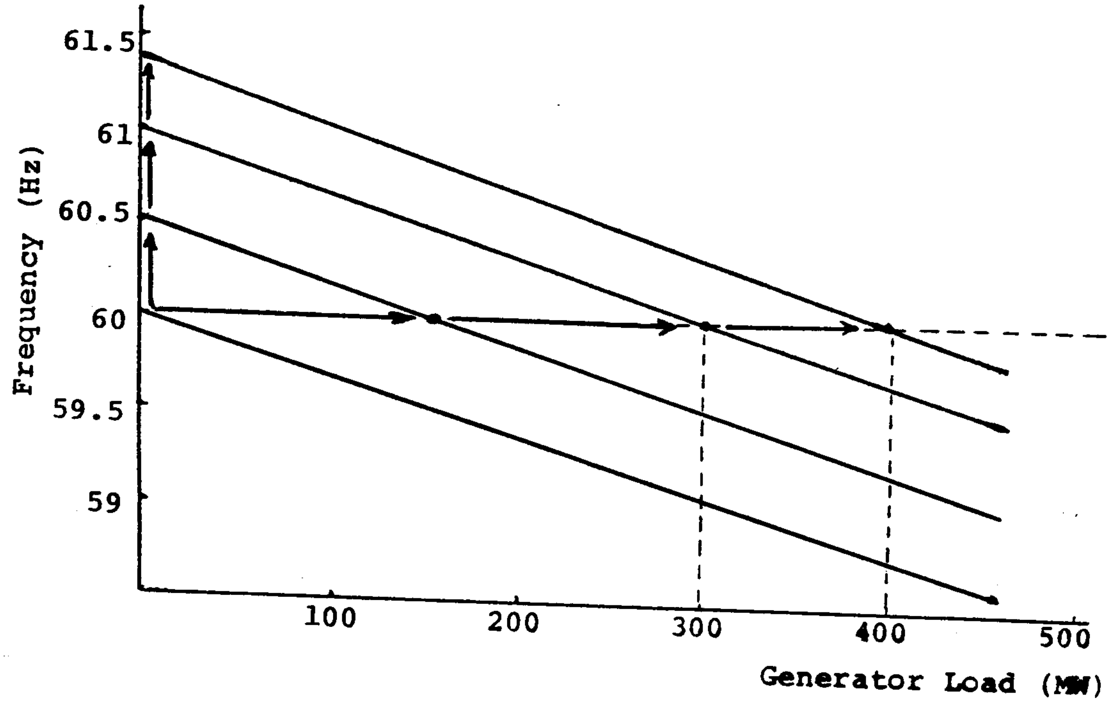


Figure 4.14

The operator can bring the turbine up to 1800 rpm (60 Hz) by moving the speeder gear in the "raise speed" direction. This raises the speed droop curve and the governor admits more steam to the turbine to keep turbine speed equal to the no-load speed of the speed droop curve (Figure 4.14).

Loading

At 1800 rpm, the generator is synchronized to the Hydro grid. Once this has been done, the generator can run at no speed other than 60 Hz (1800 rpm). Regardless of what the operator does with the speeder gear (and therefore the speed droop curve) the turbine and generator must run at 60 Hz. Therefore, as the speeder gear is moved in the "raise speed" direction the speed droop curve will move up but the net effect will be an increase in steam flow and, therefore, an increase in load (Figure 4.15).



Increasing Load on a Synchronized Turbine/Generator

Figure 4.15

Load Rejection

If the generator output breaker trips open due to an electrical fault, the speed will start to rise and the governor will start to close the governor steam valves. However, because of the speed droop of the governor, the governor will attempt to control speed at the no-load value which may be 5% above the normal operating speed. This means the governor has a built-in bias which works against holding speed down on a load rejection. Even though the speeder gear is driven back to the position corresponding to a no-load speed of 1800 rpm, it cannot move fast enough to eliminate the effect of speed droop. In later lessons we will discuss how this problem is handled.

ASSIGNMENT

1. What is the disadvantage of a simply flyball governor?

2. What is the disadvantage of an isochronous (constant speed) governor?

3. What is speed droop? Why are governors designed with speed droop?

4. How can a governor with a 5% speed droop allow a turbine generator to go from 0% to 100% of full load at 60 Hz?

5. A single turbine is supplying a 60 MW load. An additional load of 10 MW is energized. Explain how the turbine responds to supply this load.

6. Why can't the Pickering NGS turbines respond to an additional 10 MW load being energized from the grid?

7. How is the speed increased on a 540 MW turbine/generator which is unconnected from the grid?

8. How is the output load of a 750 MW turbine/generator which is supplying the Hydro grid increased?

9. Why is the governor biased in the wrong direction to handle an overspeed following a load rejection?

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