Parallel Operation of Alternators & Infinite Busbar

Introduction:

Since the demand of electricity varies during a day, also during the various seasons in a year, a modern power station employs two or more units so that one or more alternators can supply power efficiently according to the need.

The parallel operation is required because;

1. ***Several generators can supply a bigger load than one machine by itself.***
2. ***Having many generators increases the reliability of the proper system, since the failure of any one of them does not cause a total power losses to the load.***
3. ***Having many generators operating in parallel allows once or more of them to be removed for shutdown and preventive maintenance.***
4. ***If only one generator is used and it is not operating at near full load, then it will be relatively inefficient. With several smaller machines in parallel, it is possible to operate only a fraction of them. The ones that do operate are operating near full load and thus more efficiently.***

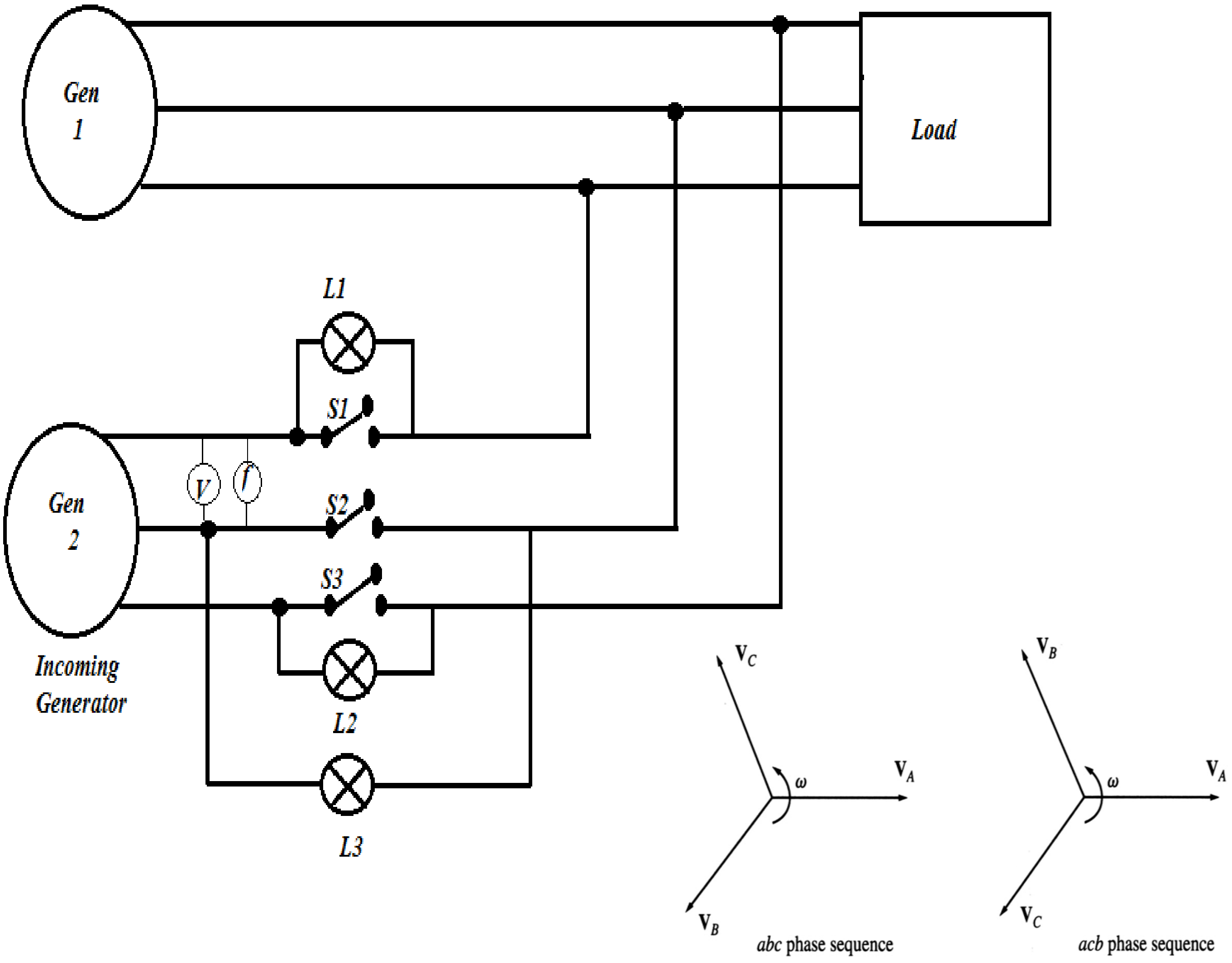
The conditions for synchronizing:

1. ***The rms line voltages of two generators must be equal.***
2. ***The two generators must have the same phase sequence.***
3. ***The frequency of the new generator, which is called oncoming generator, must be slightly higher or equal to than the frequency of running system.***
4. ***The phase angle between two phases must be equal.***

19.1 Synchronizing Methods:

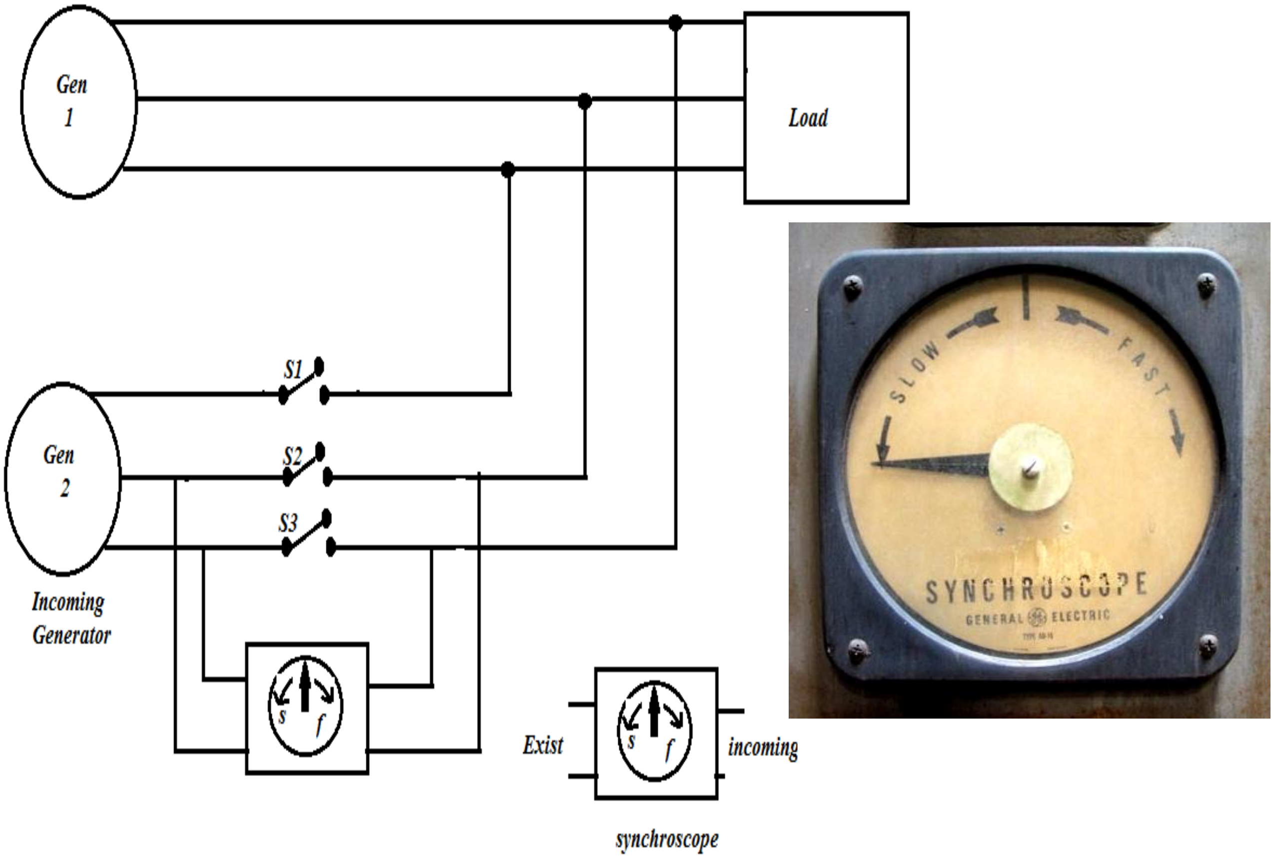
1- Three dark lamps method:

The three lights are connected across the open terminals of switch connecting the generator to the another generator or busbars. As the phase angle changes between the two systems , the light first get bright and dark together. If all lamps get bright and dark together, then the systems have the same phase sequences. The voltage must be noted by voltmeter & frequency by frequency meter until the two are equal or close to other.



2-Synchroscope:

A Synchroscope is a meter that measures the difference in phase angle between the same lines of the two systems. Since the frequency of the two systems are slightly different, the phase angle of the Synchroscope changes slowly. If incoming generator is faster than the running generator then the phase angle advances and the Synchroscope needle rotate clockwise. If the incoming machine is slower, the needle rotates counter clockwise direction. When the Synchroscope needle is in vertical position, the voltage are in phase, and the switch can be close to connect the systems. The Synchroscope checks the relation ship on only one phase. It gives no information about phase sequence.



19.2 The Load Sharing:

The total real and reactive power delivered to the load connected across the common bus bars are shared among the synchronous generators operating in parallel based on the following factors:

i- The prime-mover Characteristics
ii- The Excitation Characteristics
iii- The synchronous impedance ratio (R_a/X_s)

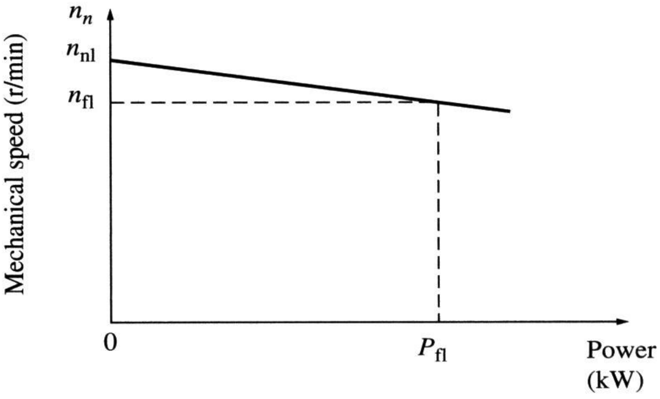
19.2.1 The Prime Mover Characteristics:

All generators are driven by a prime mover, which is the generators source of mechanical power, such steam or diesel, gas turbine. All prime movers tend to behave in a similar fashion, as the power drawn from them increases, the speed is non linear. Whatever governor mechanism is present on a prime mover, it will be adjusted to provide slight drooping characteristics with increasing load.

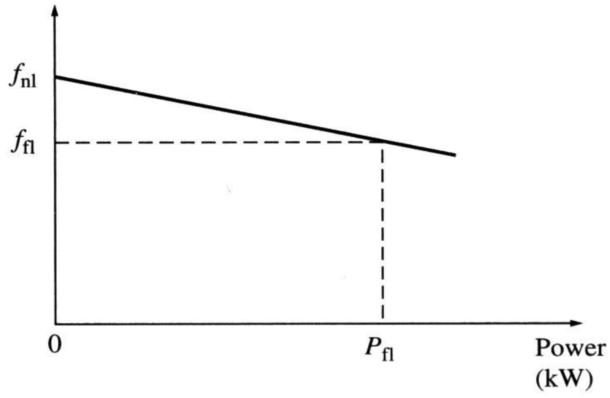
The Speed Droop (SD) of a prime mover is defined;

$$SD = \frac{n_{nl} - n_{fl}}{n_{fl}} \cdot 100\%$$

Most prime movers have a speed drop from 2% to 4%. Most governors have a mechanism to adjust the turbine's no-load speed (set-point adjustment).



(A typical speed vs. power plot)



(A typical frequency vs. power plot)

The power output from the generator is related to its frequency:

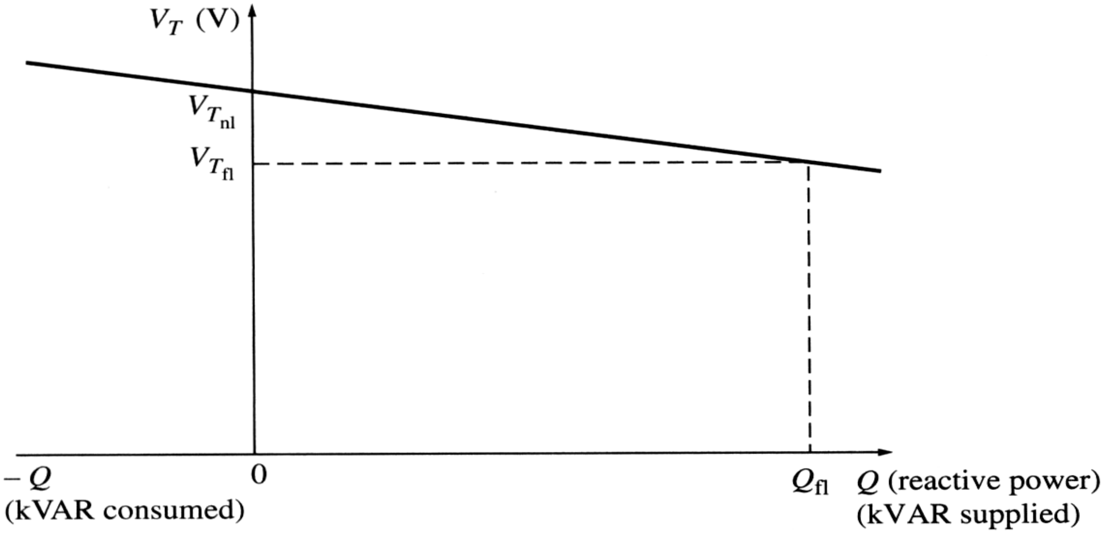
$$P = s_p \left(f_{nl} - f_{sys} \right)$$

P= Power out put of generator
f_{nl} = no-load frequency
f_{sys} = operating frequency
s_P= slop of curve in W/Hz

19.2.2 The Excitation Power Characteristics:

A similar relationship can be derived for the reactive power Q and terminal voltage VT. When adding a lagging load to a synchronous generator, its terminal voltage decreases. When adding a leading load to a synchronous generator, its terminal voltage increases.

The plot of terminal voltage vs. reactive power is not necessarily linear. Both the frequency-power and terminal voltage vs. reactive power characteristics are important for parallel operations of generators.



$Q=S_p\ (V_{tnl} - V_{sys})$
S_p = slop in Var/Volt
Q= Reactive power supplied
V_{tnl}= Voltage at no load
V_{sys}=Operating voltage system

Note:

When a generator is operating alone supplying the load:

1-The real and reactive powers are the amounts demanded by the load.

2-The governor of the prime mover controls the operating frequency of the system.

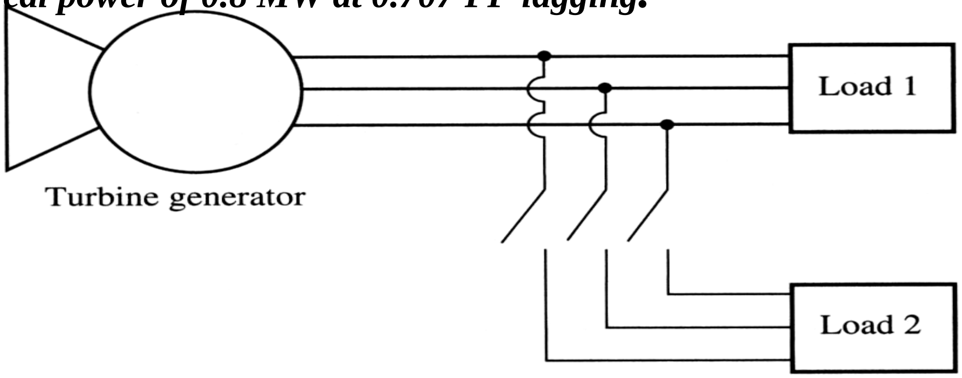
Governor →Real power→ operating frequency

3- The field current controls the terminal voltage of the power system.

Field regulator→Reactive Power→terminal voltage

$f=f(P)$ & $V=f(Q)$

Example 19.1: A generator with no-load frequency of 61.0 Hz and a slope sp of 1 MW/Hz is connected to Load 1 consuming 1 MW of real power at 0.8 PF lagging. Load 2 (that is to be connected to the generator) consumes a real power of 0.8 MW at 0.707 PF lagging.



a. ***Find the operating frequency of the system before the switch is closed.***
b. ***Find the operating frequency of the system after the switch is closed.***
c. ***What action could an operator take to restore the system frequency to 60 Hz after both loads are connected to the generator?***

The power produced by the generator is

$$P = s_p \left(f_{nl} - f_{sys} \right)$$

Therefore:

$$f_{sys} = f_{nl} - \frac{P}{s_p}$$

a. The frequency of the system with one load is

$$f_{sys} = f_{nl} - \frac{P}{s_p} = 61 - \frac{1}{1} = 60\ Hz$$

b. The frequency of the system with two loads is

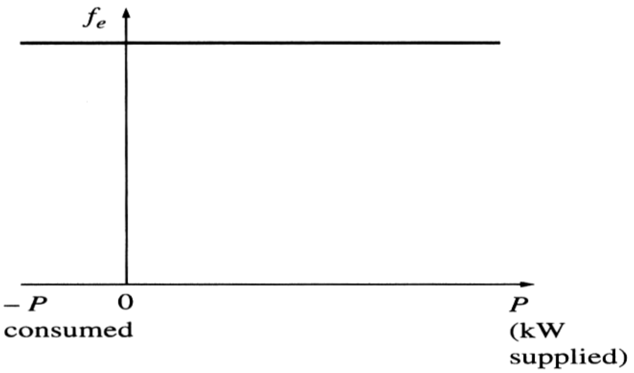
$$f_{sys} = f_{nl} - \frac{P}{s_p} = 61 - \frac{1.8}{1} = 59.2\ Hz$$

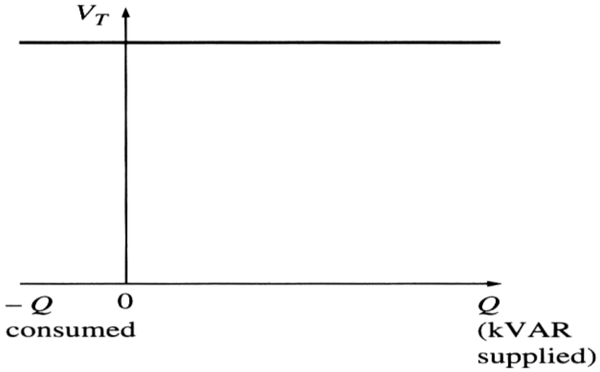
c. To restore the system to the proper operating frequency, the operator should increase the governor no-load set point by 0.8 Hz, to 61.8 Hz. This will restore the system frequency of 60 Hz.

19.3 Operation of Generator with Large Power System or Infinite Bus bar:

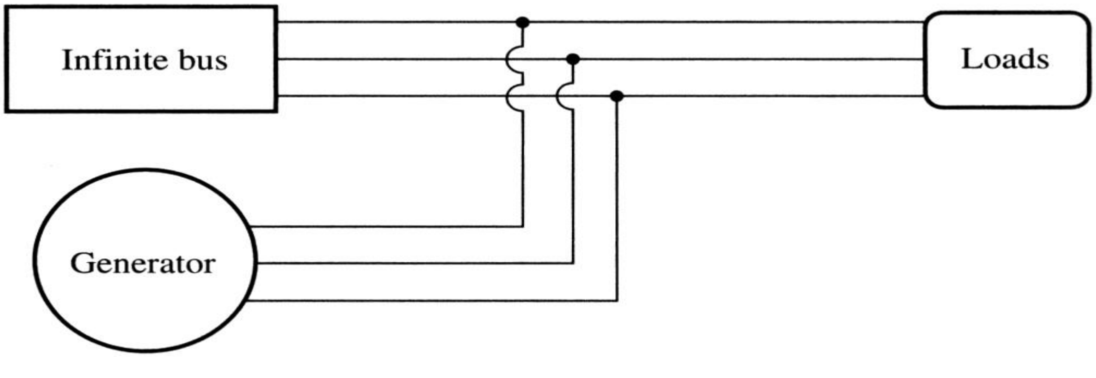
Often, when a synchronous generator is added to a power system, that system is so large that one additional generator does not cause observable changes to the system. A concept of an infinite bus is used to characterize such power systems.

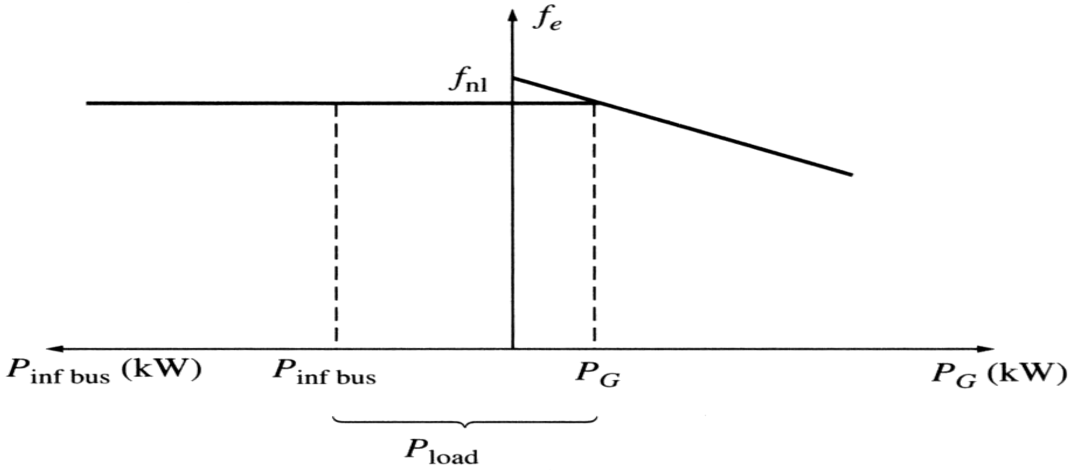
An infinite bus is a power system that is so large that its voltage and frequency do not vary regardless of how much real and reactive power is drawn from or supplied to it. The power-frequency and reactive power-voltage characteristics are:



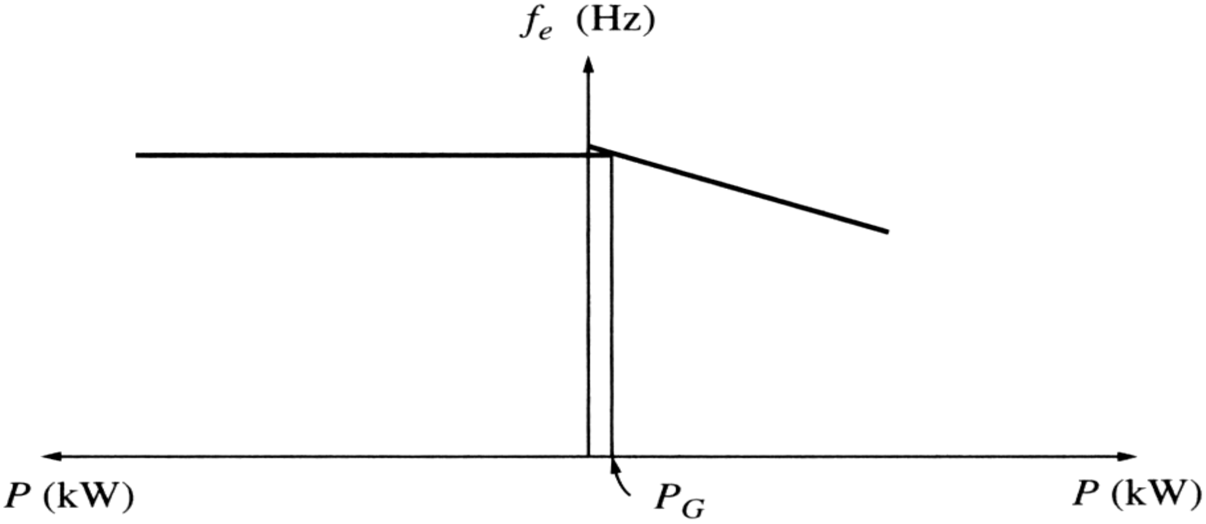


The frequency and terminal voltage of all machines must be the same. Therefore, their power-frequency and reactive power-voltage characteristics can be plotted with a common vertical axis. Such plots are called sometimes as <u>house diagrams</u>.

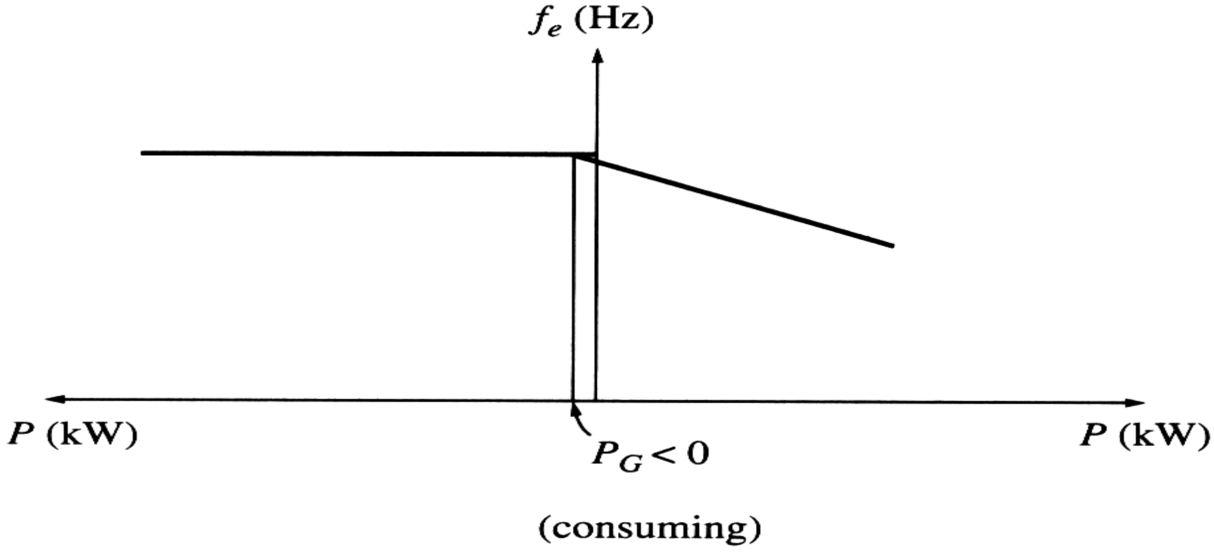




If the no-load frequency of the oncoming generator is slightly higher than the system's frequency, the generator will be "floating" on the line supplying a small amount of real power and little or no reactive power.

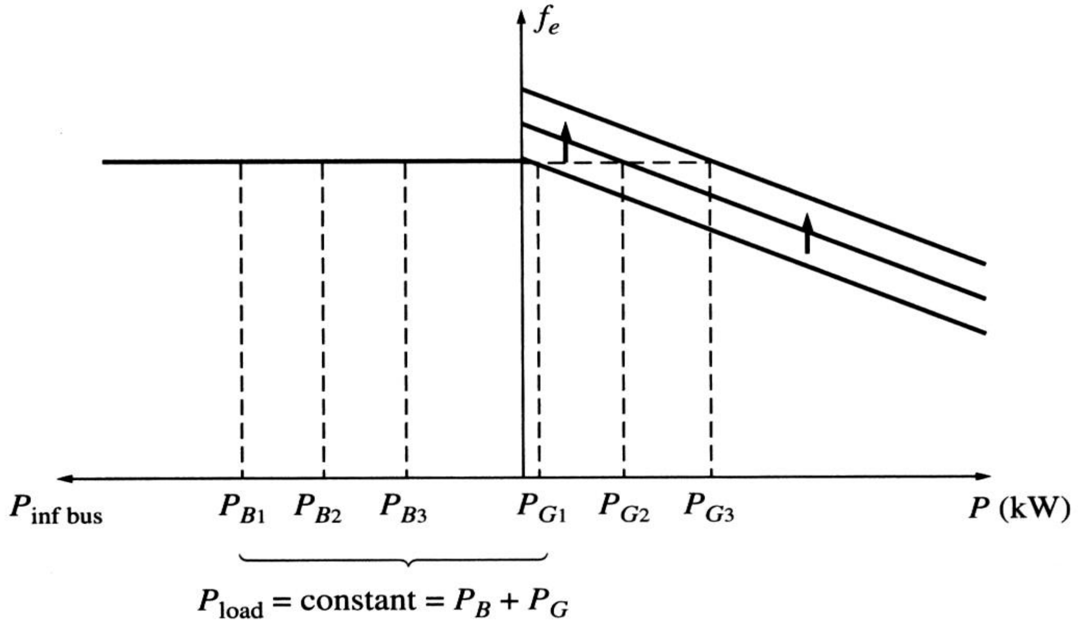


If the no-load frequency of the oncoming generator is lightly lower than the system's frequency, the generator will supply a negative power to the system: the generator actually consumes energy acting as a motor! Many generators have a reverse power trip circuitry automatically disconnecting them from the line when they start consuming energy.



If the frequency of the generator is increased after it is connected to the infinite bus, the system frequency cannot change and the power supplied by the generator increases.

If the frequency of the generator is further increased, power output from the generator will be increased and at some point it may exceed the power consumed by the load. This extra power will be consumed by the load.



After the real power of the generator is adjusted to the desired value, the generator will be operating at a slightly leading PF acting as a capacitor that consumes reactive power. Adjusting the field current of the machine, it is possible to make it to supply reactive power Q to the system.

Summarizing, when the generator is operating in parallel to an infinite bus:

1. ***The frequency and terminal voltage of the generator are controlled by the system to which it is connected.***
2. ***The governor set points of the generator control the real power supplied by the generator to the system.***
3. ***The generator's field current controls the reactive power supplied by the generator to the system.***

19.4 Generators in parallel with other generators of the same size:

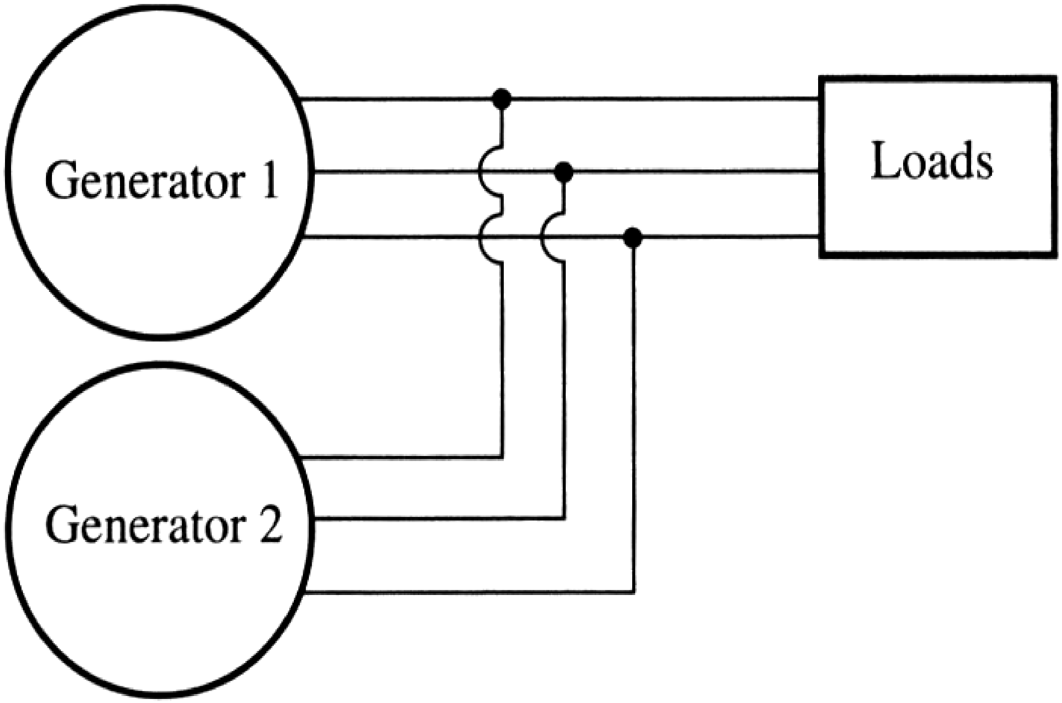
When a generator is working alone, its real and reactive power are fixed and determined by the load.

When a generator is connected to an infinite bus, its frequency and the terminal voltage are constant and determined by a bus.

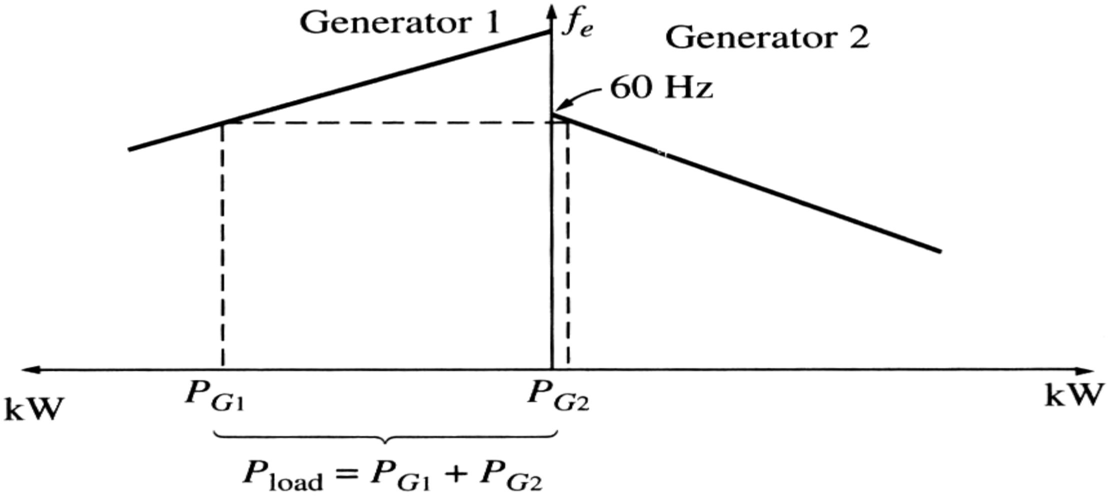
When two generators of the same size are connected to the same load, the sum of the real and reactive powers supplied by the two generators must equal the real and reactive powers demanded by the load:

$$P_{tot} = P_{load} = P_{G1} + P_{G2}$$

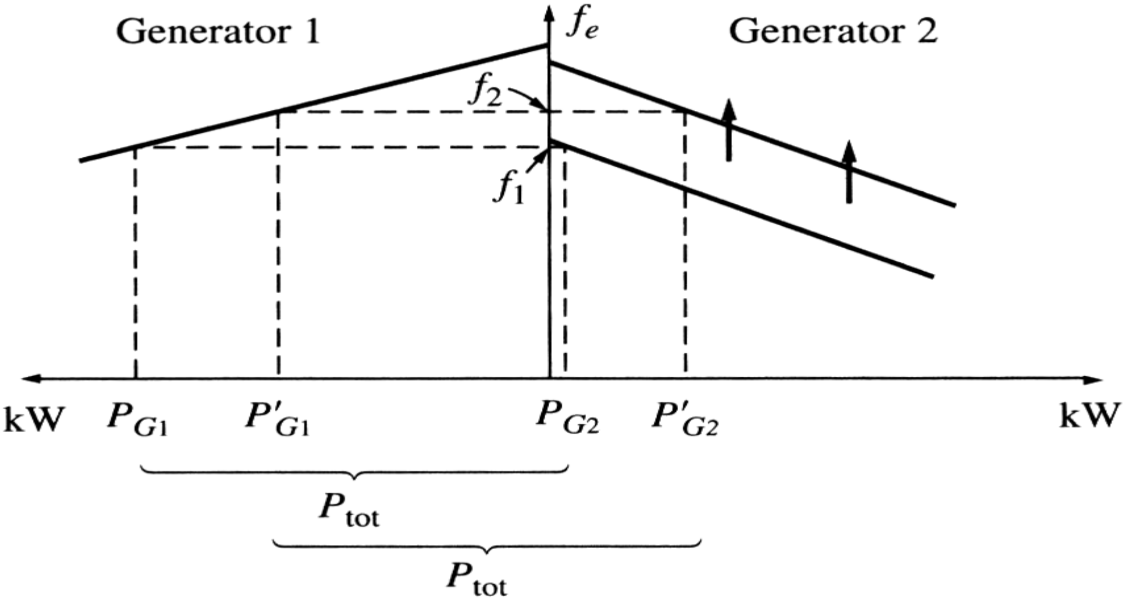
$$Q_{tot} = Q_{load} = Q_{G1} + Q_{G2}$$



Since the frequency of G2 must be slightly higher than the system's frequency, the power-frequency diagram right after G2 is connected to the system is shown.



If the frequency of G2 is next increased, its power-frequency diagram shifts upwards. Since the total power supplied to the load is constant, G2 starts supplying more power and G1 starts supplying less power and the system's frequency increases.

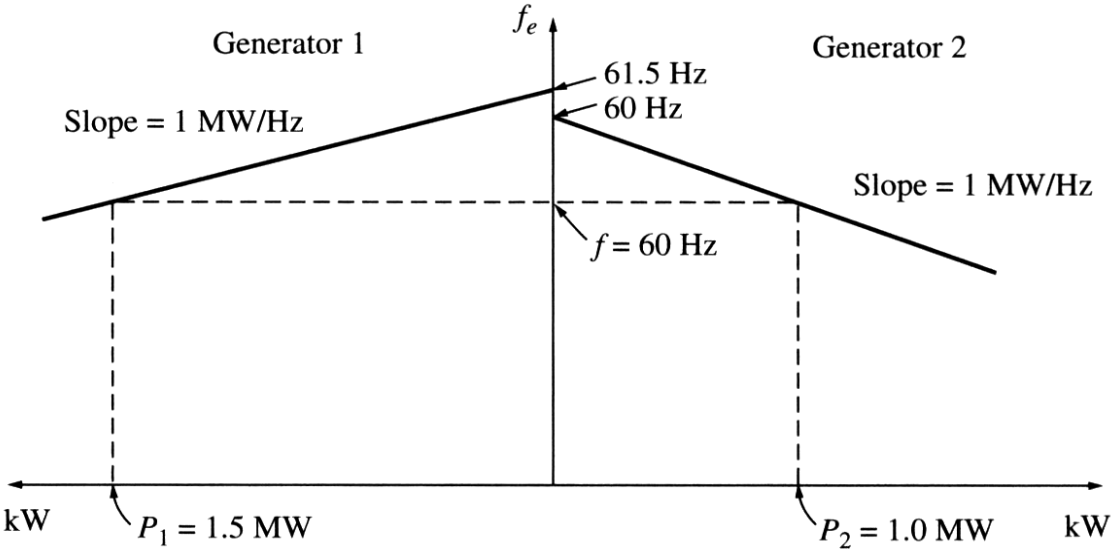


Example 19.2: Two generators are set to supply the same load. Generator 1 has a no-load frequency of 61.5 Hz and a slope sp1 of 1 MW/Hz. Generator 2 has a no-load frequency of 61.0 Hz and a slope sp2 of 1 MW/Hz. The two generators are supplying a real load of 2.5 MW at 0.8 PF lagging.

a. ***Find the system frequency and power supplied by each generator.***
b. ***Assuming that an additional 1 MW load is attached to the power system, find the new system frequency and powers supplied by each generator.***
c. ***With the additional load attached (total load of 3.5 MW), find the system frequency and the generator powers, if the no-load frequency of G2 is increased by 0.5 Hz.***

The power produced by a synchronous generator with a given slope and a no-load frequency is

$$P = s_p \left(f_{nl} - f_{sys} \right)$$



The total power supplied by the generators equals to the power consumed by the load:

$$P_{load} = P_1 + P_2$$

a. The system frequency can be found from:

$$P_{load} = P_1 + P_2 = s_{p1}\left(f_{nl,1} - f_{sys}\right) + s_{p2}\left(f_{nl,2} - f_{sys}\right)$$

$$f_{sys} = \frac{s_{p1}f_{nl,1} + s_{p2}f_{nl,2} - P_{load}}{s_{p1} + s_{p2}} = \frac{1\cdot 61.5 + 1\cdot 61.0 - 2.5}{1+1} = 60.0\,Hz$$

The powers supplied by each generator are:

$$P_1 = s_{p1}\left(f_{nl,1} - f_{sys}\right) = 1\cdot(61.5 - 60) = 1.5\,MW$$

$$P_2 = s_{p2}\left(f_{nl,2} - f_{sys}\right) = 1\cdot(61.0 - 60) = 1\,MW$$

b- For the new load of 3.5 MW, the system frequency is

$$f_{sys} = \frac{s_{p1}f_{nl,1} + s_{p2}f_{nl,2} - P_{load}}{s_{p1} + s_{p2}} = \frac{1\cdot 61.5 + 1\cdot 61.0 - 3.5}{1+1} = 59.5\,Hz$$

$$P_1 = s_{p1}\left(f_{nl,1} - f_{sys}\right) = 1\cdot(61.5 - 59.5) = 2.0\,MW$$

$$P_2 = s_{p2}\left(f_{nl,2} - f_{sys}\right) = 1\cdot(61.0 - 59.5) = 1.5\,MW$$

c. If the no-load frequency of G2 increases, the system frequency is

$$f_{sys} = \frac{s_{p1} f_{nl,1} + s_{p2} f_{nl,2} - P_{load}}{s_{p1} + s_{p2}} = \frac{1 \cdot 61.5 + 1 \cdot 61.5 - 3.5}{1+1} = 59.75\,Hz$$

$$P_1 = P_2 = s_{p1}\left(f_{nl,1} - f_{sys} \right) = 1 \cdot \left(61.5 - 59.75\right) = 1.75\,MW$$

Example 19.3: Two similar 1500KVA are operate in parallel, their prime mover characteristics are such that the frequency of alternator 1 drops from 50.5 to 49Hz and of alternator 2 drops from 50 t0 48Hz. How will two alternators share a load of 2250KW and its system frequency.

Solution:

$$P_1 + P_2 = 2.25MW \qquad (1)$$

$$P_1 = SP_1(f_{nl1} - f_{sys}) \qquad (2)$$

$$P_2 = SP_2(f_{nl2} - f_{sys}) \qquad (3)$$

Where

$$SP_1 = \frac{1500KVA}{50.5-49} = 1MW/Hz \ \ unity\ p.f$$

$$SP_2 = \frac{1500KVA}{50-48} = 0.75MW/Hz$$

$sub\,2\ \&\ 3\ in\ 1,$

$$1 \times (50.5 - f_{sys}) + 0.75 \times (50 - f_{sys}) = 2.25$$

$$f_{sys} = 49Hz$$

$$\therefore P_1 = 1(50.5-49) = 1.5MW$$

$$P_2 = 0.75(50-49) = 0.75MW$$

Example 19.4: Two alternators 100MW and 75MW operating in parallel on load, have the following data:

G1 speed droop from no load to full load is 3%

G2 speed droop from no load to full load is 4%

Compute the load sharing, bus frequency when the total load connected is 125MW and no load frequency is 50Hz. Assume linear speed regulation.

Solution:

$$P_1 + P_2 = 125MW \qquad (1)$$

$$P_1 = SP_1(f_{nl} - f_{sys}) \qquad (2)$$

$$P_2 = SP_2(f_{nl} - f_{sys}) \qquad (3)$$

Where

$$SP_1 = \frac{100MW}{0.03\times 50} = 66.667MW/Hz \ \ unity\ p.f$$

$$SP_2 = \frac{75MW}{0.04\times 50} = 37.5MW/Hz$$

$$sub\, 2\ \&\ 3\ in\, 1,$$

$$66.667\times(50 - f_{sys}) + 37.5\times(50 - f_{sys}) = 125$$

$$f_{sys} = 48.8Hz$$

$$\therefore P_1 = 66.667(50 - 48.8) = 80MW$$

$$P_2 = 37.5(50 - 48.8) = 45MW$$

H.W:

1- Two 60MW alternators operate in parallel. The full load speed regulation of alternator 1 is 3% and that of alternator 2 is 4%. If the connected load is 90MW. Calculate the load sharing supplied by each alternator and the system frequency if the no load frequency is 50Hz. Ans. (51.6MW, 38.4MW, 48.72Hz)

2- Three alternators operating in parallel at unity power factor shares a total load of 40MW at a bus frequency 50Hz. Alternator 1 & 2 delivering 10MW each. The governors are so adjusted that the fall in speed from no load to full load are;

G1is 1Hz, G2 is 1.25Hz,G3 is 1.5Hz. Determine the load sharing and bus frequency when the total load is raised to 60MW at unity power factor.