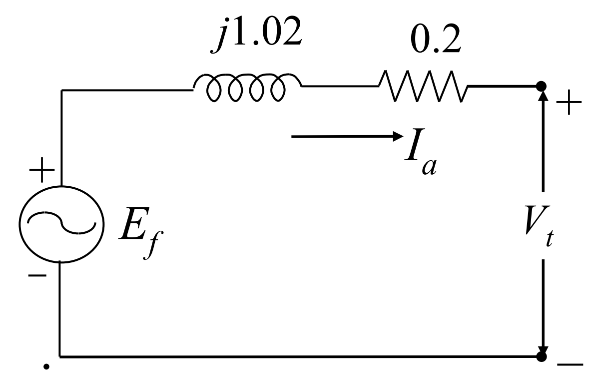
LECTURE 6

Solution



1.

f_e = electrical frequency = $Pn_m/120$

f_e = 60Hz

P = number of poles = 4

n_m = mechanical speed of rotation in r/min.

So, speed of rotation n_m = $120\, f_e / P$

= (120 x 60)/4 = 1800 r/min

2. In open-circuit test, $I_a = 0$ and $E_f = V_t$

$E_f = 540/1.732$

= 311.8 V (as the machine is Y-connected)

In short-circuit test, terminals are shorted, $V_t = 0$

$E_f = I_a Z_s$ or $Z_s = E_f/I_a$ =311.8/300=1.04 ohm

From the DC test, $R_a = V_{DC}/(2I_{DC})$

= 10/(2X25) = 0.2 ohm

Synchronous reactance $Z_{s,sat} = \sqrt{R_a^2 + X_{s,sat}^2}$

$$X_{s,sat} = \sqrt{Z_{s,sat}^2 - R_a^2} = \sqrt{1.04^2 - 0.2^2} = 1.02$$

Parallel operation of synchronous generators

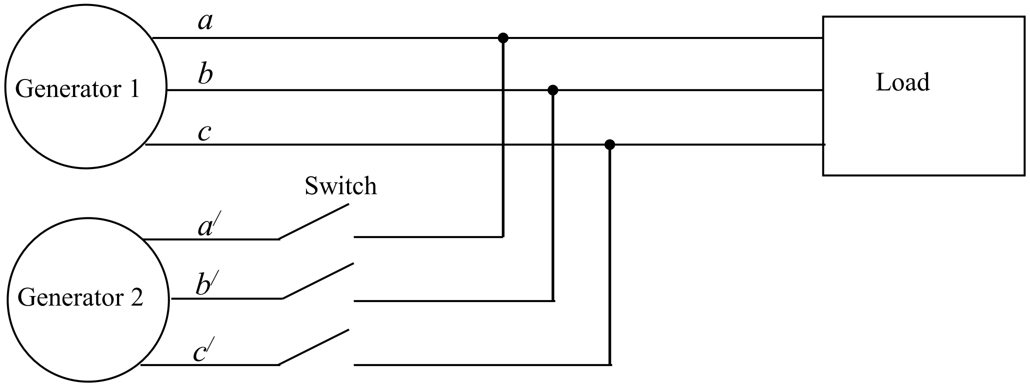
There are several major advantages to operate generators in parallel:

- Several generators can supply a bigger load than one machine by itself.
- Having many generators increases the reliability of the power system.
- It allows one or more generators to be removed for shutdown or preventive maintenance.

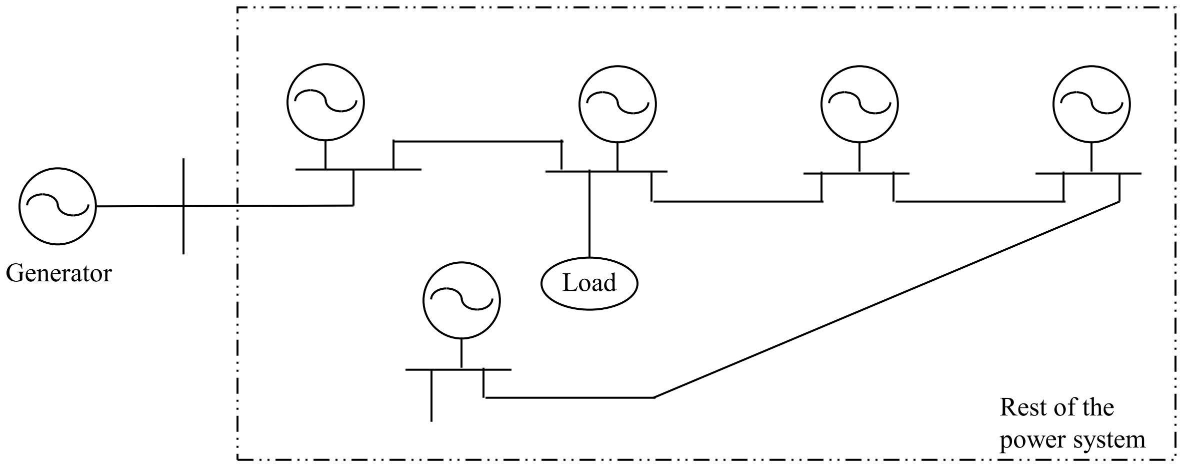
Synchronization

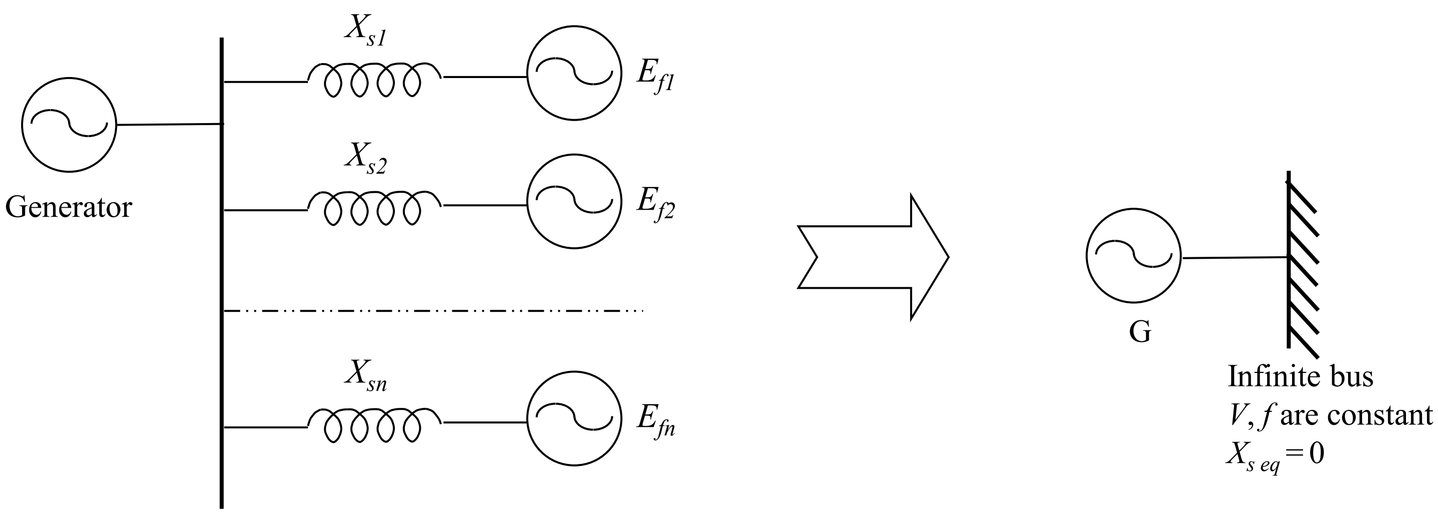
Before connecting a generator in parallel with another generator, it must be synchronized. A generator is said to be synchronized when it meets all the following conditions:

- The *rms line voltages* of the two generators must be equal.
- The two generators must have the same *phase sequence*.
- The *phase angles* of the two *a* phases must be equal.
- The *oncoming generator frequency* is equal to the running system frequency.



Synchronization





Concept of the infinite bus

When a synchronous generator is connected to a power system, the power system is often so large that nothing the operator of the generator does will have much of an effect on the power system. An example of this situation is the connection of a single generator to the Canadian power grid. Our Canadian power grid is so large that no reasonable action on the part of one generator can cause an observable change in overall grid frequency. This idea is idealized in the concept of an infinite bus. *An infinite bus is a power system so large that its voltage and frequency do not vary regardless of how much real or reactive power is drawn from or supplied to it.*

Active and reactive power-angle characteristics

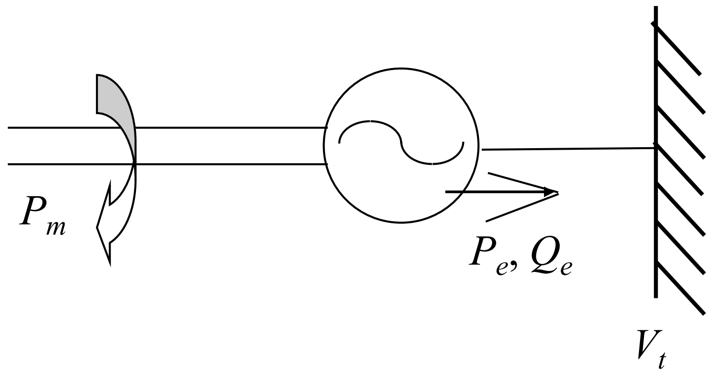
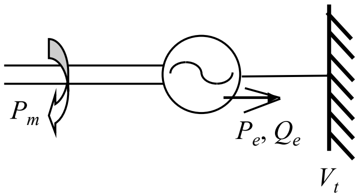


Fig. Synchronous generator connected to an infinite bus.

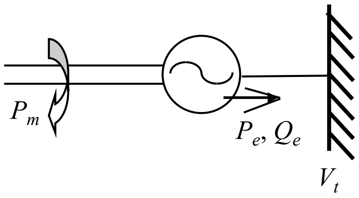
- P>0: generator operation
- P<0: motor operation
- Positive Q: delivering inductive vars for a generator action or receiving inductive vars for a motor action
- Negaive Q: delivering capacitive vars for a generator action or receiving capacitive vars for a motor action

Active and reactive power-angle characteristics



- The real and reactive power delivered by a synchronous generator or consumed by a synchronous motor can be expressed in terms of the terminal voltage V_t, generated voltage E_f, synchronous impedance Z_s, and the power angle or torque angle δ.
- Referring to Fig. 8, it is convenient to adopt a convention that makes positive real power P and positive reactive power Q delivered by an *overexcited generator*.
- The generator action corresponds to positive value of δ, while the motor action corresponds to negative value of δ.

Active and reactive power-angle characteristics



The complex power output of the generator in volt-amperes per phase is given by

$$S = P + jQ = \bar{V}_t \, I_a^*$$

where:

V_t = terminal voltage per phase

I_a^* = complex conjugate of the armature current per phase

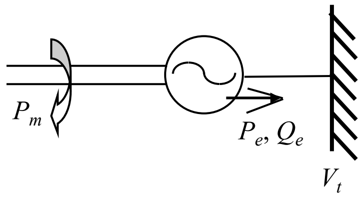
Taking the terminal voltage as reference

$$\bar{V}_t = V_t + j0$$

the excitation or the generated voltage,

$$\bar{E}_f = E_f(\cos\delta + j\sin\delta)$$

Active and reactive power-angle characteristics



and the armature current,

$$\bar{I}_a = \frac{\bar{E}_f - \bar{V}_t}{jX_s} = \frac{\left(E_f \cos\delta - V_t\right) + jE_f \sin\delta}{jX_s}$$

where X_s is the synchronous reactance per phase.

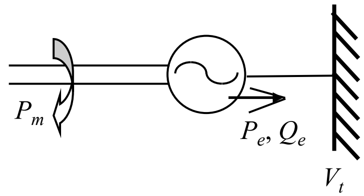
$$S = P + jQ = \bar{V}_t \bar{I}_a^* = V_t\left[\frac{\left(E_f \cos\delta - V_t\right) - jE_f \sin\delta}{-jX_s}\right]$$

$$= \frac{V_t E_f \sin\delta}{X_s} + j\frac{V_t E_f \cos\delta - V_t^2}{X_s}$$

$$\therefore \quad P = \frac{V_t E_f \sin\delta}{X_s} \qquad \&$$

$$Q = \frac{V_t E_f \cos\delta - V_t^2}{X_s}$$

Active and reactive power-angle characteristics



$$\therefore \quad P = \frac{V_t E_f \sin\delta}{X_s} \qquad \& \qquad Q = \frac{V_t E_f \cos\delta - V_t^2}{X_s}$$

- The above two equations for active and reactive powers hold good for cylindrical-rotor synchronous machines for negligible resistance
- To obtain the total power for a three-phase generator, the above equations should be multiplied by 3 when the voltages are line-to-neutral
- If the line-to-line magnitudes are used for the voltages, however, these equations give the total three-phase power