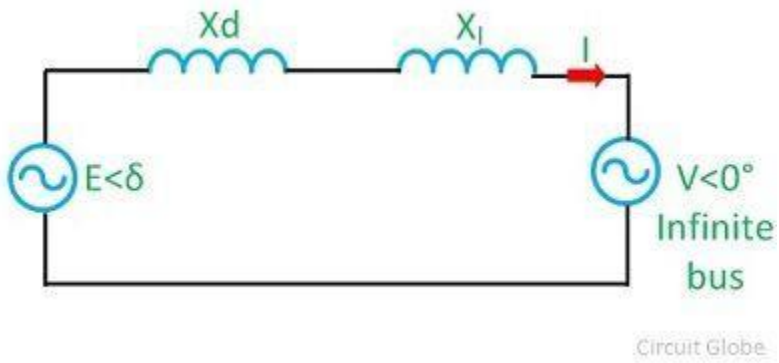
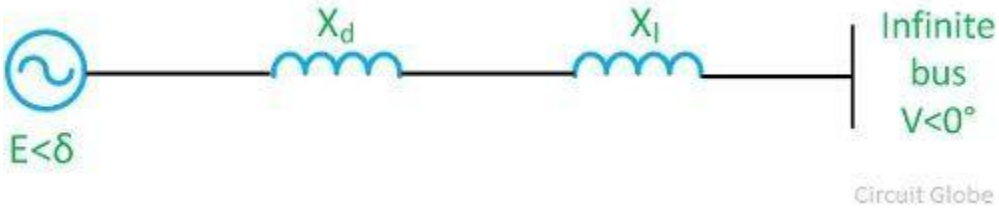
Power-Angle Curve

Consider a synchronous machine connected to an infinite bus through a transmission line of reactance X_l shown in a figure below. Let us assume that the resistance and capacitance are neglected.



Equivalent diagram of synchronous machine connected to an infinite bus through a transmission line of series reactance X_l is shown below:



Let, V = V<0^0 – voltage of infinite bus, E = E<δ – voltage behind the direct axis synchronous reactance of the machine, X_d = synchronous / transient resistance of the machine. The complex power delivered by the generator to the system is

$$S = VI$$

$$S = V\left[\frac{E < \delta - V < 0^0}{j(X_d + X_l)}\right]$$

Let,

$$X_d + X_l = X$$

$$S = V\left[\frac{E < \delta}{X < 90^0} + j\frac{V}{X}\right]$$

$$S = \frac{EV}{X} < (90^0 - \delta) - j\frac{V^2}{X}$$

$$S = V\left[\frac{EV}{X}sin\delta + j\frac{EV}{X}cos\delta - j\frac{V^2}{X}\right]$$

$$P_e + jQ_e = \frac{EV}{X}sin\delta + j\left(\frac{EV}{X}cos\delta - \frac{V^2}{X}\right)$$

Active power transferred to the system

$$P_e = \frac{EV}{X}sin\delta$$

The reactive power transferred to the system

$$Q_e = \frac{EV}{X}cos\delta - \frac{V^2}{X}$$

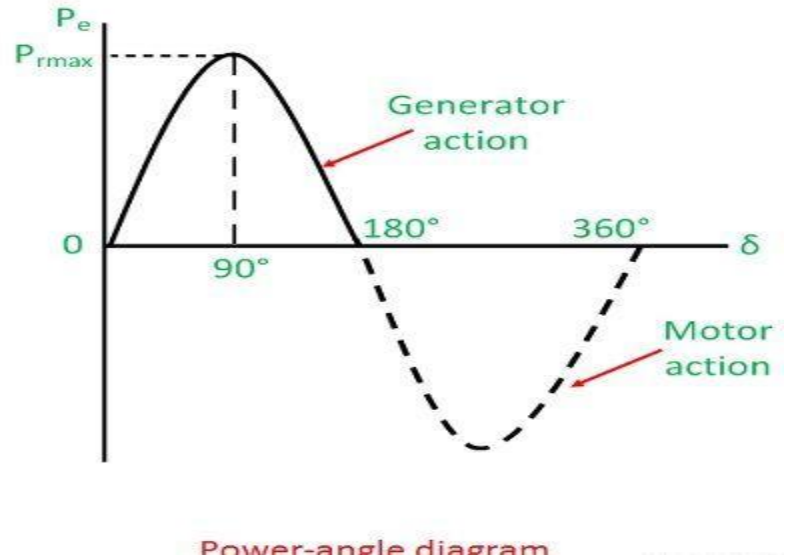
The maximum steady-state power transfers occur when δ = 0

$$P_e = \frac{EV}{X}sin90^0$$

$$(\sin 90^0 = 1)$$

$$P = \frac{EV}{X} \quad P_e = P_{emax}sin\delta$$

The graphical representation of P_e and the load angle δ is called the power angle curve. It is widely used in power system stability studies. The power angle curve is shown below



Power-angle diagram

Maximum power is transferred when $\delta = 90^0$. As the value of load angle δ is above 90, P_e decrease and becomes zero at $\delta = 180^0$. Above 180^0, Pe becomes negative, which show that the direction of power flow is reversed, and the power is supplied from infinite bus to the generator. The value of P_e is often called pull out power. It is also called the steady-state limit.

The total reactance between two voltage sources E and X is called the transfer reactance. The maximum power limit is inversely proportion to the transfer reactance.