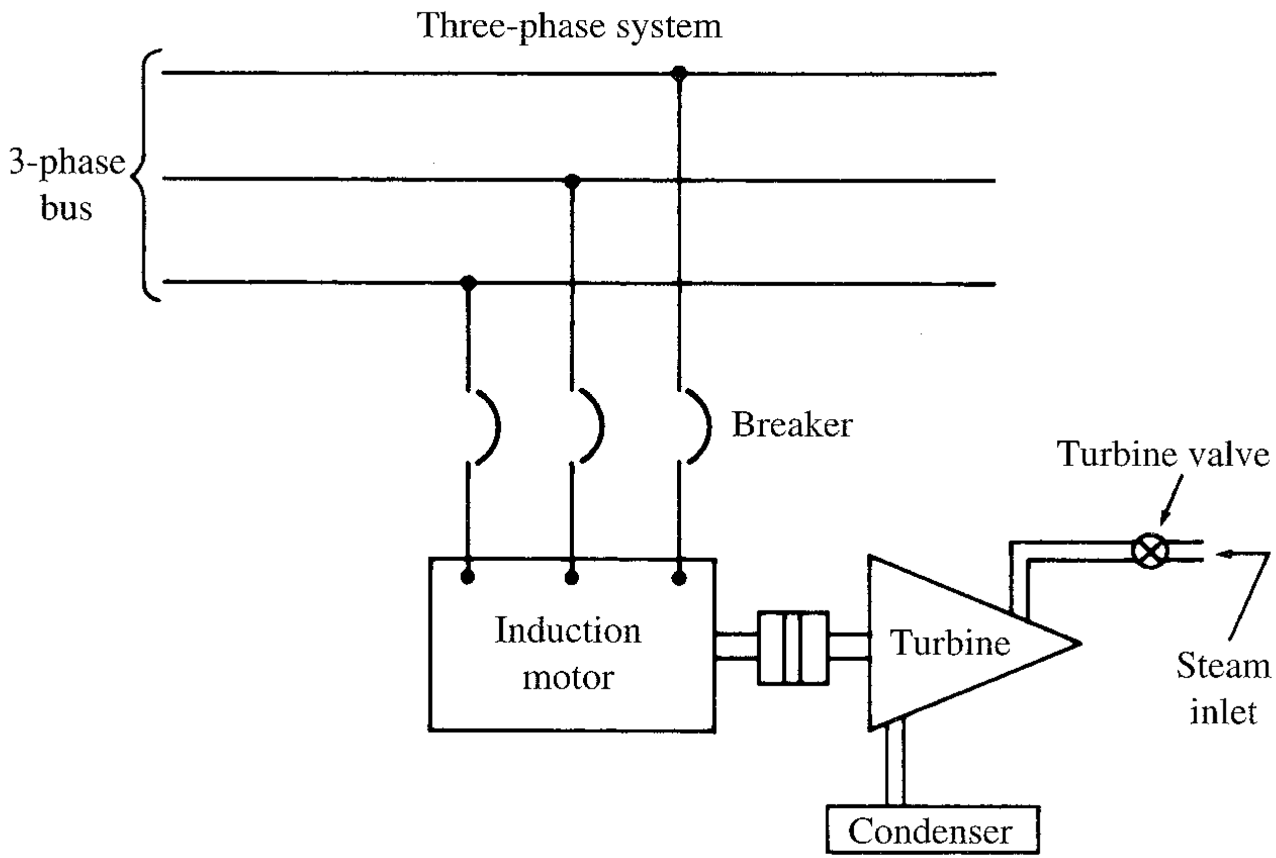
LECTURE 6

Induction Generators

- Same basic construction as squirrel-cage induction motors
- Drive at a speed greater than the synchronous speed
- Not started as a motor
- Operated by wind turbines, steam turbines, etc.

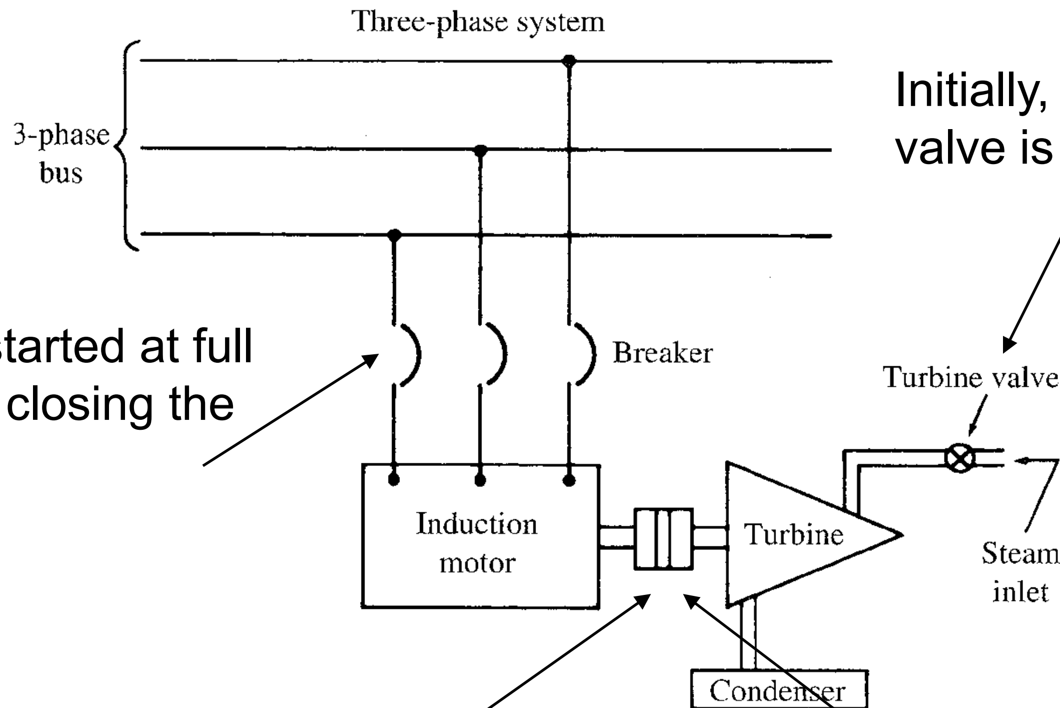
Motor – to – Generator Transition



Typical setup for induction-generator operation

Initially, the turbine valve is closed

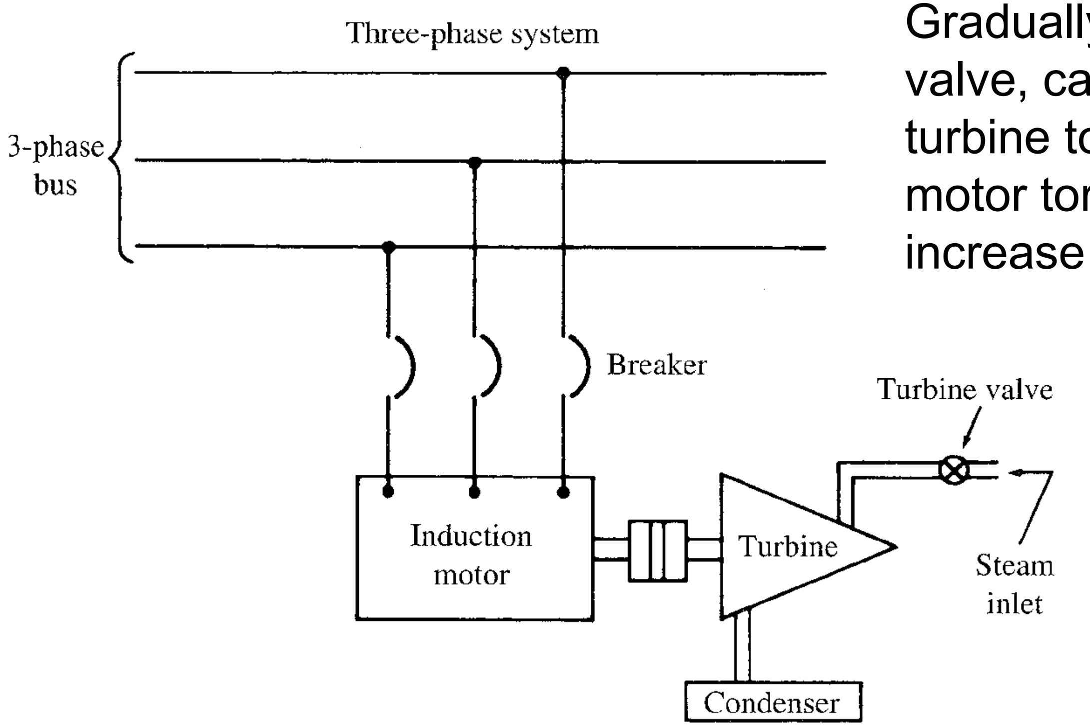
2 - Motor started at full voltage by closing the breaker



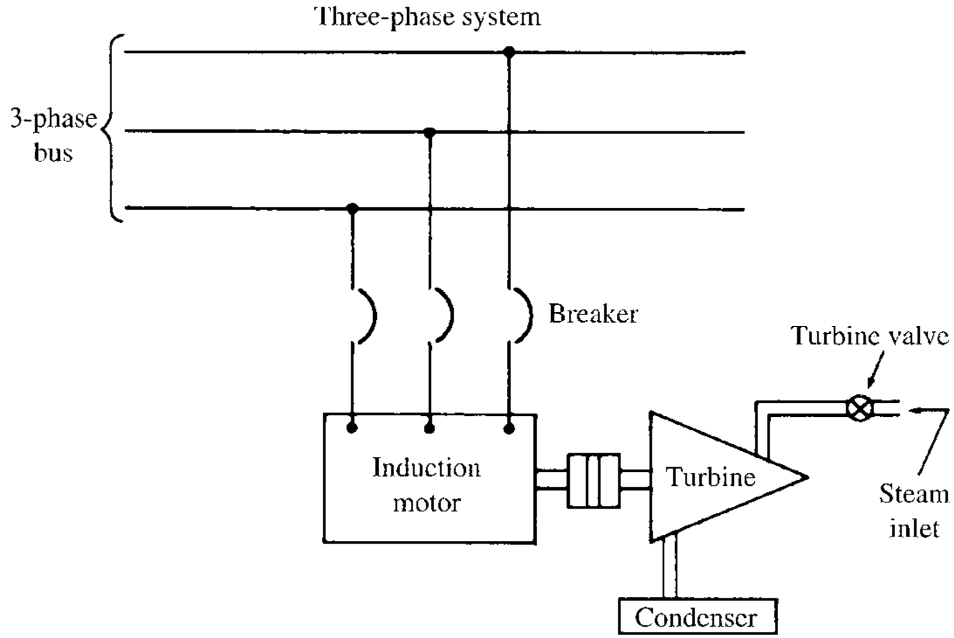
1 - Motor shaft coupled to a steam turbine

3 –Motor drives the turbine at less than synchronous speed

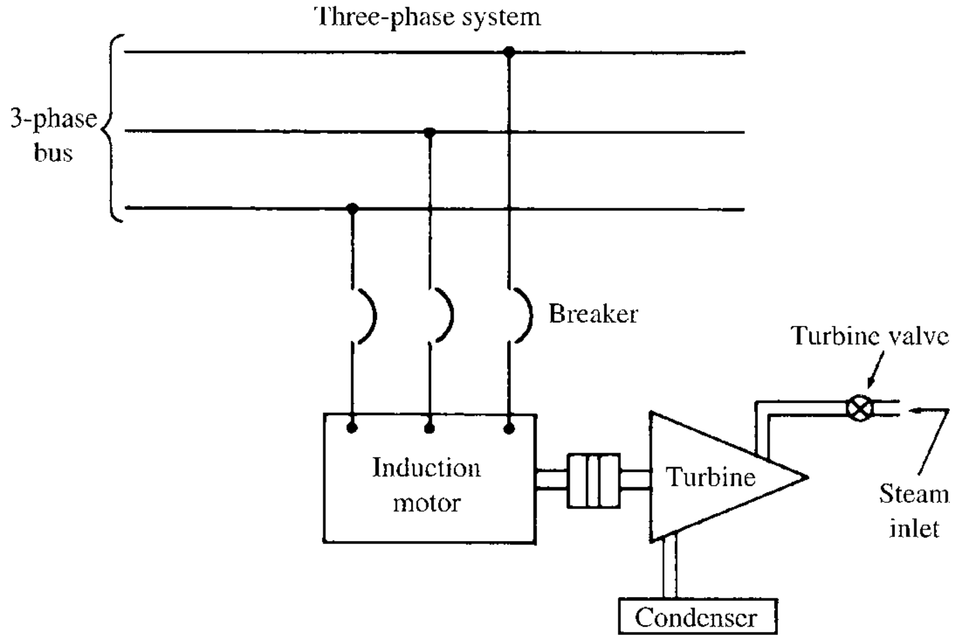
Operation as an Induction-Generator continued



Gradually open the turbine valve, causing a buildup of turbine torque, adding to the motor torque, resulting in an increase in rotor speed.

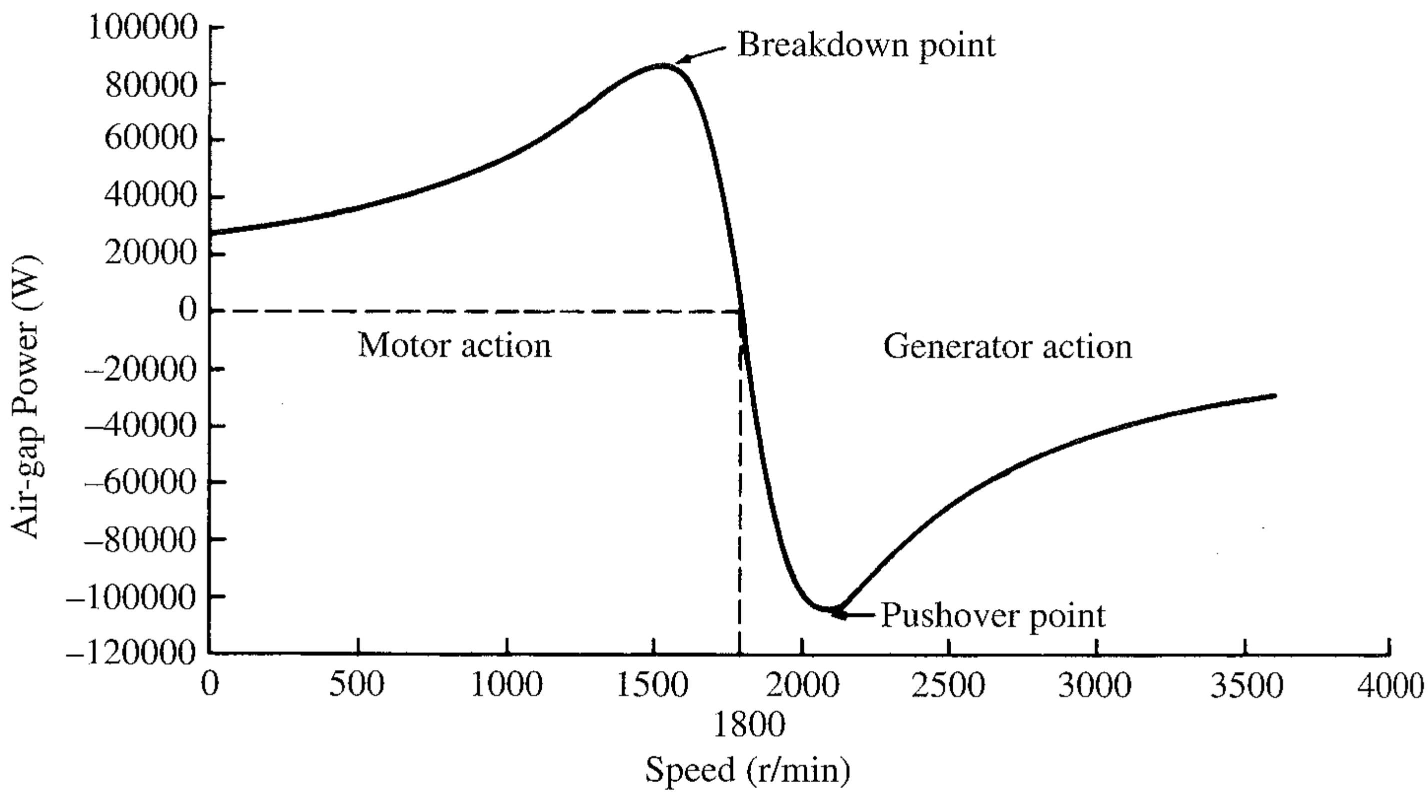


When the speed approaches synchronous speed, the slip = 0, R_s/s becomes infinite, rotor current $I_r = 0$, and no motor torque is developed. (The motor is neither a motor or a generator – it is “floating” on the bus. The only stator current is the exciting current to supply the rotating magnetic field and the iron losses.

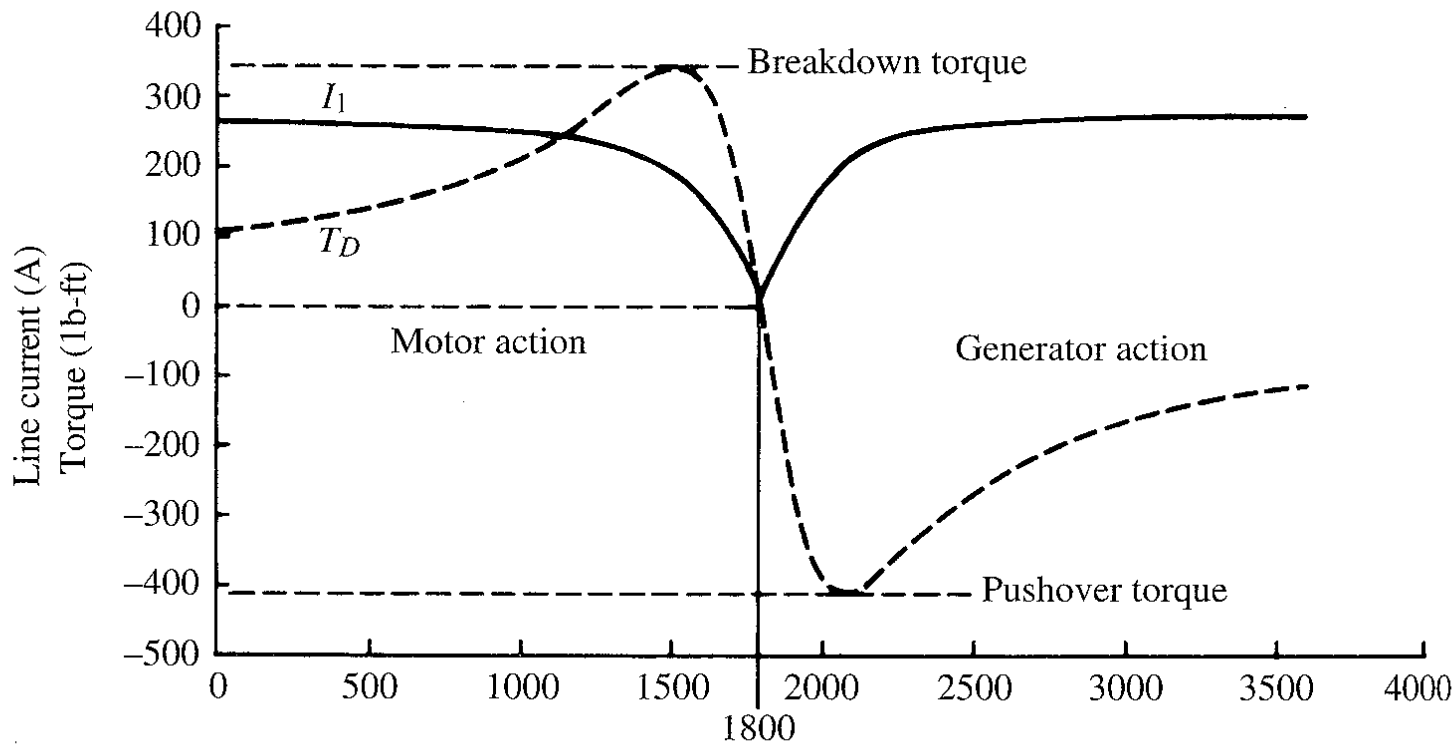


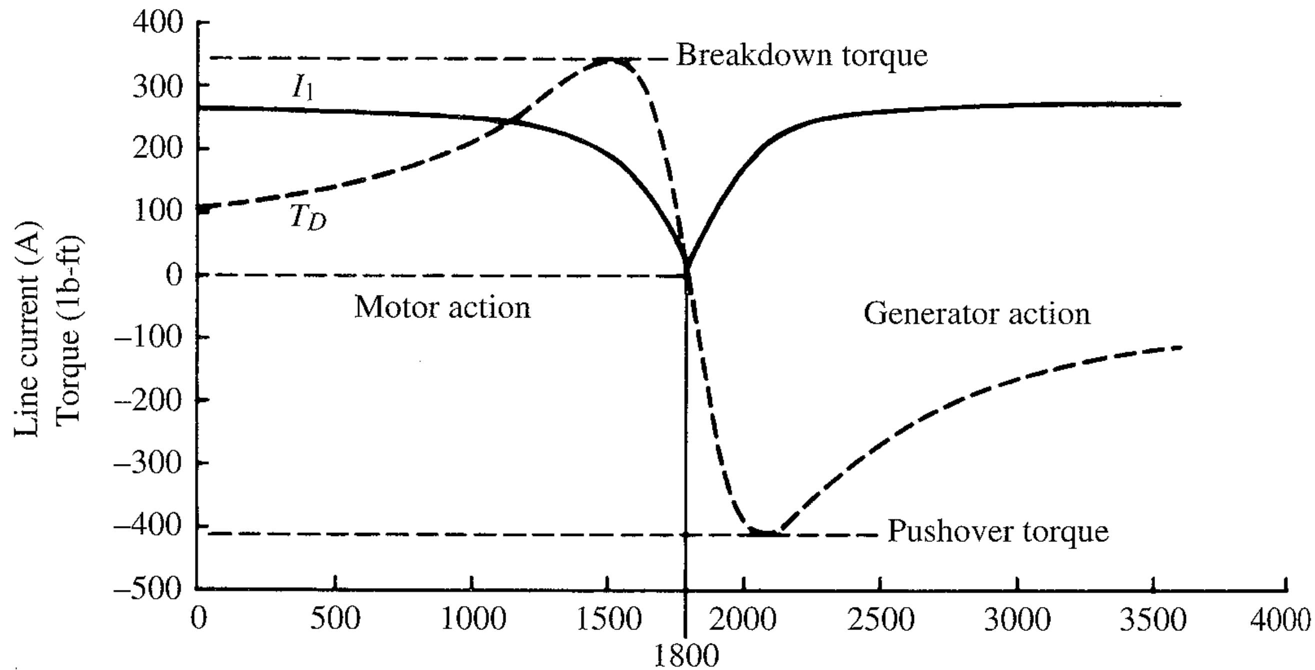
The speed of the rotating flux is independent of the rotor speed – only a function of the number of poles and the frequency of the applied voltage. *Increasing the rotor speed above the synchronous speed causes the slip* $[(n_s - n_r)/n_s]$ *to become negative! The gap power,* $P_{gap} = P_{rcl}/s$ *becomes negative, now supplying power to the system!*

Air – gap Power vs. rotor speed

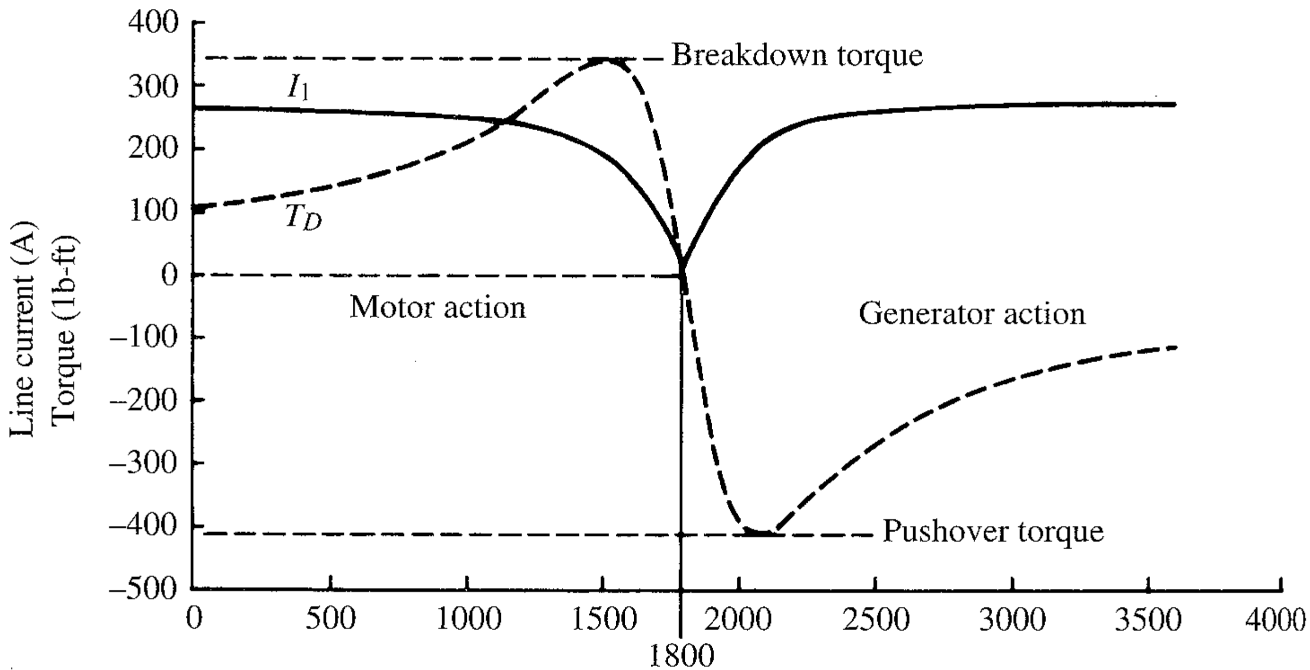


Developed torque and line current vs. rotor speed





The interaction of the magnetic flux of the stator and the magnetic flux of the rotor produce a "countertorque" that opposes the driving torque of the prime mover. Increasing the speed of the rotor increases the countertorque and the power delivered to the system by the generator. The maximum value of the countertorque is called the "pushover" torque.



Increasing the speed of the prime mover beyond the pushover point causes the power output to decrease. The countertorque decreases and the speed increases. This also occurs if the generator is loaded and the breaker is tripped. Motors used in these applications must be able to withstand overspeeds without mechanical injury. See Table 5.11, page 223.

Table

TABLE 5.11
Allowable emergency overspeed of squirrel-cage and wound-rotor motors

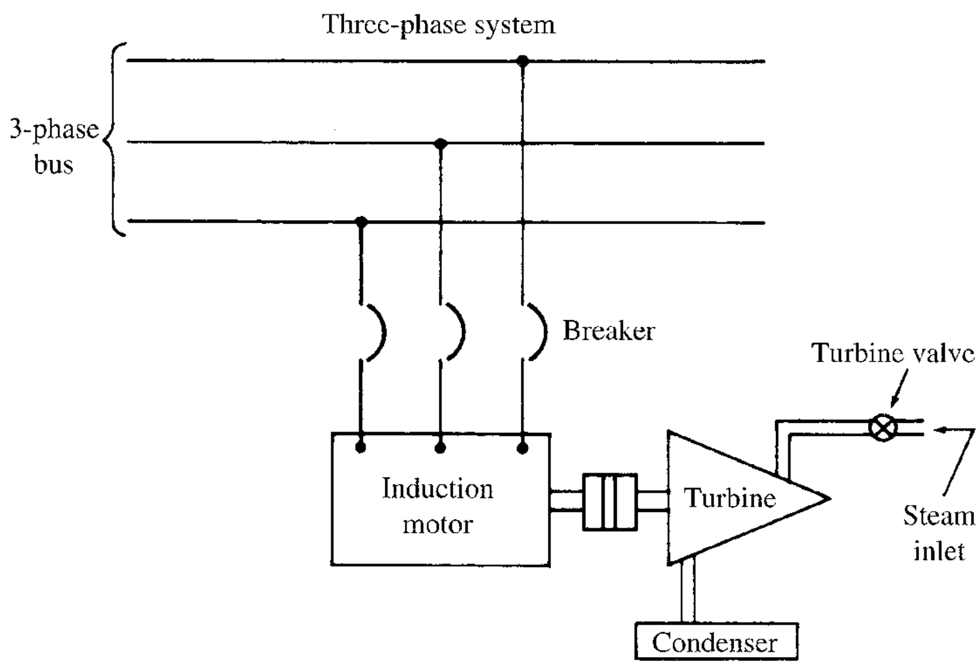
hp	Synchronous Speed (r/min)	Percent above Synchronous Speed
≤200	1201 and over	25
	1200 and below	50
250–500, inclusive	1801 and over	20
	1800 and below	25

Example

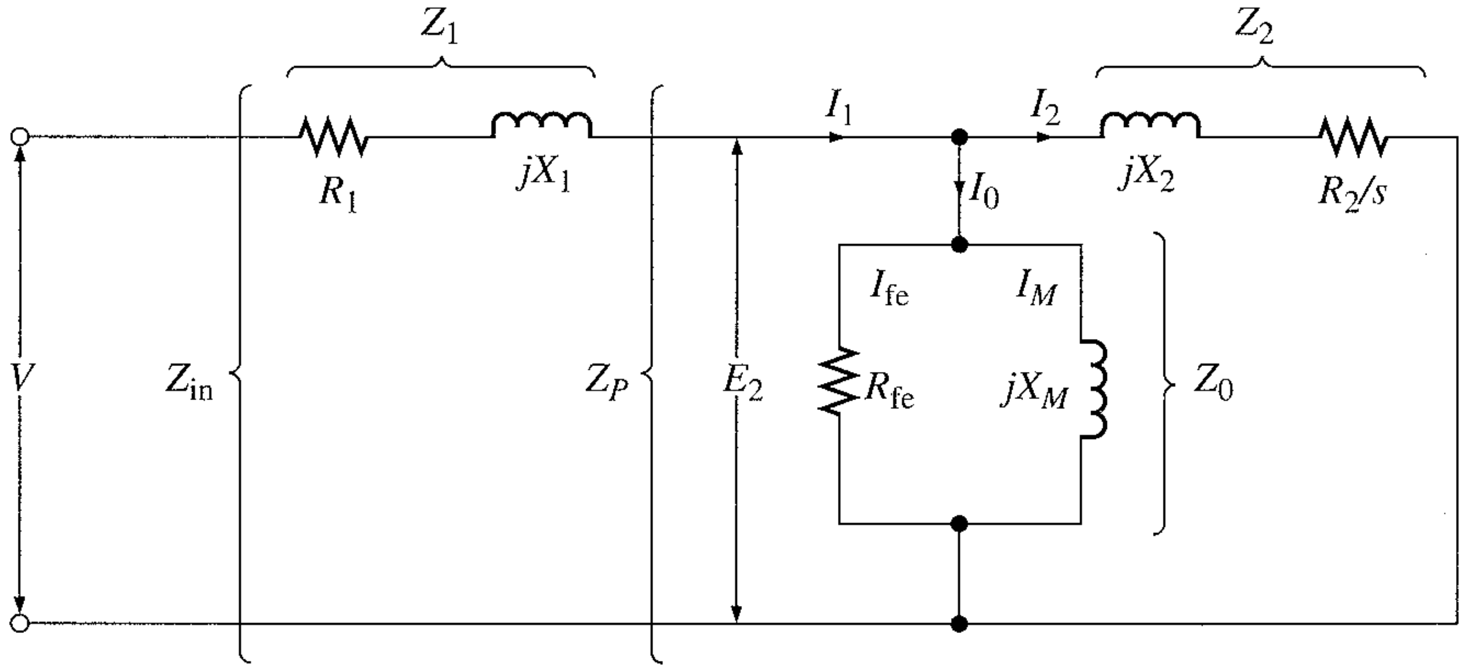
- A three-phase, six-pole, 460-V, 60-hZ, Induction motor rated at 15-hp, 1182 r/min, is driven by a turbine at 1215 r/min. 2The equivalent circuit is shown and the motor parameters (in Ohms) are:
- $R_1 = 0.200$ $R_2 = 0.250$ $R_{fe} = 317$
- $X_1 = 1.20$ $X_2 = 1.29$ $X_M = 42.0$

Example continued

- Determine the active power that the motor, driven as an induction generator, delivers to the system.



Induction Motor Equivalent Circuit



Example continued

$$s = \frac{n_s - n_r}{n_s} = \frac{1200 - 1215}{1200} = -0.0125$$

$$Z_2 = \frac{R_2}{s} + jX_2 = -\frac{0.250}{0.0125} + j1.29 = 20.0416\angle 176.30°\Omega$$

$$Z_P = \frac{Z_2 \cdot Z_0}{Z_2 + Z_0} = \frac{(20.0416\angle 176.30°)(41.6361\angle 82.4527°)}{(-20 + j1.29) + (5.4687 + j41.2754)}$$

$$Z_P = 18.5527\angle 149.91° = -16.0530 + j9.31\Omega$$

$$Z_{in} = Z_1 + Z_P = (0.2 + j1.2) + (-16.0530 + j9.301) = 19.0153\angle 146.4802°$$

Example 5.17 continued

$$I_1 = \frac{V}{Z_{in}} = \frac{\frac{460}{\sqrt{3}}}{19.0153\angle 146.4802^\circ} = 13.9667\angle -146.4802^\circ = A$$

$$S = 3VI_1^* = 3\left(\frac{460}{\sqrt{3}}\angle 0^\circ\right)(13.9667\angle 146.4802^\circ) = 11{,}127.87\angle 146.48^\circ VA$$

$$S = -9277 + j6145VA$$

$$P = -9277W$$