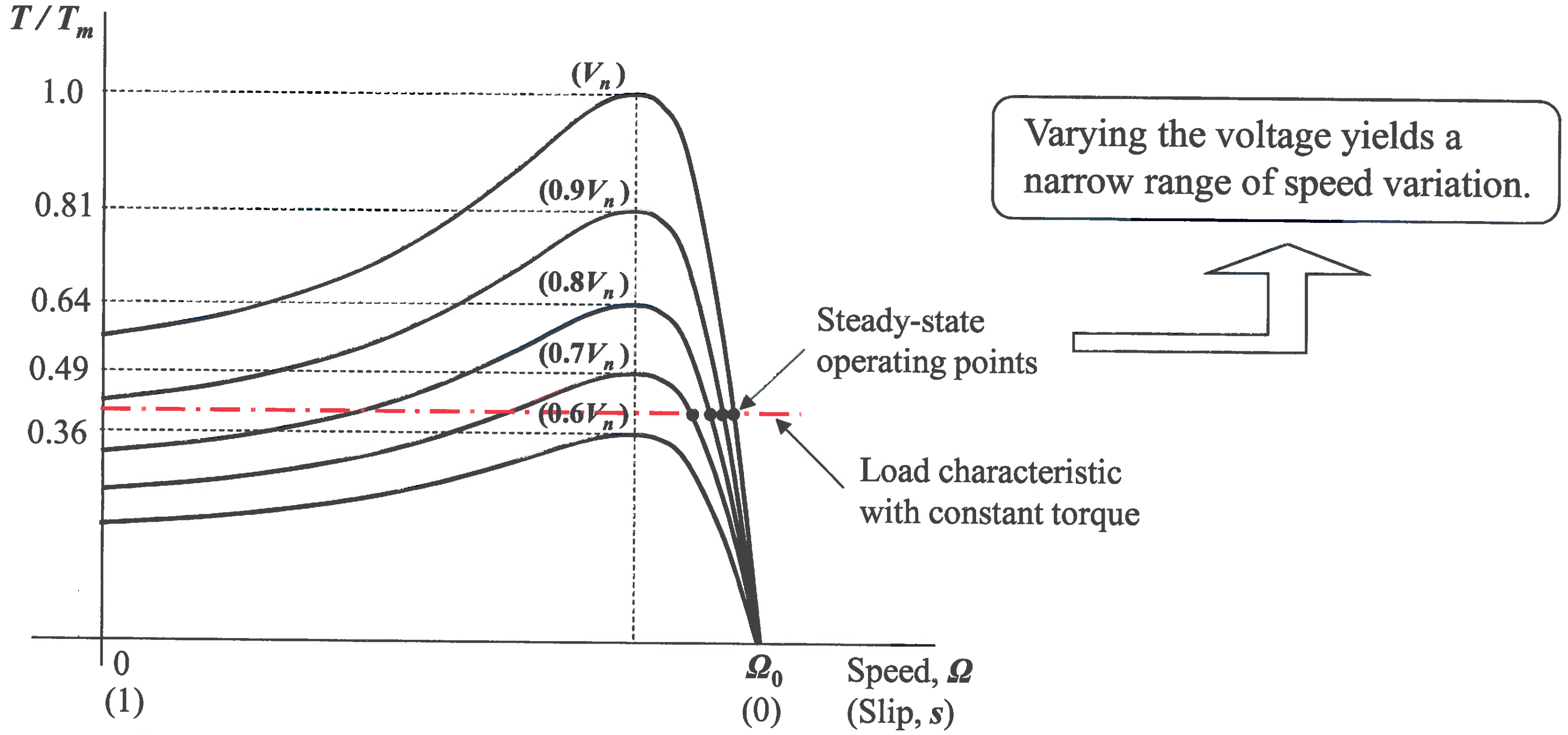
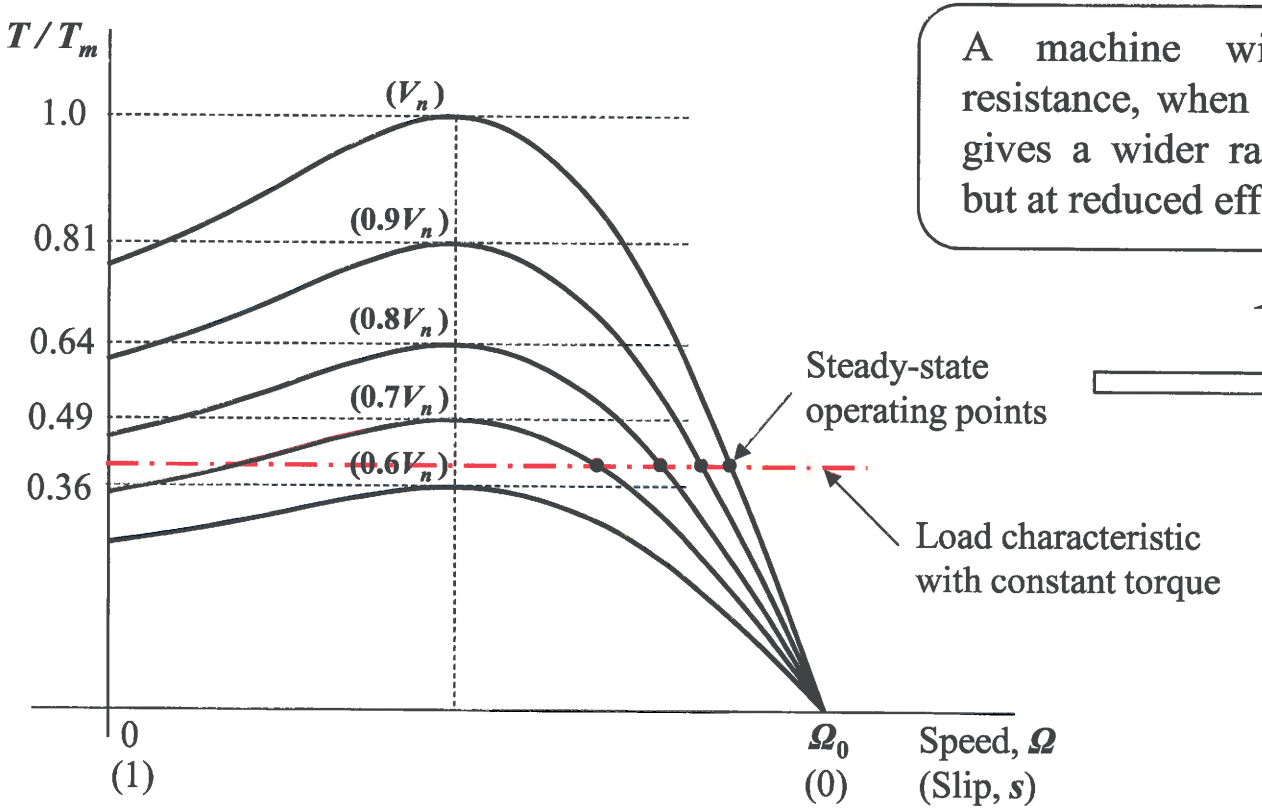
METHODS FOR SPEED CONTROL OF INDUCTION MOTOR DRIVES

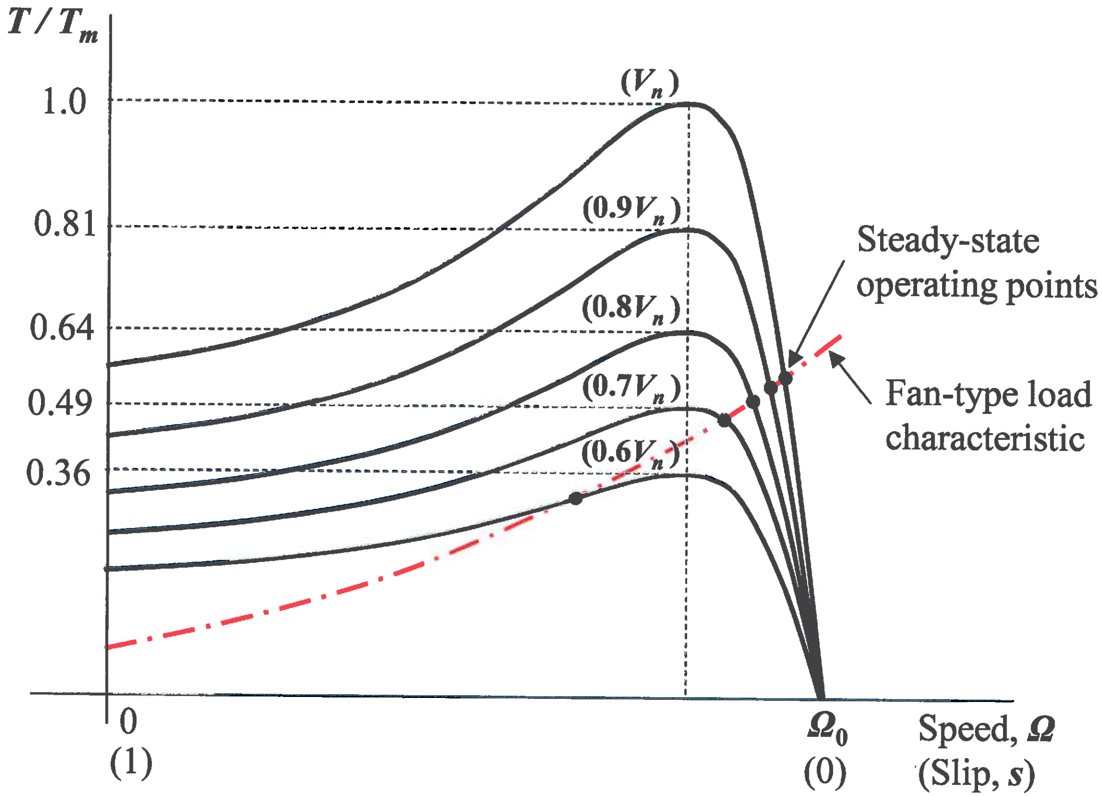
Speed control by varying the supply voltage

$$T = \frac{P_0}{\Omega_0} = \frac{3(I_2')^2 R_2'/s}{\Omega_0} = \frac{3V_1^2}{\Omega_0} \cdot \frac{R_2'/s}{(R_2'/s)^2 + X_\sigma^{\ 2}} = \frac{3V_1^2}{\Omega_0} \cdot \frac{s R_2'}{(s X_\sigma)^2 + (R_2')^2}$$

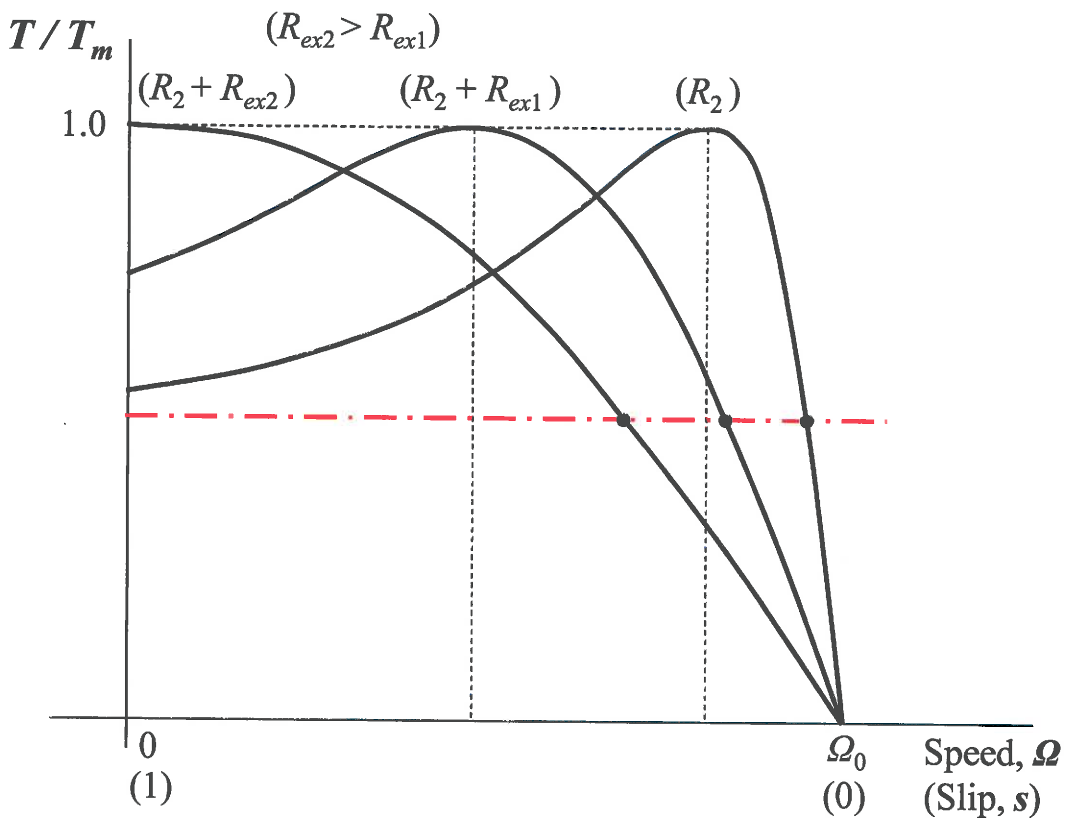




A machine with a higher rotor resistance, when controlled by voltage, gives a wider range of speed change, but at reduced efficiency.


T / T_m
1.0
0.81
0.64
0.49
0.36
(V_n)
(0.9V_n)
(0.8V_n)
(0.7V_n)
(0.6V_n)
Steady-state operating points
Fan-type load characteristic
0
(1)
Ω_0
(0)
Speed, Ω
(Slip, s)

Speed control by varying the rotor circuit resistance in the slip-ring type of induction motor



By adding extra resistance in series with each rotor phase winding, the maximum (stall) torque remains unchanged and critical slip is increased.

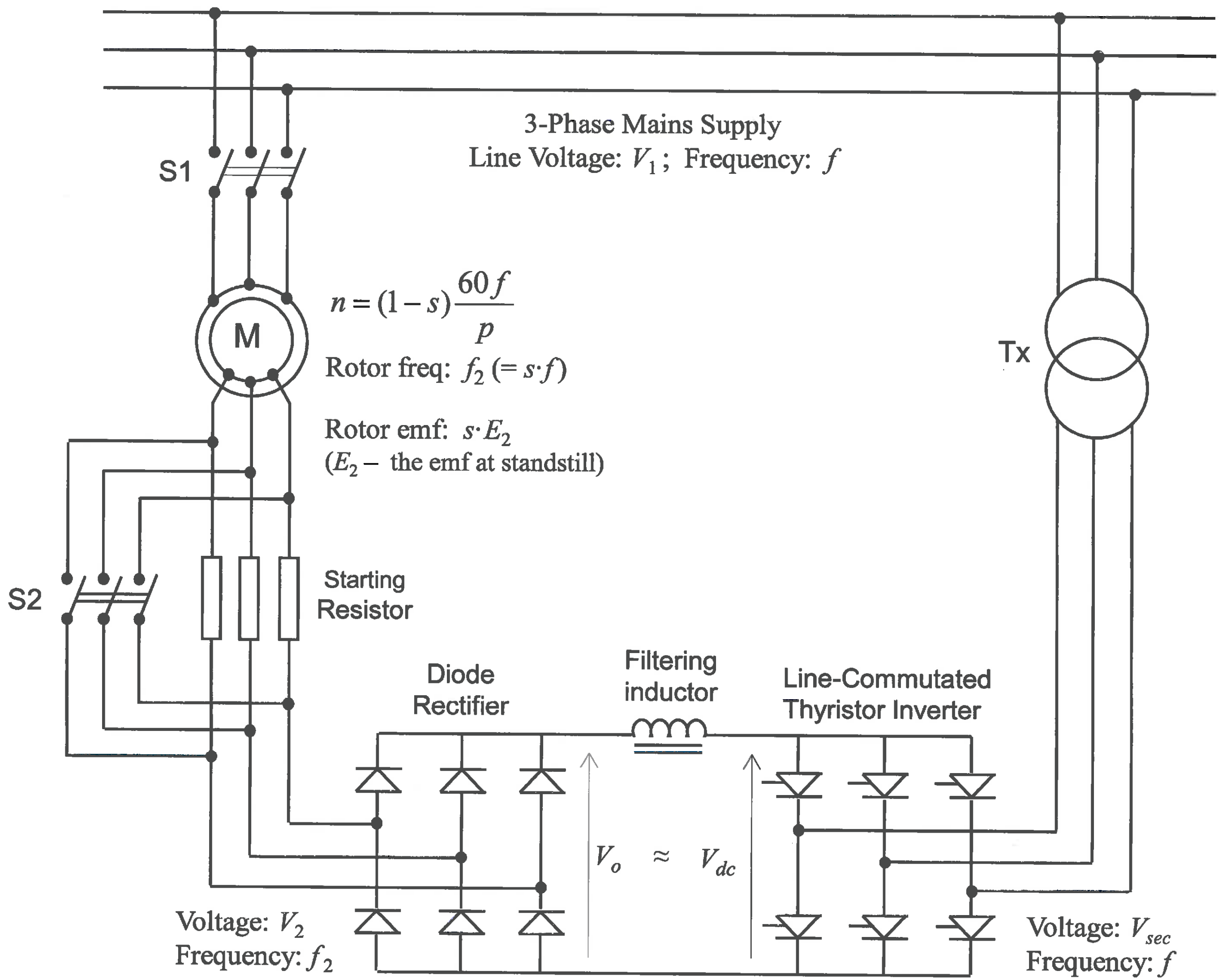
$$T_m = \frac{3V_1^2}{\Omega_0} \cdot \frac{1}{2X_\sigma}$$

$$s_m = \frac{R_2' + R_{ex}'}{X_\sigma}$$

Efficiency: $$\eta = \frac{P}{P_{in}} < \frac{P}{P_0} = \frac{P_0 - P_{Cu2}}{P_0} = \frac{P_0 - s\,P_0}{P_0} = 1 - s = \frac{\Omega}{\Omega_0}$$

When more resistance is added in the rotor circuit, the speed decreases, i.e. the slip increases, but the efficiency is reduced.
A wide range of speed change can be achieved.

Speed control of slip-ring induction motor through a subsynchronous static converter for the power recovery

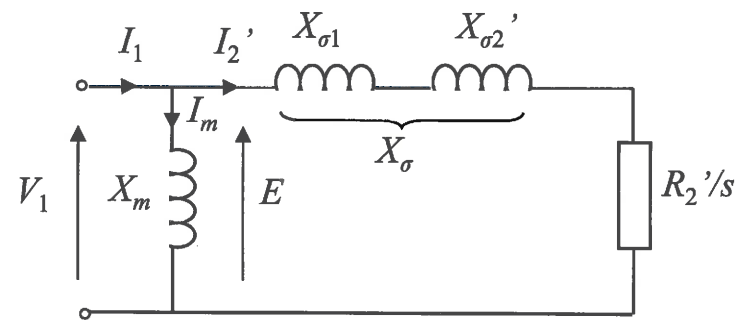


Variable-frequency operation of induction motor supplied from sinusoidal variable-voltage source

Variation of frequency (f) directly affects the speed of rotating field $\Omega_0 = \frac{\omega}{p} = \frac{2\pi f}{p}$

as well as the magnitude of air-gap flux $\Phi_{peak} = \frac{1}{4.44\,N_1} \cdot \frac{E}{f}$

Using the approximate per phase equivalent circuit



$$\Phi_{peak} = \frac{1}{4.44\,N_1} \cdot \frac{V_1}{f}$$

$\boxed{\text{Hence, the need for } V_1 \sim f}$

The motor speed $\Omega = (1-s)\,\Omega_0 = (1-s)\cdot 2\pi f / p$

depends not only on frequency (f) but on the per-unit slip (s) and thereby the torque (T).

What are the implications on the motor torque/speed characteristics?

The electromagnetic torque:

$$T = \frac{3(I_2')^2 R_2'/s}{\Omega_0} = \frac{3(V_1)^2}{\Omega_0} \cdot \frac{R_2'/s}{(R_2'/s)^2 + X_\sigma^2} = \frac{3(V_1)^2}{\Omega_0} \cdot \frac{s R_2'}{(s X_\sigma)^2 + (R_2')^2}$$

Substitutions $\quad s = \dfrac{\Omega_0 - \Omega}{\Omega_0} = \dfrac{\Delta\Omega}{\Omega_0}$ and $X_\sigma = \omega L_\sigma = p\Omega_0 L_\sigma$ yield

$$T = 3\left(\frac{V_1}{\Omega_0}\right)^2 \cdot \frac{(\Omega_0 - \Omega)R_2'}{(\Omega_0 - \Omega)^2 (pL_\sigma)^2 + (R_2')^2} = 3\left(\frac{p}{2\pi}\right)^2 \cdot \left(\frac{V_1}{f}\right)^2 \cdot \frac{\Delta\Omega \cdot R_2'}{\Delta\Omega^2 (pL_\sigma)^2 + (R_2')^2}$$

N.B. The difference $\Delta\Omega = \Omega_0 - \Omega$ is referred to as the slip speed.

The critical slip speed ($\Delta\Omega_m$) and the corresponding maximum (stall) torque (T_m):

$$\Delta\Omega_m = s_m \Omega_0 = \frac{R_2'}{pL_\sigma}$$

$$T_m = \frac{3(V_1)^2}{\Omega_0} \cdot \frac{1}{2X_\sigma} = \frac{3}{2pL_\sigma} \cdot \left(\frac{V_1}{\Omega_0}\right)^2 = \frac{3p}{8\pi^2 L_\sigma} \cdot \left(\frac{V_1}{f}\right)^2$$

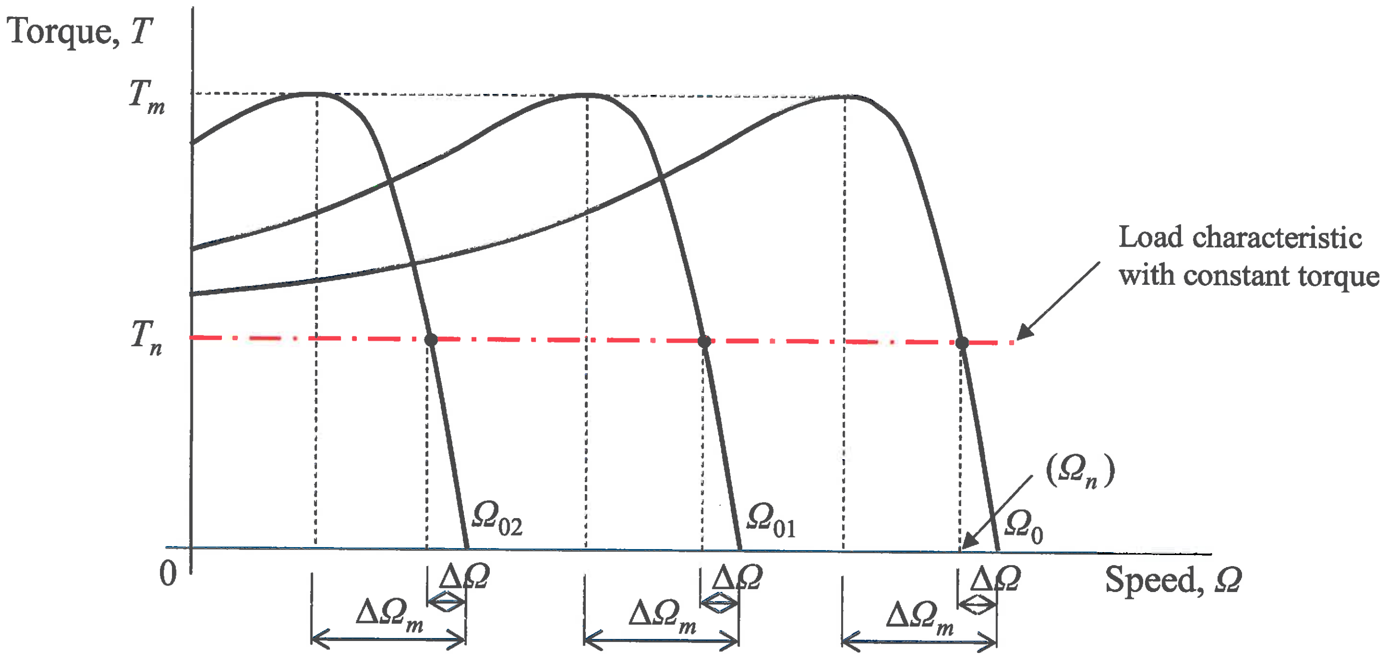
If frequency and supply voltage are changed in proportion, i.e. V/f = **const.**, then:

(i) the magnitude of air-gap flux remains constant;

(ii) the gradient of torque/speed characteristics remains unchanged ;

(iii) the critical slip speed and the corresponding maximum (stall) torque remain unchanged.

This speed control mode is usually called the **‘constant Volts per Hertz’** operation.



<u>The main remarks of ‘constant Volts per Hertz’ control:</u>

- the rated slip speed ($\Delta\Omega$) remains constant and small resulting in efficient variable-speed operation;
- the temporary overload capacity (ratio T_m/T_n) remains constant;
- the starting torque is increased at lower frequencies.