## Introduction to AC Induction Machines:

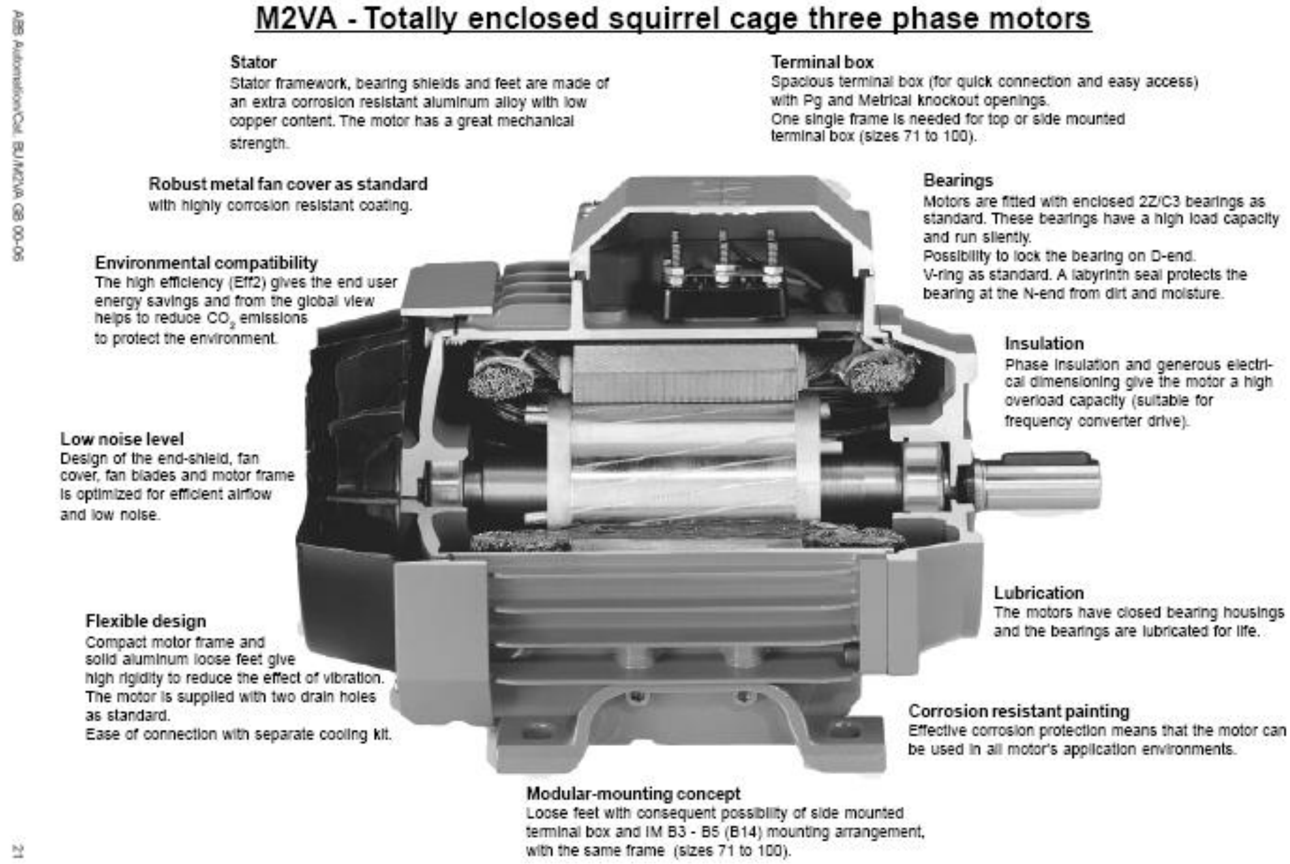
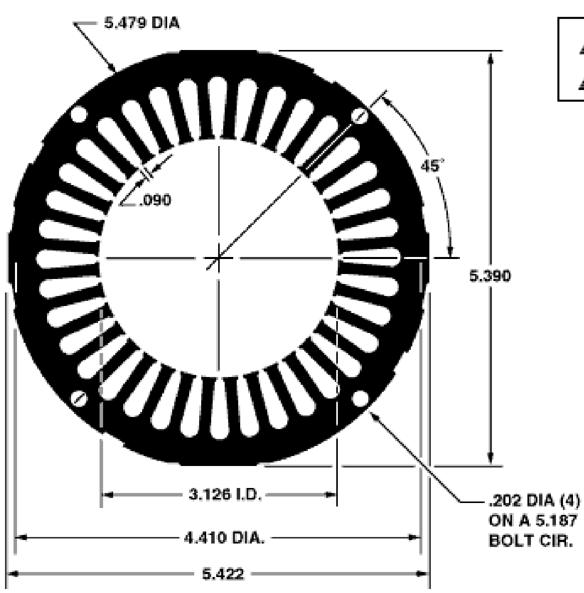
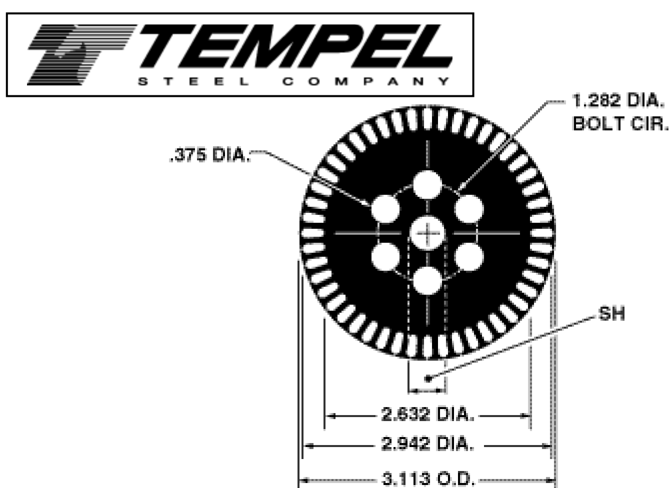



ABB Induction Motor

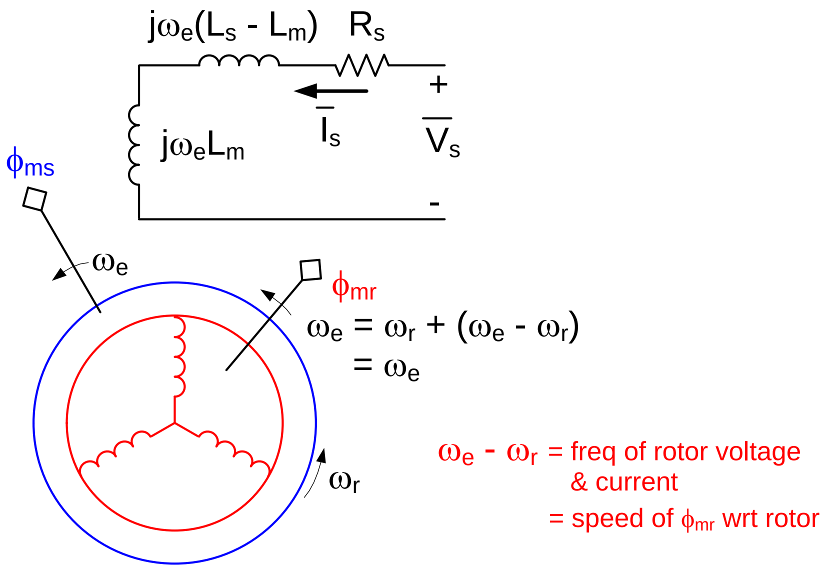



Induction Motor Stator — Induction Motor Rotor

Stator and Rotor Laminations from Tempel Steel Company

***Basic Theory of Squirrel Cage Induction Machines:***

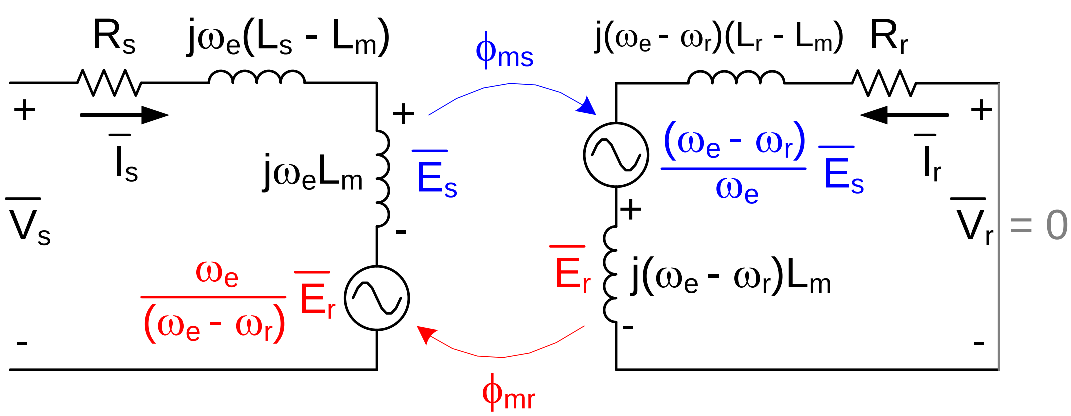



$\omega_e$ = excitation frequency

$\omega_r$ = rotor electrical speed

$$\omega_{em} = \frac{\omega_e}{P/2}$$

$$\omega_{rm} = \frac{\omega_r}{P/2}$$



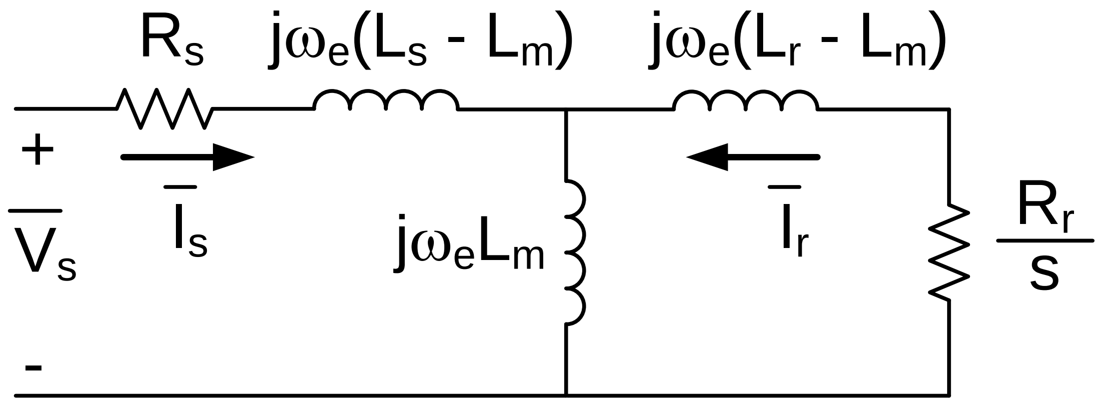

Per Phase Equivalent Schematic of Induction Motor

Circuit Model of Induction Motor

stator: $\overline{V}_s =$

rotor: $0 =$

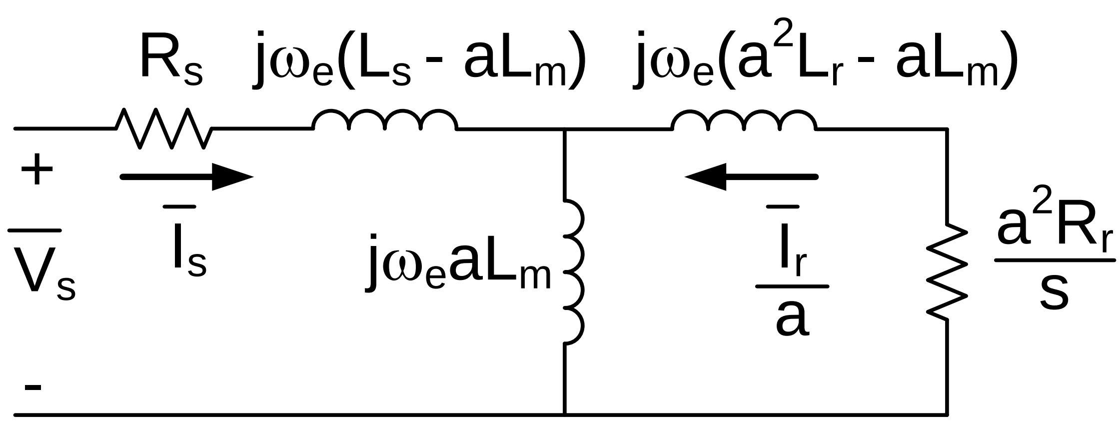
multiply rotor equation by




Per Phase Equivalent Schematic of Induction Motor Reflected to Stator

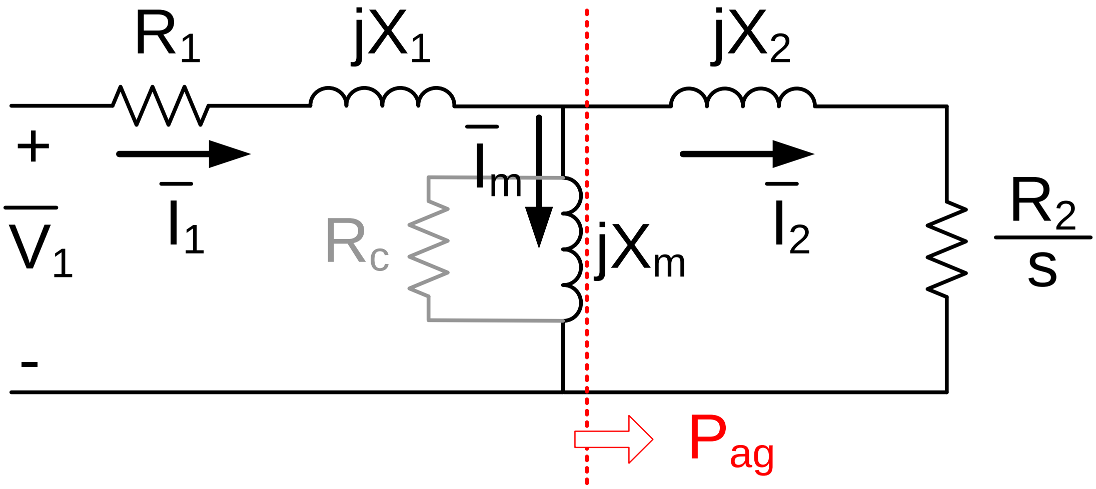
multiply rotor equation by $a \neq 0$ and introduce a new rotor current $= \frac{\bar{I}_r}{a}$

$0 =$



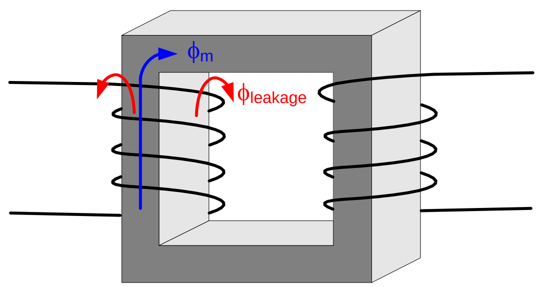

Per Phase Equivalent Schematic of Induction Motor Reflected to Stator

***Conventional Per Phase Equivalent Circuit:***




Per Phase Equivalent Schematic of Induction Motor Reflected to Stator

$a =$ $\qquad R_2 =$




$X_1$ & $X_2$ are called "Leakage" Inductances

$X_1 =$ $\qquad X_2 =$

$X_m = \omega_e \frac{N_s}{N_r} L_m$

Airgap Power:

$P_{ag} = \frac{3I_2^2 R_2}{s} \quad \rightarrow \quad 3I_2^2 R_2 = sP_{ag}$

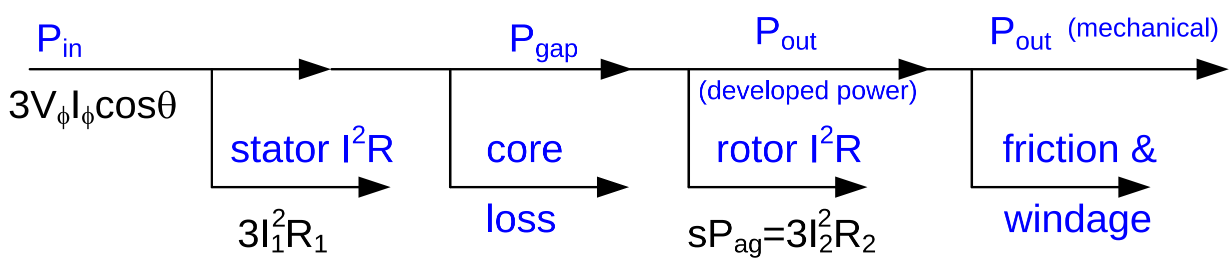
Rotor Loss $= sP_{ag}$

$P_{out} = \frac{3I_2^2 R_2}{s}(1-s) = P_{ag}(1-s)$

A good (efficient) induction motor must run with low slip.

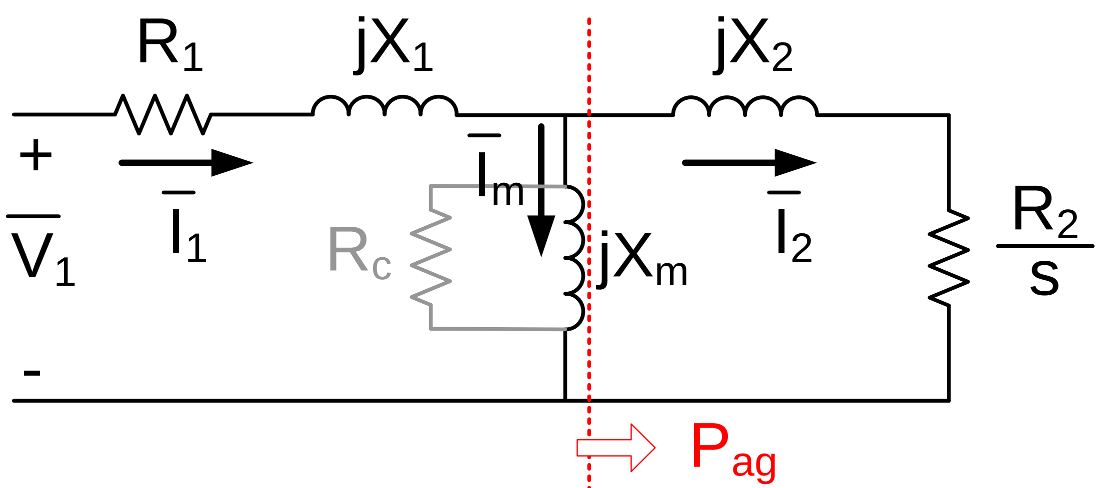
***Electromagnetic Torque:***

$$T_{em} = \frac{P_{out}}{\omega_{rm}} = \frac{P}{2}\frac{P_{out}}{\omega_r} = \frac{P}{2}\frac{P_{ag}(1-s)}{\omega_r} = \frac{P}{2}\frac{P_{ag}(1-s)}{\omega_e(1-s)} = \frac{P}{2}\frac{P_{ag}}{\omega_e}$$




Power Flow in an Induction Motor

***Conventional Per Phase Equivalent Circuit:***




Per Phase Equivalent Schematic of Induction Motor Reflected to Stator

$$T_{em} = \frac{P}{2}\frac{P_{ag}}{\omega_e} \qquad P_{ag} = \frac{3I_2^2 R_2}{s}$$

$$\boxed{T_{em} = \frac{3P}{2}\frac{I_2^2 R_2}{s\omega_e}}$$

## For a "good" motor

*for sure:*

$R_1 \rightarrow 0$ economics only (amount of wire)

$X_m \rightarrow \infty$ economics only (small air gap, good magnetic steel)

*probably:*

$R_2 \rightarrow 0$

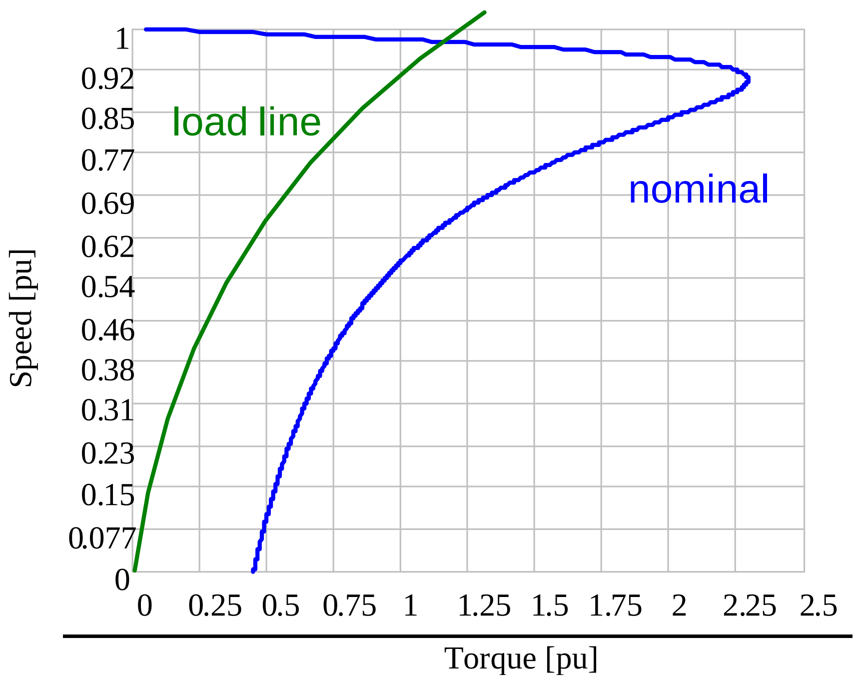
$X_1, X_2 \rightarrow 0$

Large $T_{max}$ (good)
Large Current at $T_{max}$ (bad)
Large Starting Currents (bad)

## Controlling the speed of an induction motor:

***Reduced Voltage Operation:***

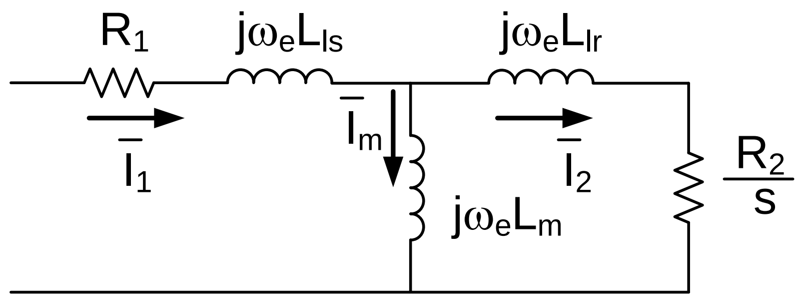
$T_{em} \propto V^2$




**Reduced Voltage Operation of Induction Motor**

***Constant Volts/Hz operation:***

$$Z_{in} = R_1 + j\omega_e L_{ls} + j\omega_e L_m \Big/\!\!\Big/ \left(\frac{R_2}{s} + j\omega_e L_{lr}\right)$$




**Induction Motor Per Phase Equivalent Circuit**

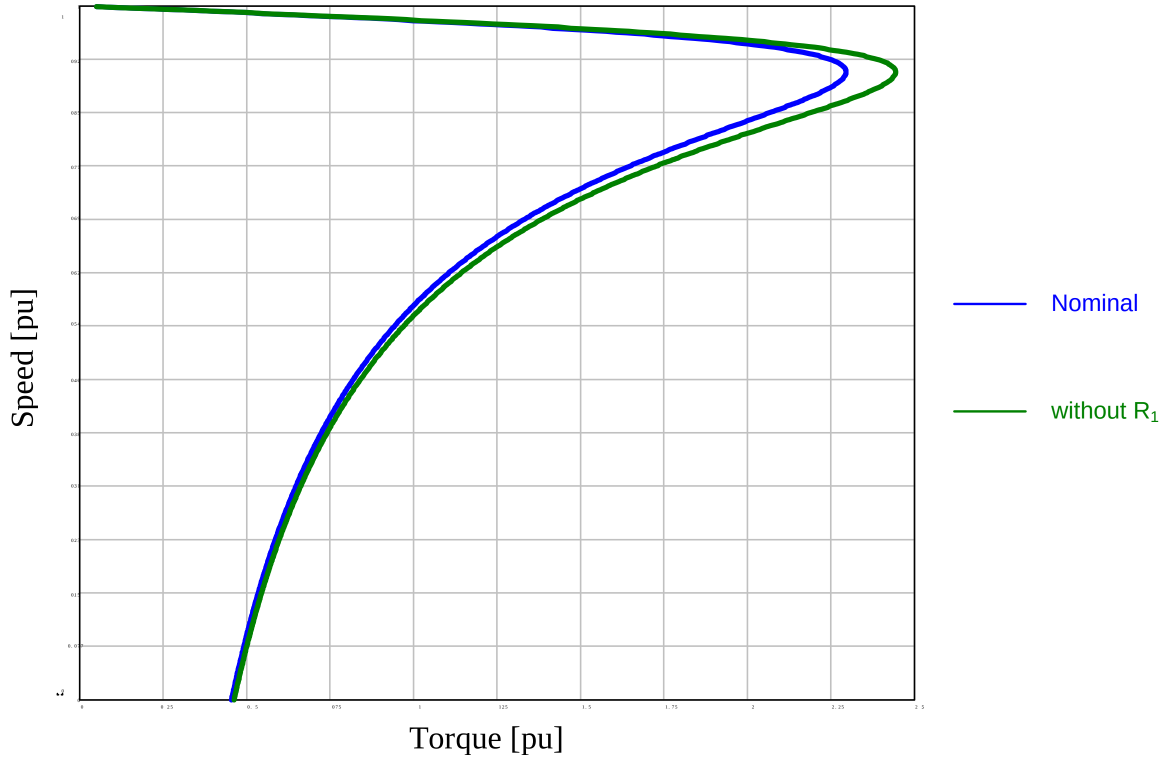
Neglecting $R_1$:

$$Z_{in}(\omega_e) = j\omega_e L_{ls} + j\omega_e L_m \Big/\!\!\Big/ \left(\frac{R_2}{s\omega_e}\omega_e + j\omega_e L_{lr}\right)$$

$$T_{em} = \frac{3P}{2}\frac{I_2^2 R_2}{s\omega_e}$$

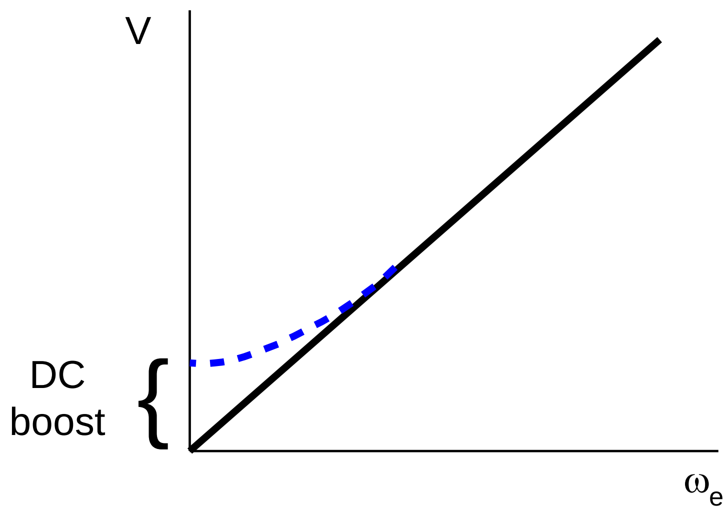
Maintain constant V/f:

- Maintains circuit (machine) impedance
- Maintains stator current
- Maintains rotor current (and thus torque)
- Maintains magnetizing current (and thus flux)

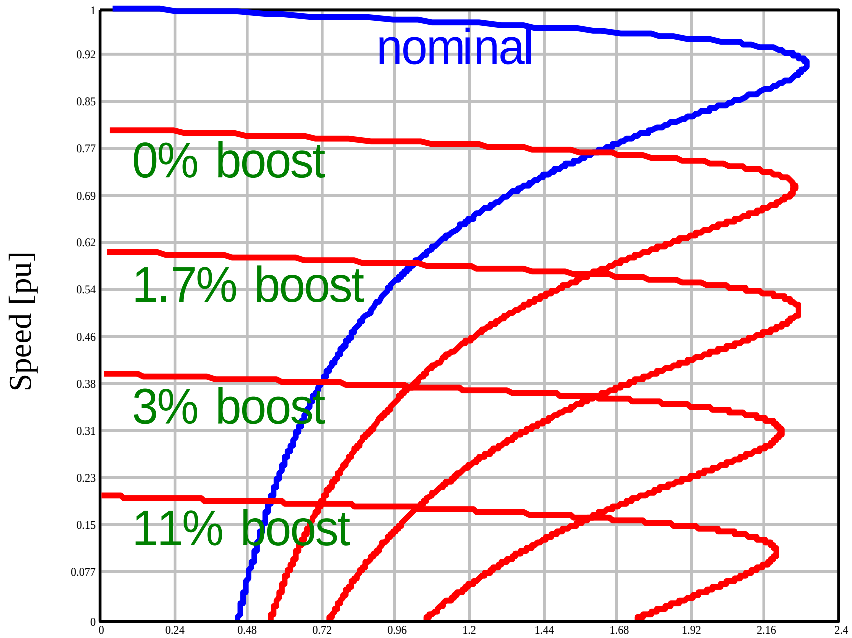



**Induction Motor Speed Torque Curves with Constant V/Hz**

Stator resistance causes deviation from ideal → use voltage boost to (partially) compensate

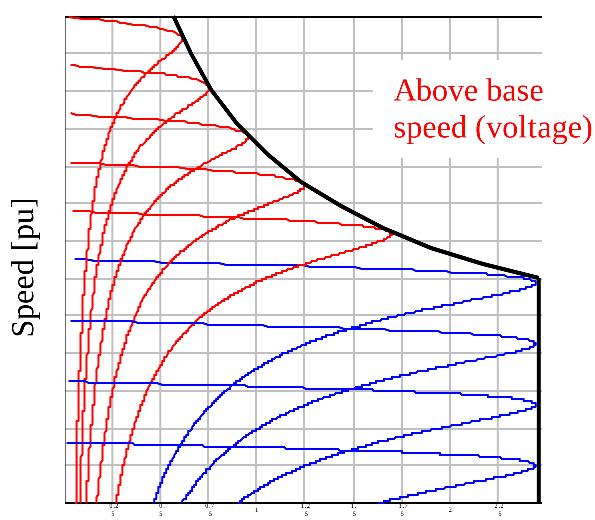



**Typical Voltage Boost Strategy for V/Hz Drives**




Torque [pu]

**Induction Motor Speed Torque Curves with Constant V/Hz with Boost**




Torque [pu]

**Induction Motor Capability Curves**

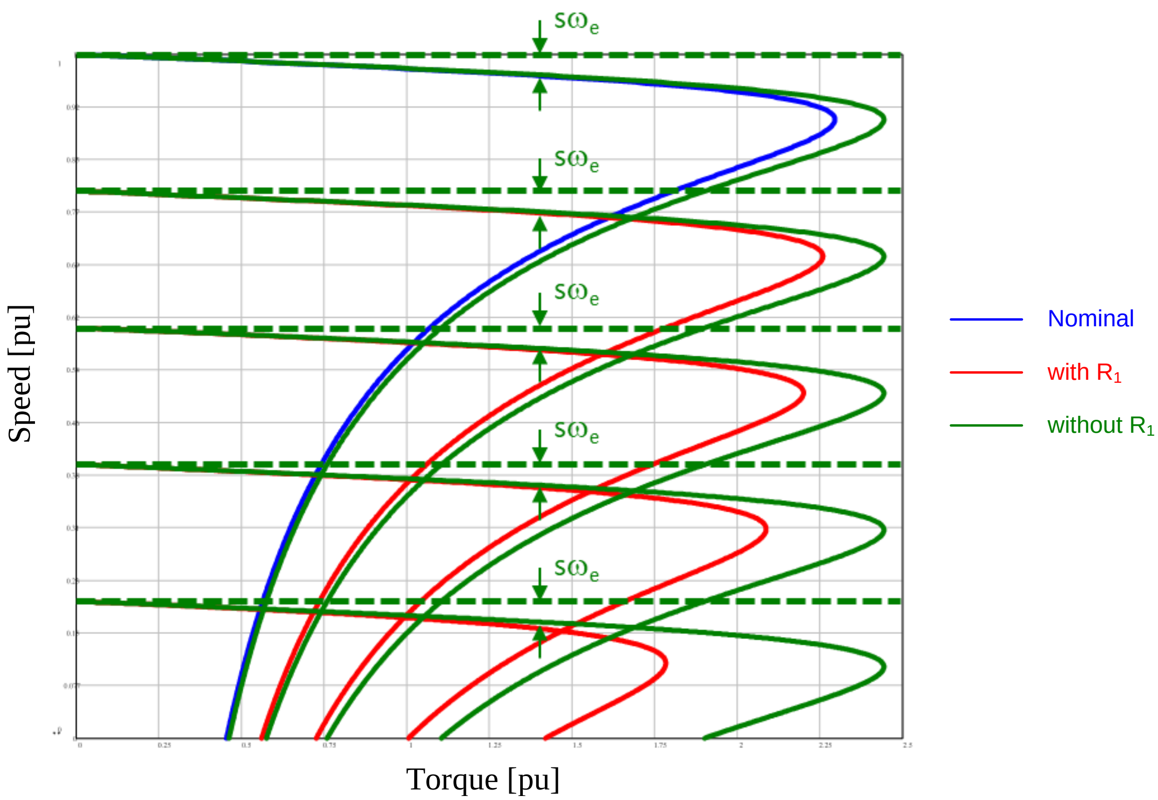
***Recap – Constant Volts/Hz operation:***

$$Z_{in} = R_1 + j\omega_e L_{ls} + j\omega_e L_m // \left(\frac{R_2}{s} + j\omega_e L_{lr}\right)$$

Neglecting $R_1$

$$Z_{in}(\omega_e) = j\omega_e L_{ls} + j\omega_e L_m // \left(\frac{R_2}{s\omega_e}\omega_e + j\omega_e L_{lr}\right)$$

$$T_{em} = \frac{3P}{2}\frac{I_2^2 R_2}{s\omega_e} \qquad s\omega_e = \omega_e - \omega_r = constant$$




**Induction Motor Speed Torque Curves with Constant V/Hz**