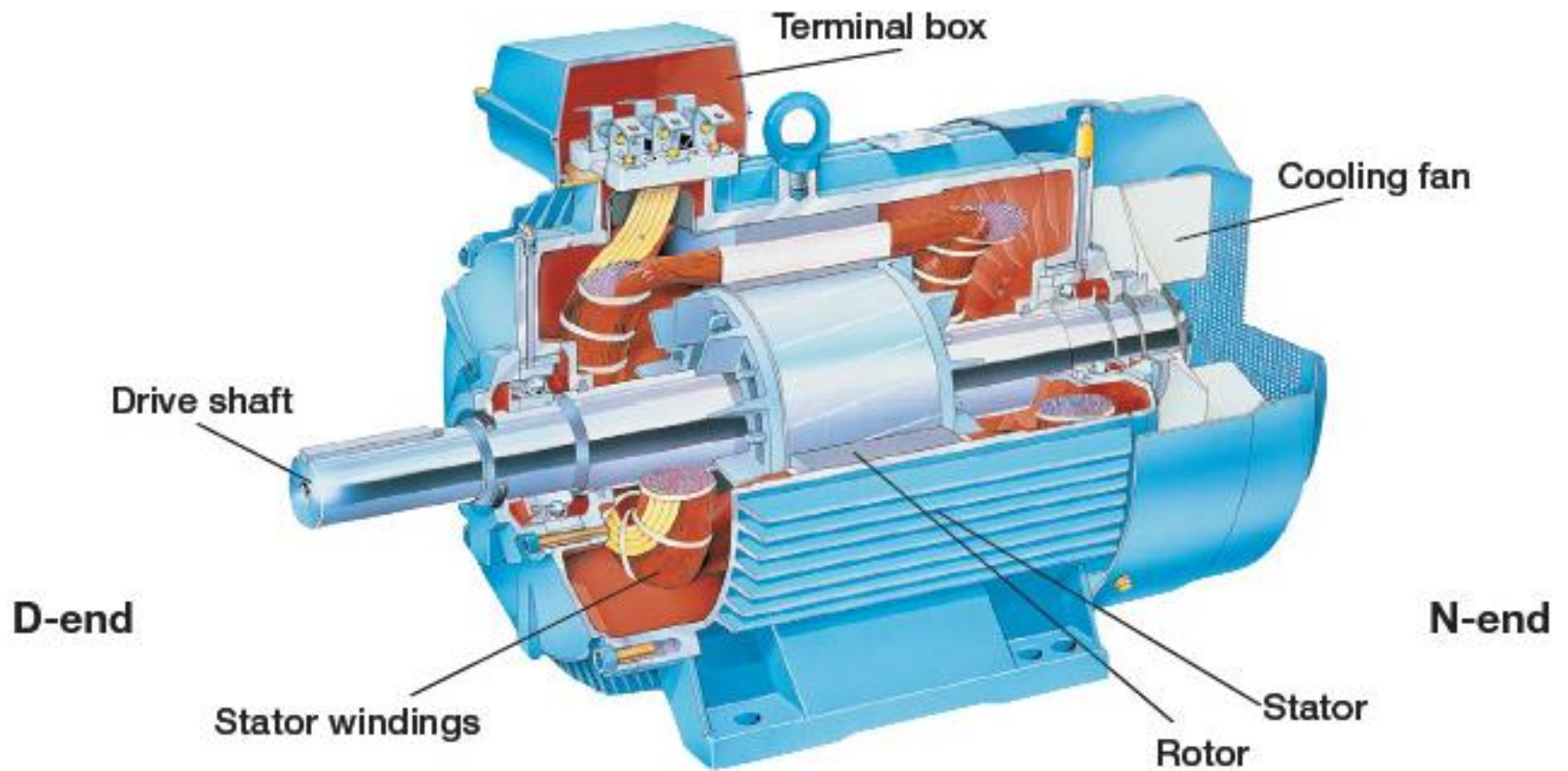


# THREE PHASE INDUCTION MOTOR

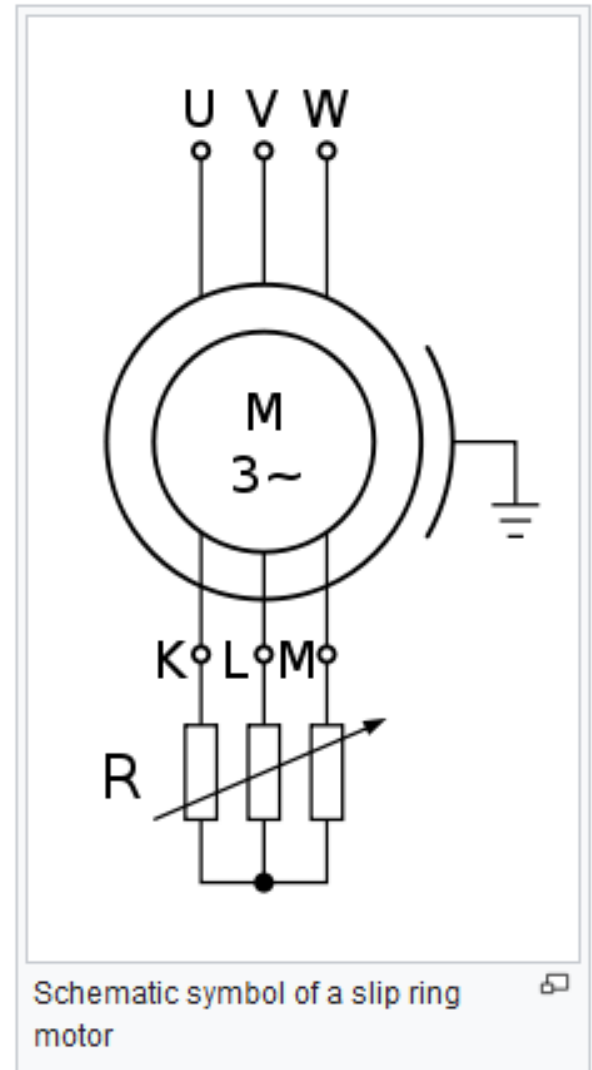
# Introduction

- Paling banyak dipakai di industri
- Sempel, kokoh, murah, dan biaya perawatan rendah
- Jenis motor induksi
  - Squirrel cage
  - Wound rotor
  - Linear motor

# Squirrel Cage

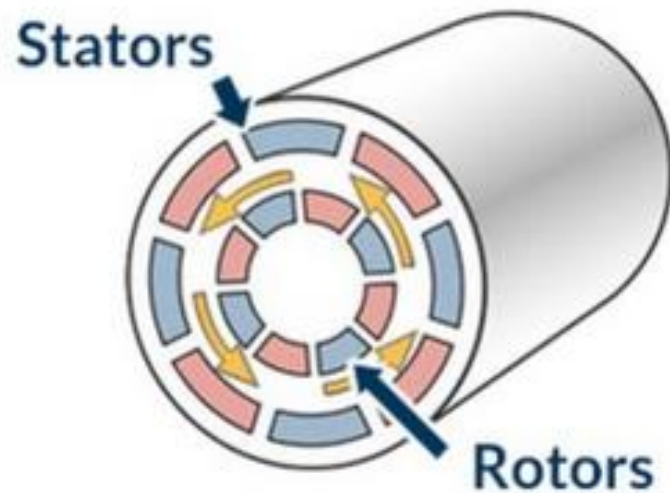


# Wound Rotor

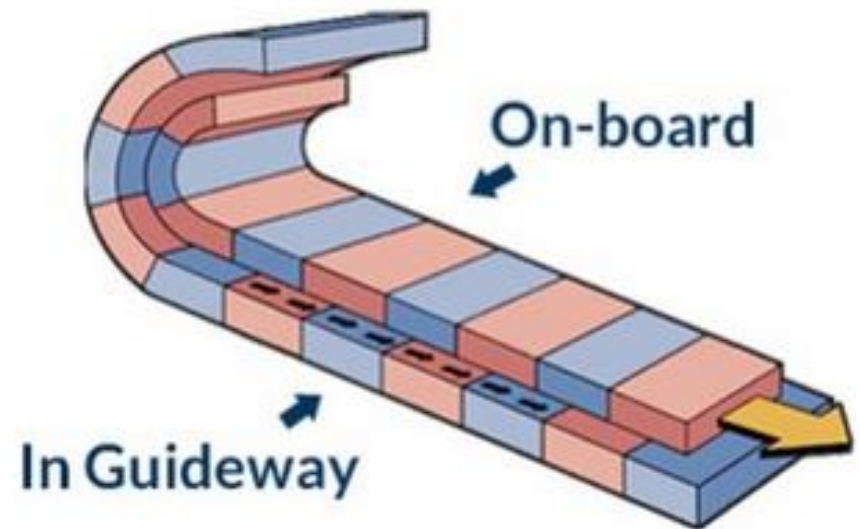


# Linier Induction Motor

## CONVENTIONAL MOTOR

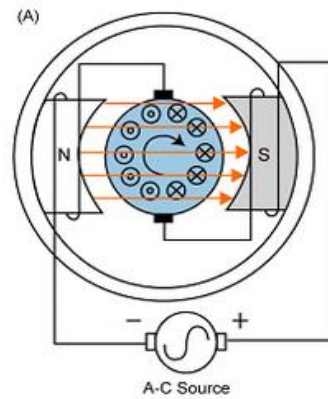


## LINEAR MOTOR

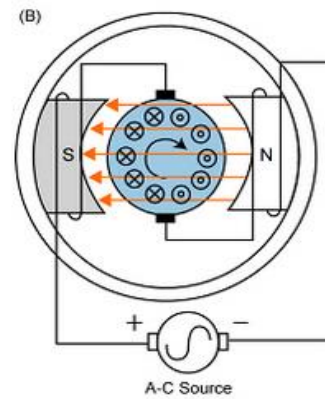


# Prinsip Kerja

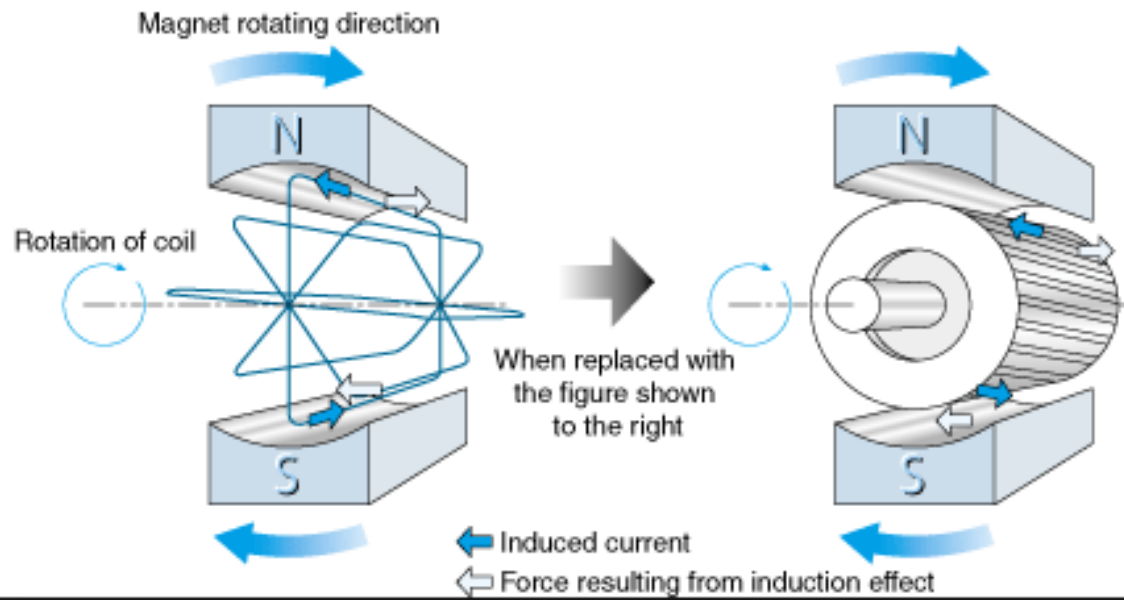
- Menerapkan Hukum Faraday dan Gaya Lorentz
- Gelombang sinus listrik AC menyebabkan polaritas magnet pada stator berubah
- Perubahan medan magnet ini menimbulkan arus induksi pada coil rotor (Hukum Faraday)
- Adanya medan magnet dan arus di kumparan akan menimbulkan Gaya Lorentz yg menyebabkan motor berputar ( $F = BIL$ )



First Half Period



Second Half Period



# Speed

- Kecepatan putar sebanding dengan frekuensi sumber AC pada kondisi tegangan konstant
- Misal  $f=60$  Hz, maka kecepatan putar motor  $1/60$  s atau 3600 rpm
- Arah putar motor dapat dibalik dengan menukar koneksi sumber tegangan
- Synchronous speed

$$n_s = \frac{120f}{p}$$

$n_s$  = synchronous speed [r/min]  
 $f$  = frequency of the source [Hz]  
 $p$  = number of poles



# Slip

- Slip adalah perbedaan kecepatan antara kecepatan sinkron dan kecepatan riil di rotor
- Karena adanya slip maka motor induksi masuk dalam katagori *Asynchronous Motor*
- Slip terjadi karena adanya pembebanan

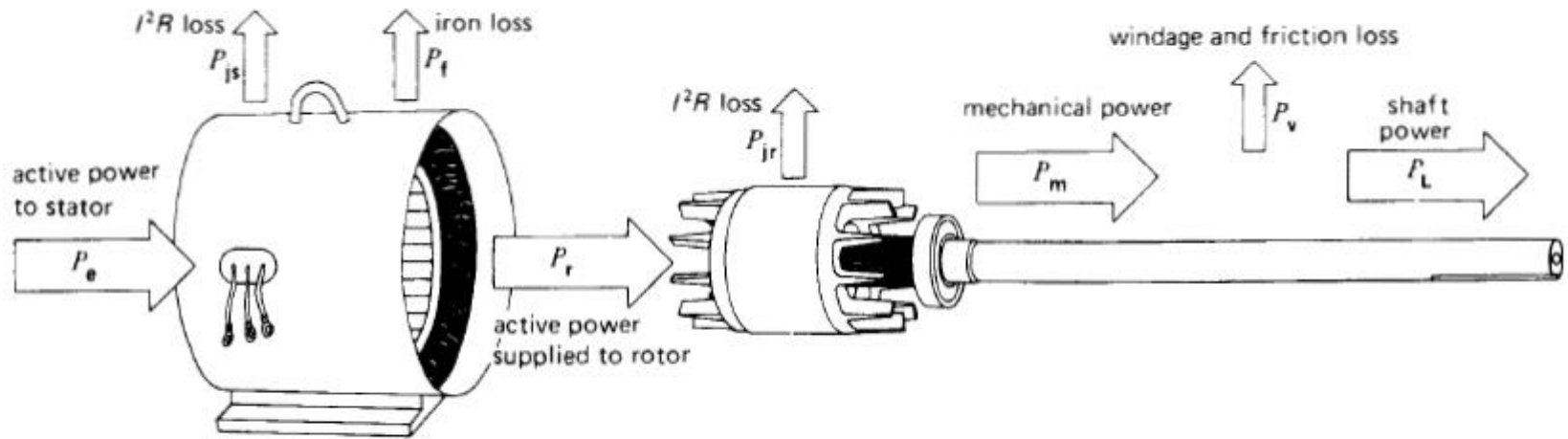
$$s = \frac{n_s - n}{n_s}$$

$s$  = slip

$n_s$  = synchronous speed [r/min]

$n$  = rotor speed [r/min]

# Power Flow



**Figure 13.15**  
Active power flow in a 3-phase induction motor.

**1. Efficiency.** By definition, the efficiency of a motor is the ratio of the output power to the input power:

$$\text{efficiency } (\eta) = P_L/P_e \quad (13.6)$$

**2.  $I^2R$  losses in the rotor.** It can be shown\* that the rotor  $I^2R$  losses  $P_{jr}$  are related to the rotor input power  $P_r$  by the equation

$$P_{jr} = sP_r \quad (13.7)$$

where

$P_{jr}$  = rotor  $I^2R$  losses [W]

$s$  = slip

$P_r$  = power transmitted to the rotor [W]

**3. Mechanical power.** The mechanical power  $P_m$  developed by the motor is equal to the power transmitted to the rotor minus its  $I^2R$  losses. Thus,

$$\begin{aligned} P_m &= P_r - P_{jr} \\ &= P_r - sP_r \end{aligned} \quad (13.7)$$

whence

$$P_m = (1 - s)P_r \quad (13.8)$$

**4. Motor torque.** The torque  $T_m$  developed by the motor at *any* speed is given by

$$\begin{aligned} T_m &= \frac{9.55 P_m}{n} \quad (3.5) \\ &= \frac{9.55 (1 - s) P_r}{n_s(1 - s)} = 9.55 P_r/n_s \end{aligned}$$

therefore,

$$T_m = 9.55 P_r/n_s \quad (13.9)$$

where

$T_m$  = torque developed by the motor at *any* speed [N·m]

$P_r$  = power transmitted to the rotor [W]

$n_s$  = synchronous speed [r/min]

9.55 = multiplier to take care of units [exact value:  $60/2\pi$ ]

**Example 13-5** \_\_\_\_\_

A 3-phase induction motor having a synchronous speed of 1200 r/min draws 80 kW from a 3-phase feeder. The copper losses and iron losses in the stator amount to 5 kW. If the motor runs at 1152 r/min, calculate the following:

- The active power transmitted to the rotor
- The rotor  $I^2R$  losses
- The mechanical power developed
- The mechanical power delivered to the load, knowing that the windage and friction losses are equal to 2 kW
- The efficiency of the motor

### Solution

a. Active power to the rotor is

$$\begin{aligned}P_r &= P_c - P_{js} - P_f \\ &= 80 - 5 = 75 \text{ kW}\end{aligned}$$

b. The slip is

$$\begin{aligned}s &= (n_s - n)/n_s \\ &= (1200 - 1152)/1200 \\ &= 48/1200 = 0.04\end{aligned}$$

Rotor  $I^2R$  losses are

$$P_{jr} = sP_r = 0.04 \times 75 = 3 \text{ kW}$$

c. The mechanical power developed is

$$\begin{aligned}P_m &= P_r - I^2R \text{ losses in rotor} \\ &= 75 - 3 = 72 \text{ kW}\end{aligned}$$

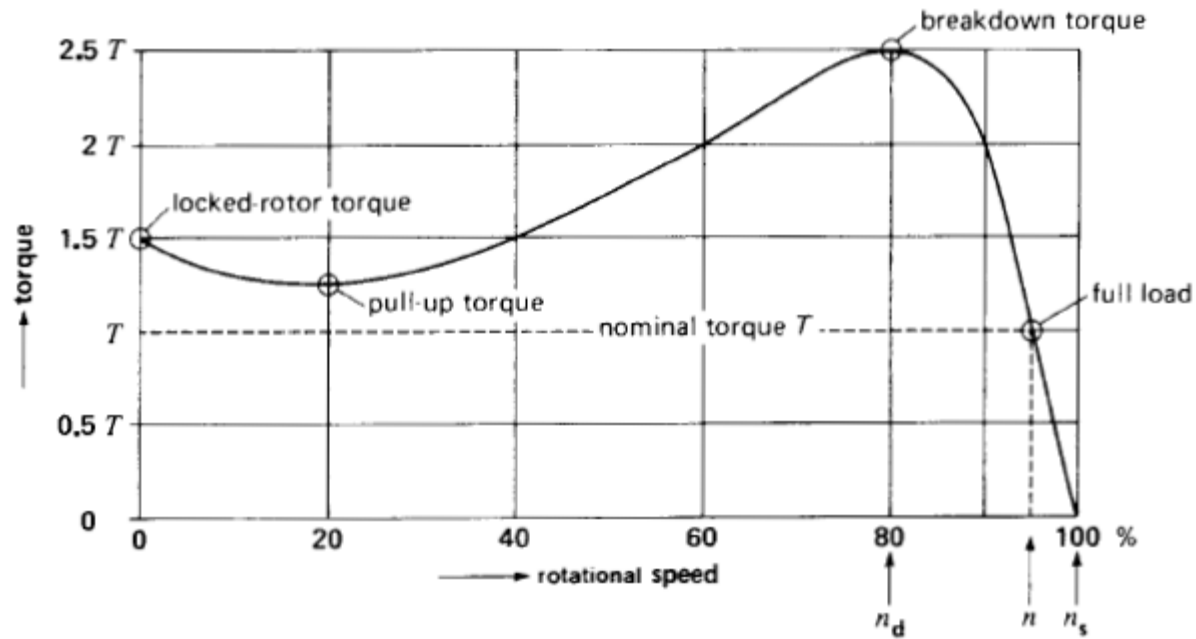
d. The mechanical power  $P_{1.}$  delivered to the load is slightly less than  $P_m$ , due to the friction and windage losses.

$$P_{1.} = P_m - P_v = 72 - 2 = 70 \text{ kW}$$

e. The efficiency is

$$\begin{aligned}\eta &= P_{1.}/P_c = 70/80 \\ &= 0.875 \text{ or } 87.5\%\end{aligned}$$

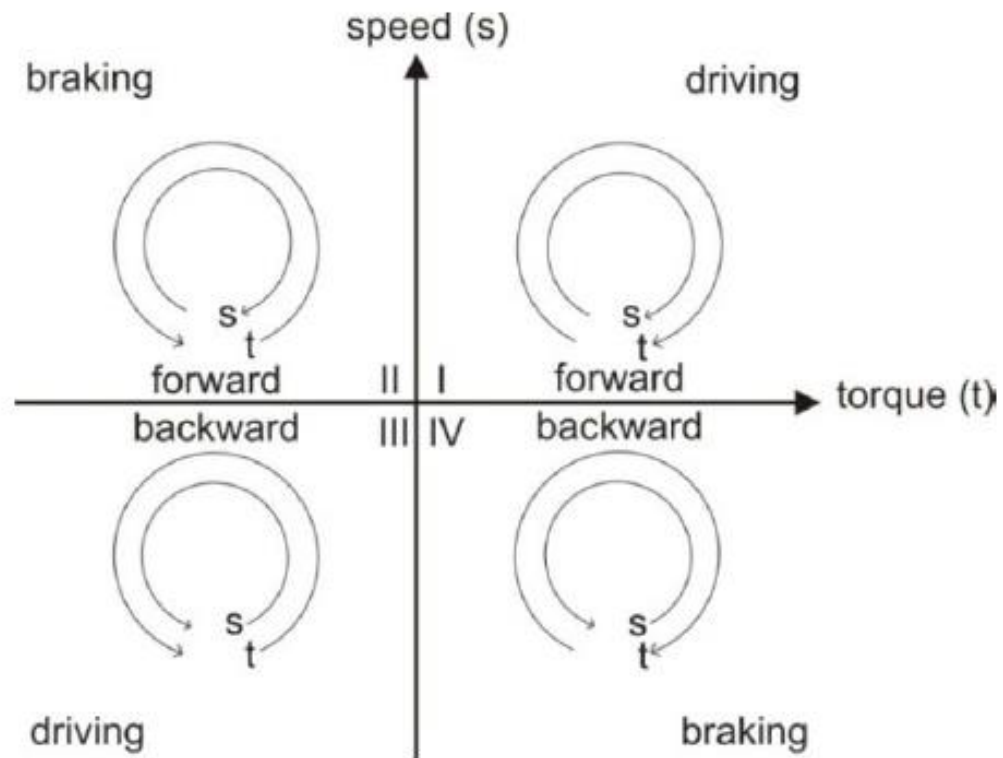
# Speed-Torque Curve



- Torsi yg dibangkit motor sebanding dengan load
- Jika load melebihi breakdown torque maka motor akan berhenti

# Speed Control

- Constant speed
  - Metode starting
- Variable speed
  - Scalar control
  - Vector Control
  - Direct Torque Control



*Fig. 2-3 Four Quadrant Operation*



# Methodode Starting

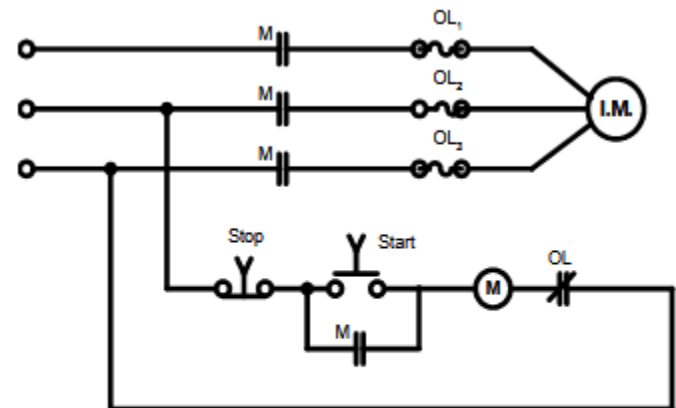
## 1) Direct OnLine (DOL)

### Kelebihan dari metode starting DOL

- ◆ Efektifitas biaya awal
- ◆ Rangkaian dan cara kerja yang sederhana

### Kelemahan dari metode starting DOL

- ◆ Hanya bisa dipakai bagi motor yang berukuran lebih kecil bila ukuran suplai membutuhkan pemakaiannya
- ◆ Arus dan torsi maksimum pada saat pengasutan (bisa juga dimasukkan kedalam faktor kelebihan)



Gambar 4. Rangkaian starting DOL

# Method Starting

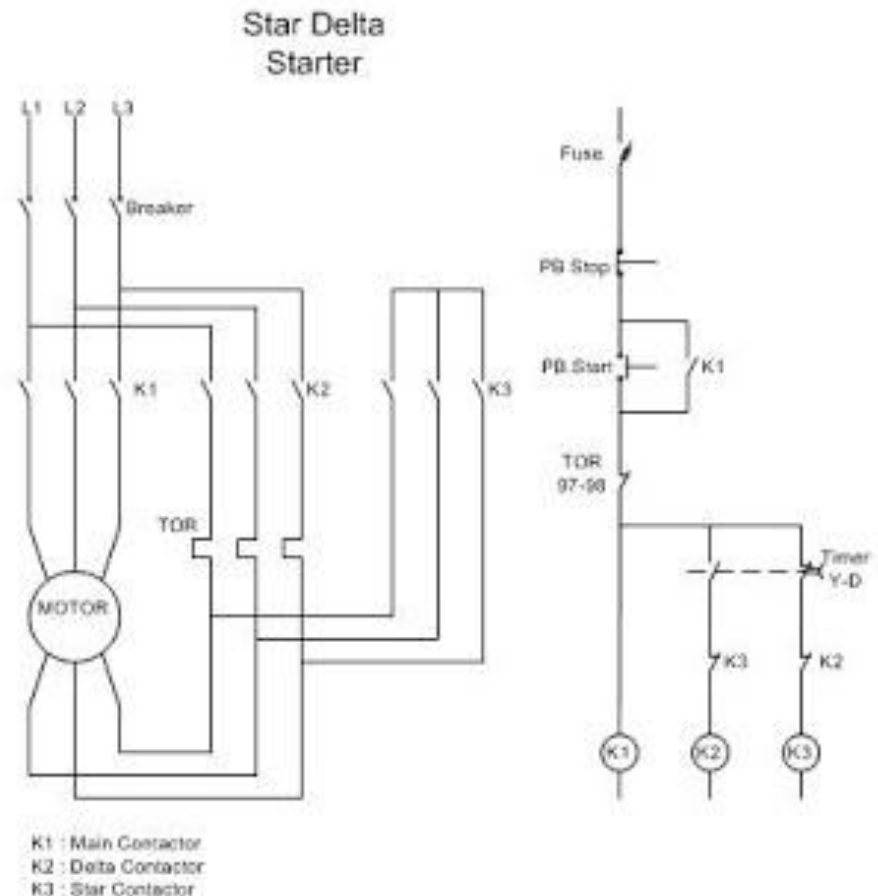
## 2) Wye-Delta

### Kelebihan

- ◆ Metode starting yang lebih murah dibandingkan metode Starting Autotransformer
- ◆ Karakteristik kecepatan/arus/torsi yang baik
- ◆ Cocok untuk berbagai jenis motor
- ◆ Mudah dipasang dalam berbagai situasi

### Kelemahan

- ◆ Motor harus memiliki enam ujung koil, dalam hal ini, enam terminal
- ◆ Pada jenis transisi terbuka, menghasilkan arus transient



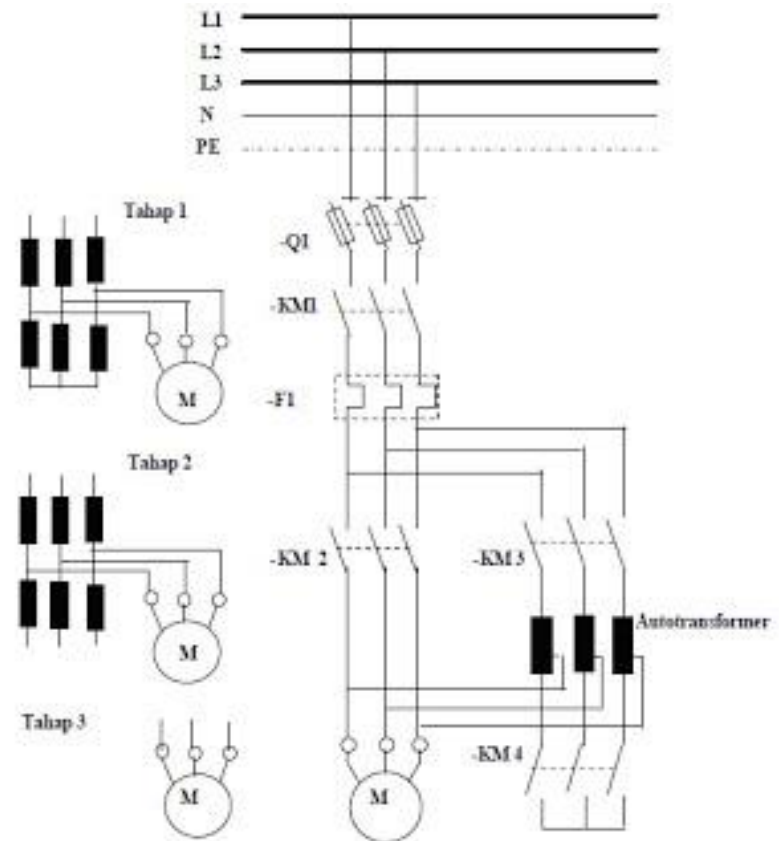
### 3) Autotransformer

#### Kelebihan

- ◆ Pengatur (tap) transformer dapat dilakukan untuk batasan beban yang luas
- ◆ Karakteristik torsi terhadap arus alir merupakan suatu nilai yang optimal
- ◆ Motor tidak diputus-hubungkan dari suplai selama perubahan akibat pengaturan (tap), dengan demikian bisa mengurangi transient.

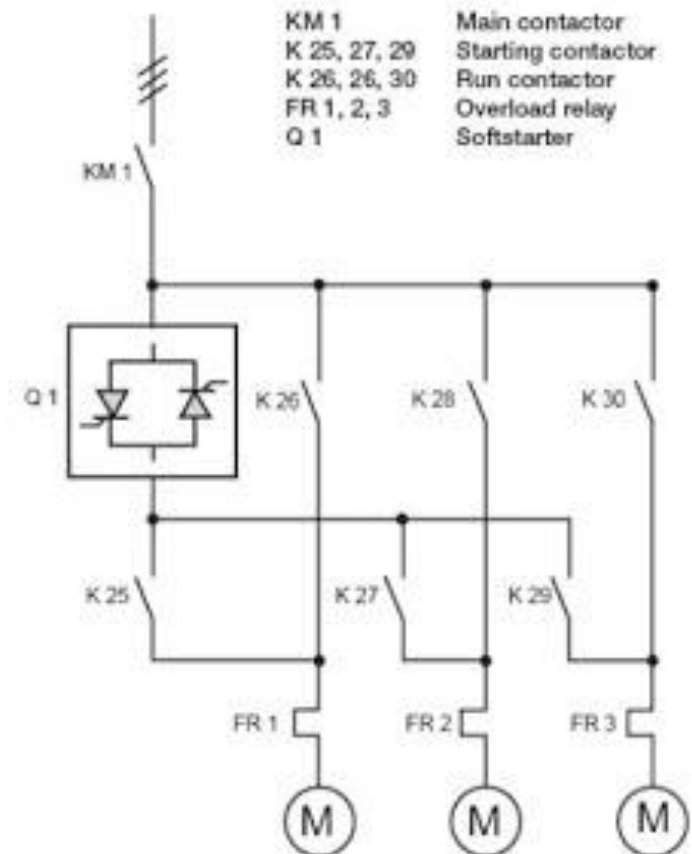
#### Kelemahan

- ◆ Mahal
- ◆ Sangat berat dan besar dibandingkan jenis-jenis pengasut lain.



## 4) Soft start

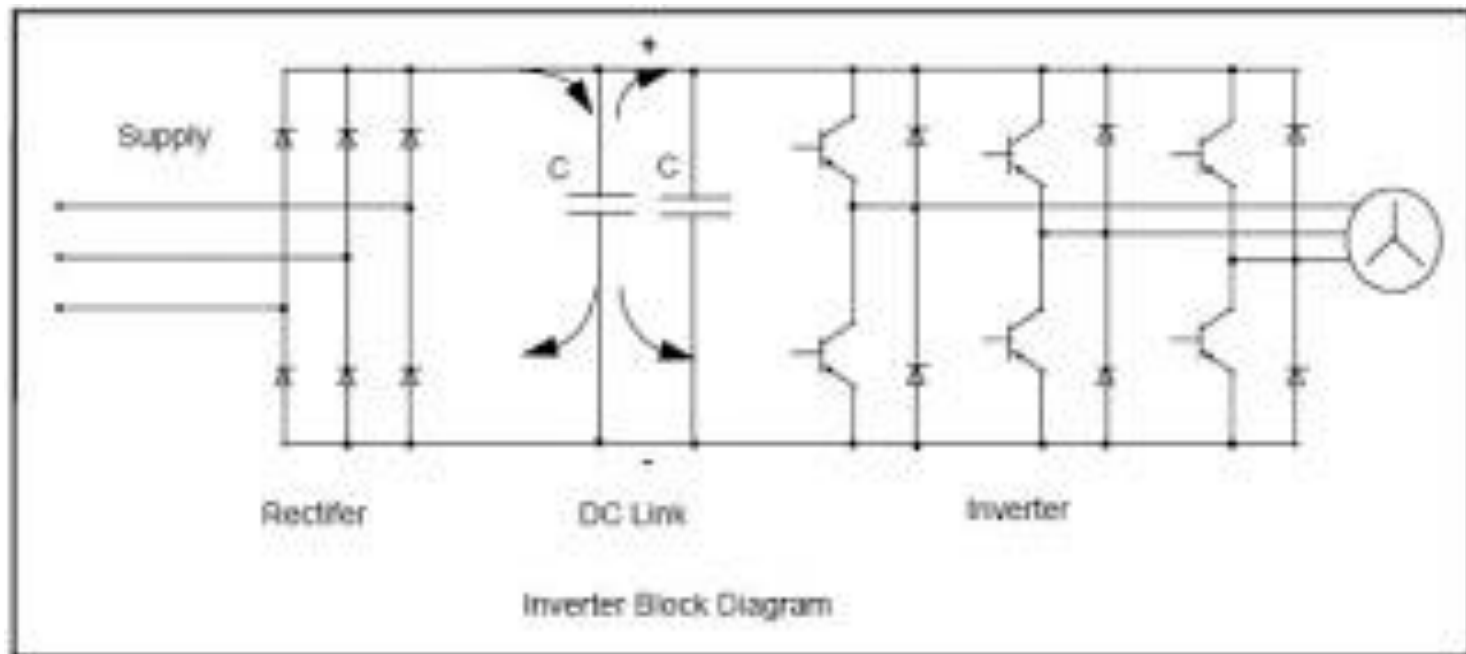
- Memakai perangkat elektronika daya untuk menaikkan dan menurunkan tegangan secara perlahan
- Lebih praktis meski agak mahal



Sequential start of motors using a softstarter

## 5) Frequency Drive

- Yaitu starting motor dengan variable drive
- Memakai metode motor control



# Scalar Control/ VF control

- Metode kontrol motor yg paling simpel
- Banyak dipakai pada aplikasi yg tidak memerlukan tingkat presisi tinggi seperti kipas, pompa dll
- Menggunakan table hubungan Voltage dan Frekuensi sehingga sering disebut VF control

# Scalar Control/ VF control

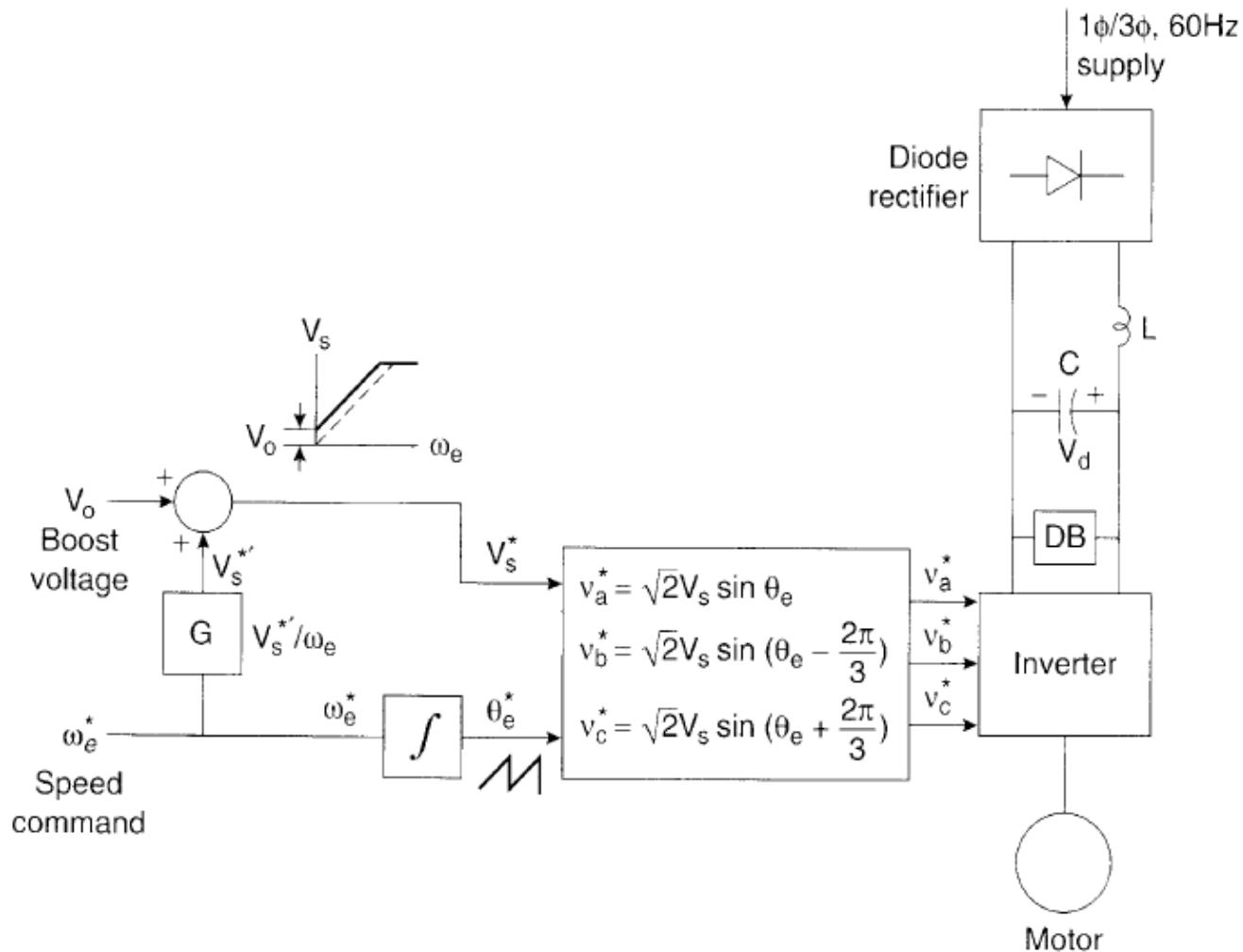
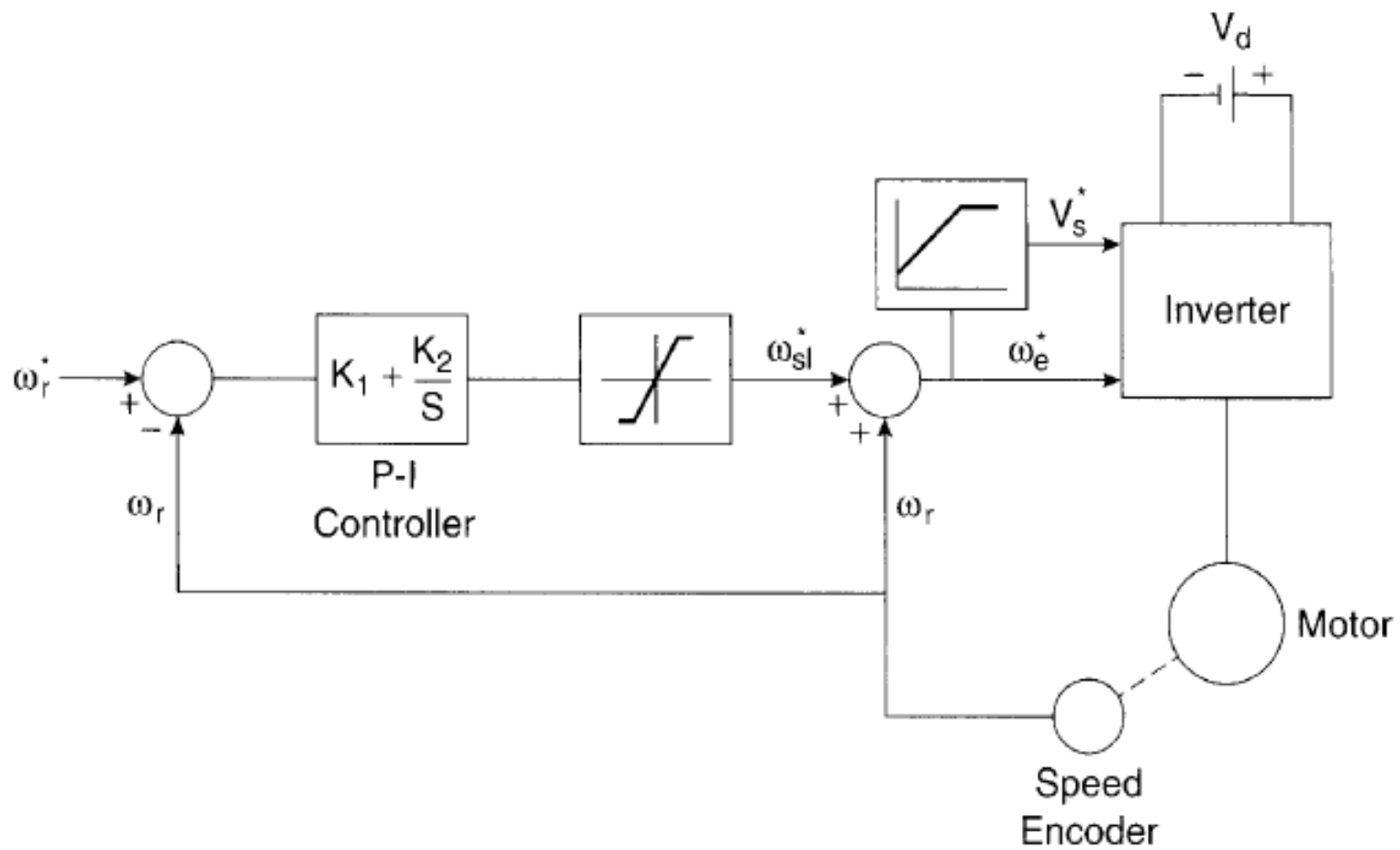


Figure 8.4 Open loop volts/Hz speed control with voltage-fed inverter



**Figure 8.9** Close loop speed control with volts/Hz control and slip regulation

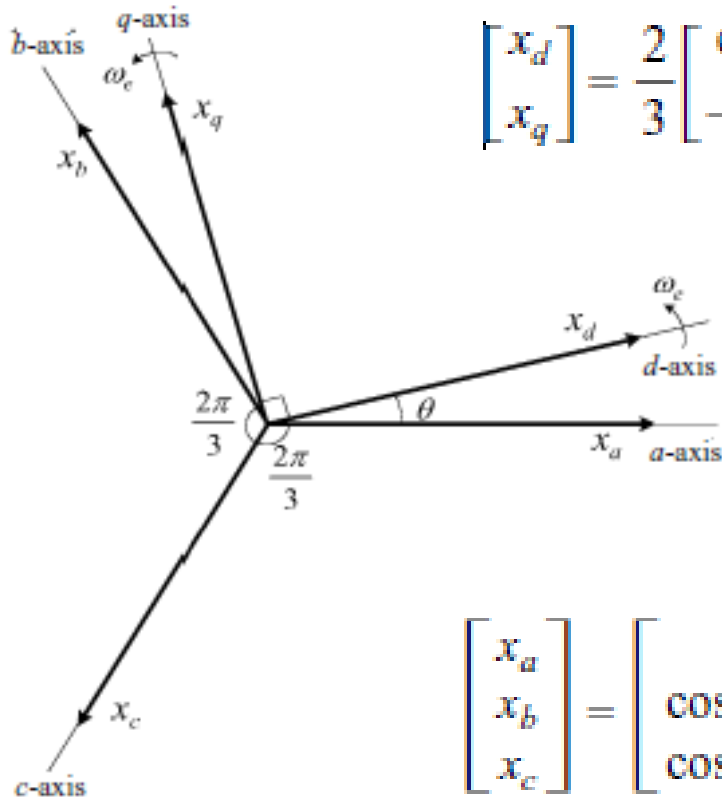


# Vector Control

- Metode kontrol motor dengan tingkat kepresisian tinggi, tetapi sistemnya kompleks
- Memerlukan data parameter motor
- Menggunakan analisa vector dengan mentransformasikan arus ac 3 phasa menjadi arus dc sehingga lebih mudah dikontrol
- Meniru motor dc eksitasi terpisah dengan melakukan decoupling antara flux dan torsi

# Transformasi pada VC

## 1) abc/dq transformation

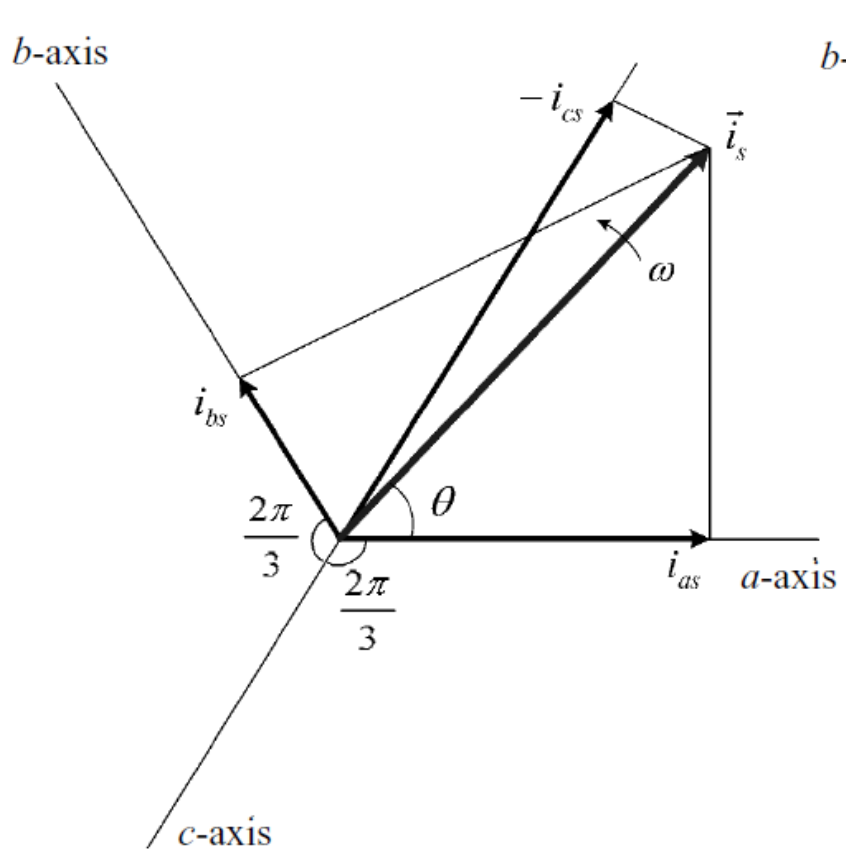


$$\begin{bmatrix} x_d \\ x_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos \theta & \cos(\theta - 2\pi/3) & \cos(\theta - 4\pi/3) \\ -\sin \theta & -\sin(\theta - 2\pi/3) & -\sin(\theta - 4\pi/3) \end{bmatrix} \cdot \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

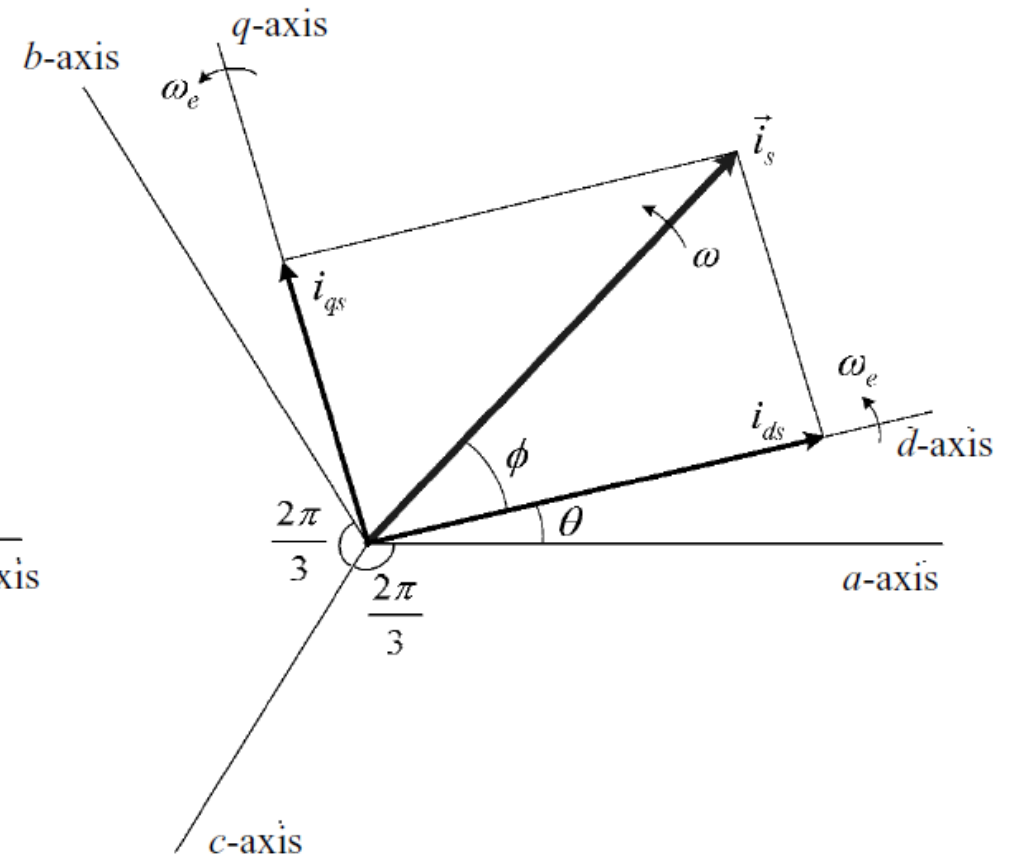
Hanya valid pada sistem 3 phasa seimbang, dimana:

$$x_a + x_b + x_c = 0$$

$$\begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \cos(\theta - 2\pi/3) & -\sin(\theta - 2\pi/3) \\ \cos(\theta - 4\pi/3) & -\sin(\theta - 4\pi/3) \end{bmatrix} \cdot \begin{bmatrix} x_d \\ x_q \end{bmatrix}$$



(a)  $abc$ -axis currents in the stationary frame



(b)  $dq$ -axis currents in the synchronous frame :

- Torsi pada motor DC

$$T_e = K_a \lambda_f i_a$$

- Torsi pada motor AC dibuat identik

$$T_e = K_T \lambda_{dr} i_{qs} = K_T \lambda_r i_{qs}$$

$$\underline{K_T = 3PL_m/2L_r}$$

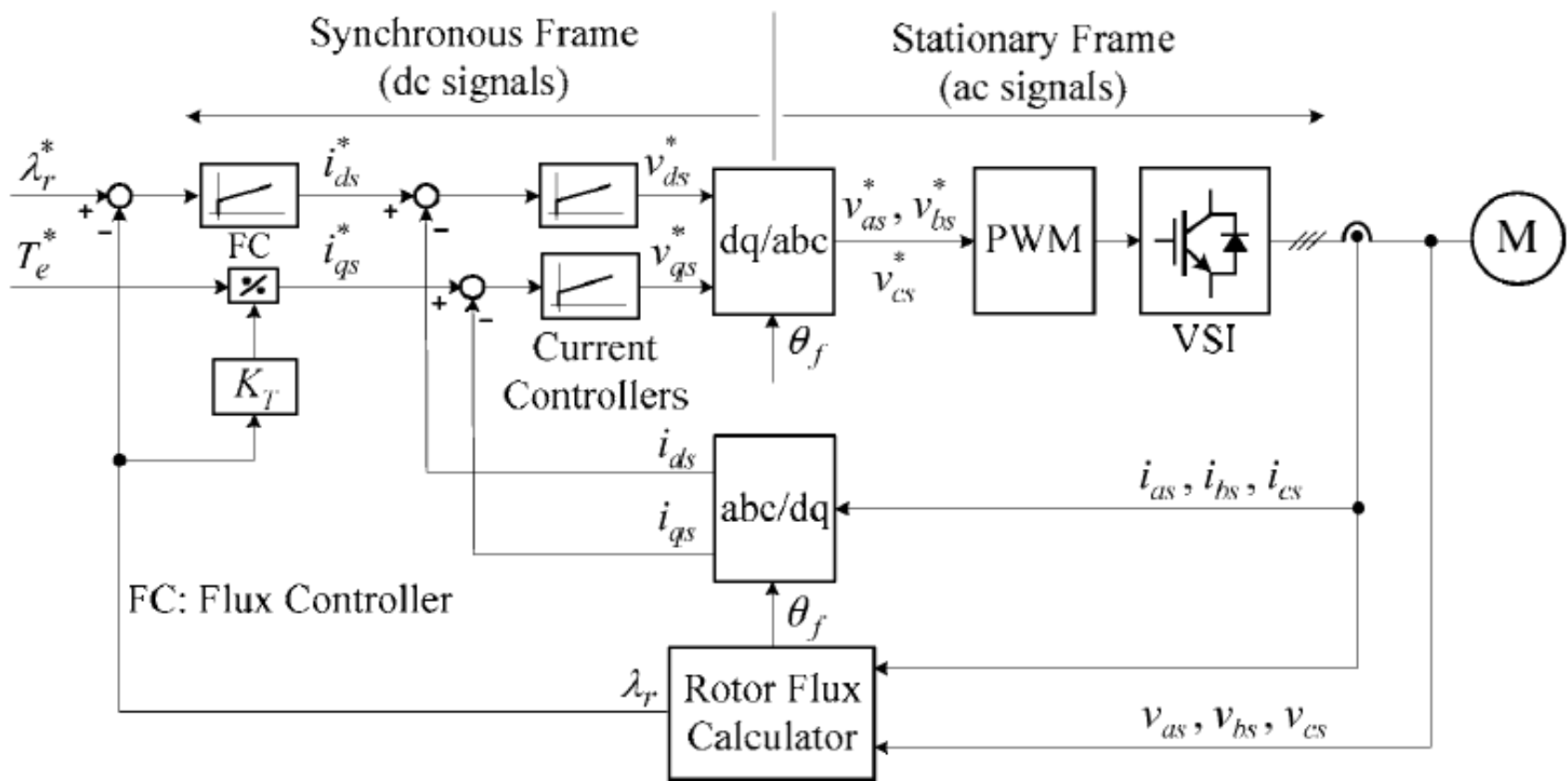
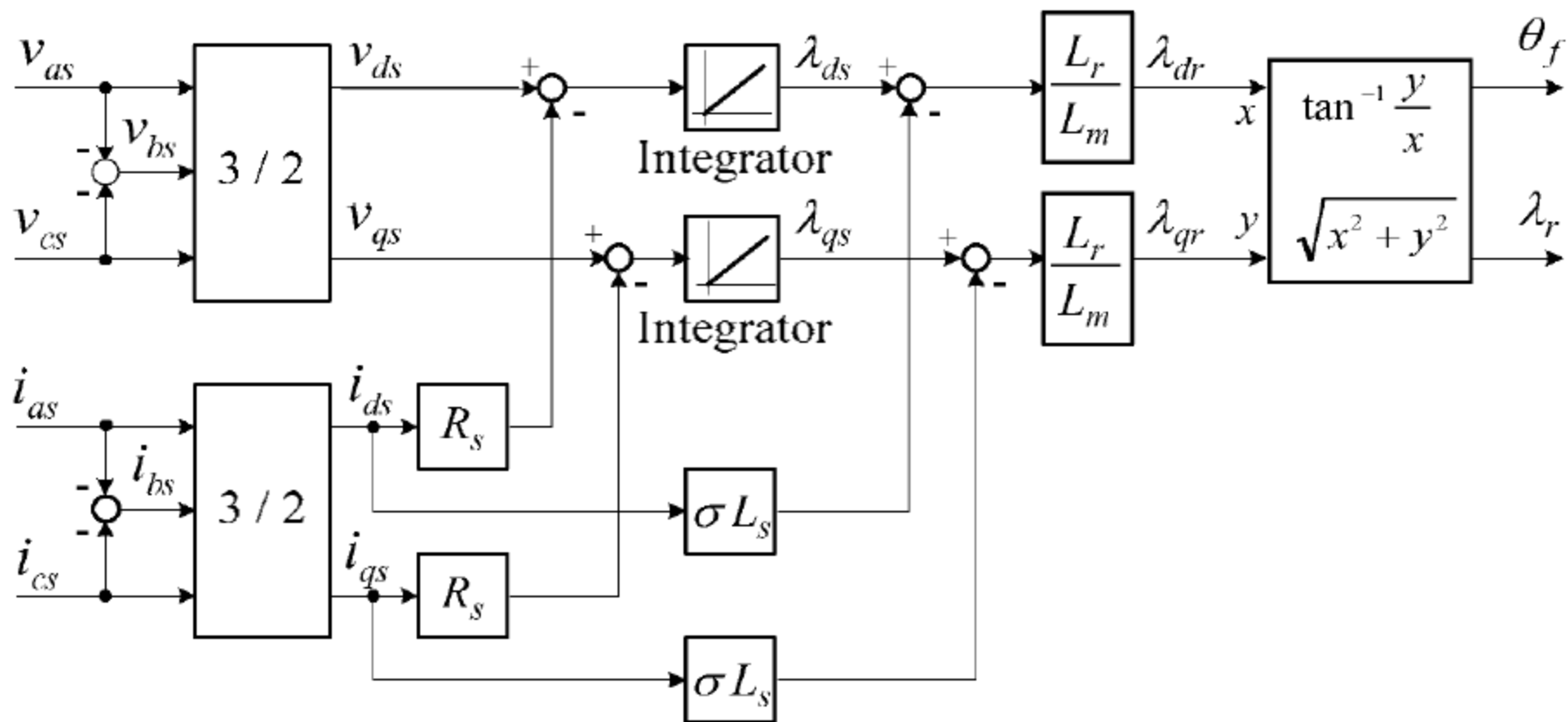


Figure 14.5-1 Direct field-oriented control with rotor flux orientation.



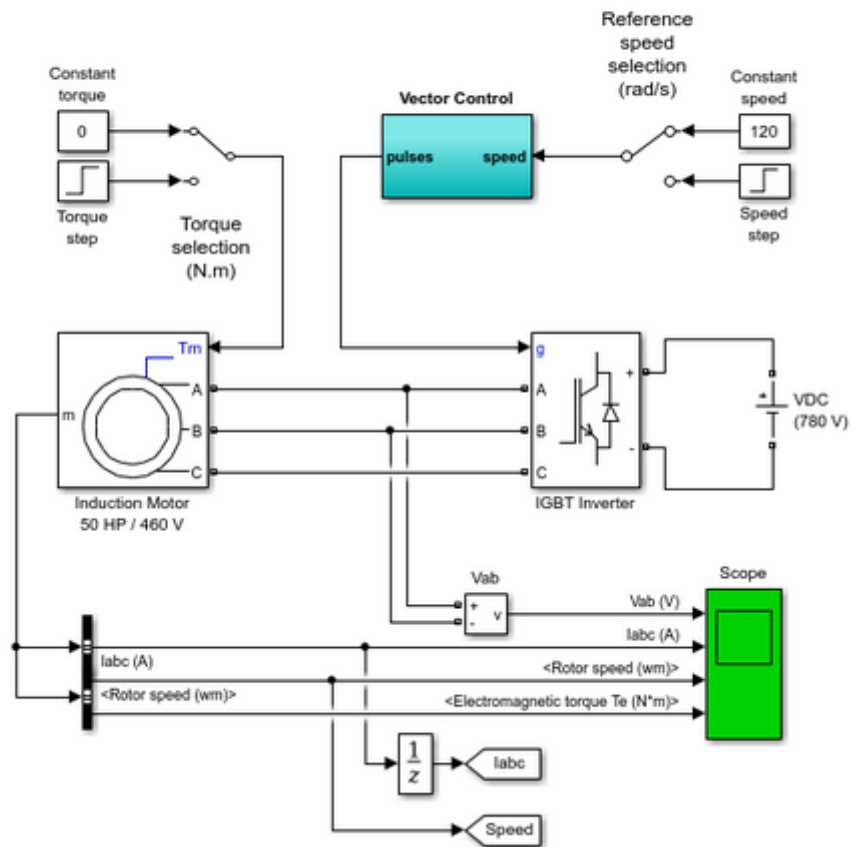
**Figure 14.5-3** Block diagram for the rotor flux calculation.

# Simulasi MATLAB

## Vector Control of AC Motor Drive

This example shows how to model a variable-frequency induction motor drive.

H. Le-Huy (Universite Laval, Quebec)



# Reference

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- Wildi, Theodore. *Electrical Machines, Drives, and Power Systems*. Prentice Hall: 2002.