DC MOTOR

Introduction

- Aplikasi DC motor: kipas, pompa, otomotif
- Aplikasi konstan torsi dan variabel torsi
- 3 tipe motor DC:
  - 1)shunt
  - 2)series
  - 3) compound

Counter Electromotive Force(cemf)

- Ketika armature dihubungkan sumber tegangan, maka arus akan mengalir dicoilnya.
- Arus di coil yg berada dalam medan magnet akan menimbulkan gaya gerak, Gaya Lorens
- Disisi lain, coil yg bergerak di medan magnat akan timbul ggl induksi, Hukum Faraday
- Sehingga timbul counter electromotive force: Es - Eo

$$E_o = Zn\Phi/60$$

E_o = voltage between the brushes [V]
Z = total number of conductors on the armature
n = speed of rotation [r/min]
Φ = flux per pole [Wb]

Counter Electromotive Force(cemf)

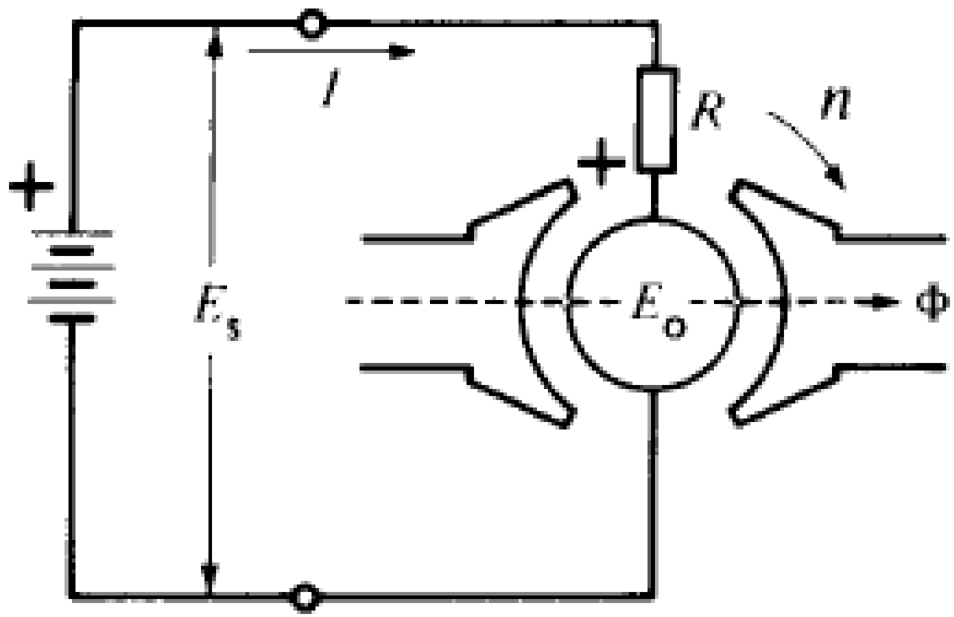


Figure 5.2
Counter-electromotive force (cemf) in a dc motor.

Speed

- Karena IR drop nilainya kecil, maka Eo $\approx$ Es

$$E_o = Zn\Phi/60$$

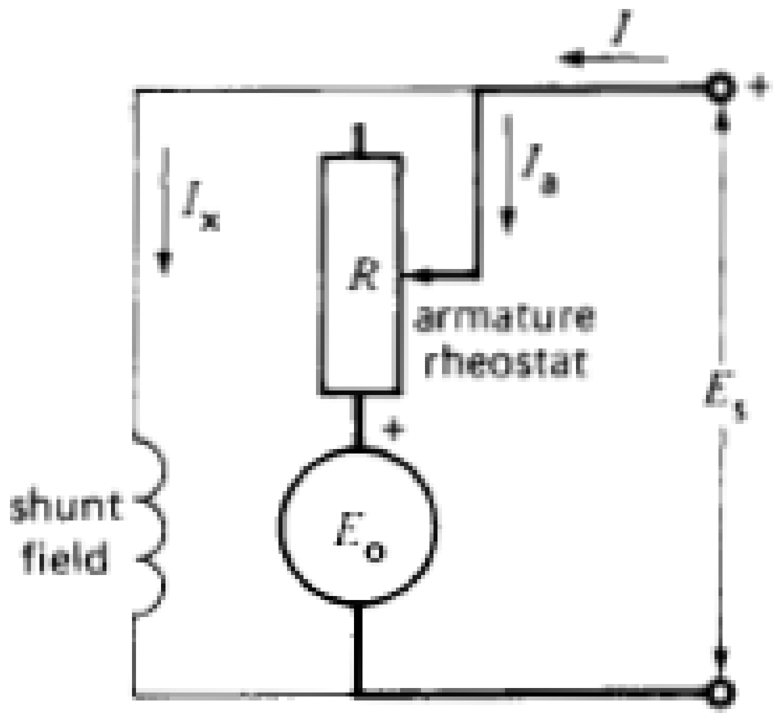
$$E_s = Zn\Phi/60$$

$$n = \frac{60E_s}{Z\Phi} \text{ (approx)}$$

n = speed of rotation [r/min]
E_s = armature voltage [V]
Z = total number of armature conductors

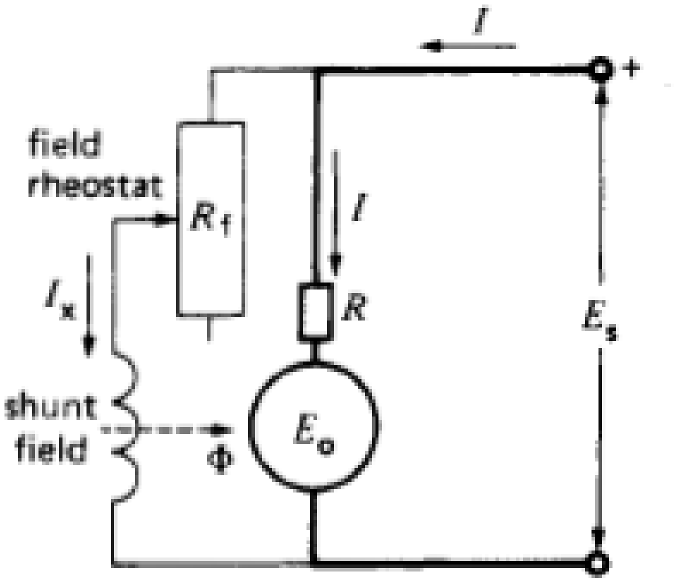
Rheostat Speed Control

- Efisiensi kecil karena drop daya terbuang menjadi panas
- Tidak disarankan untuk motor yg besar
- Untuk pengaturan speed dibawah base speed



Field Speed Control

- Variasi speed dengan variasi flux medan magnet
- Dipakai untuk control speed diatas base speed
- Jika flux naik, speed turun dan sebaliknya



Reversing the direction of rotation

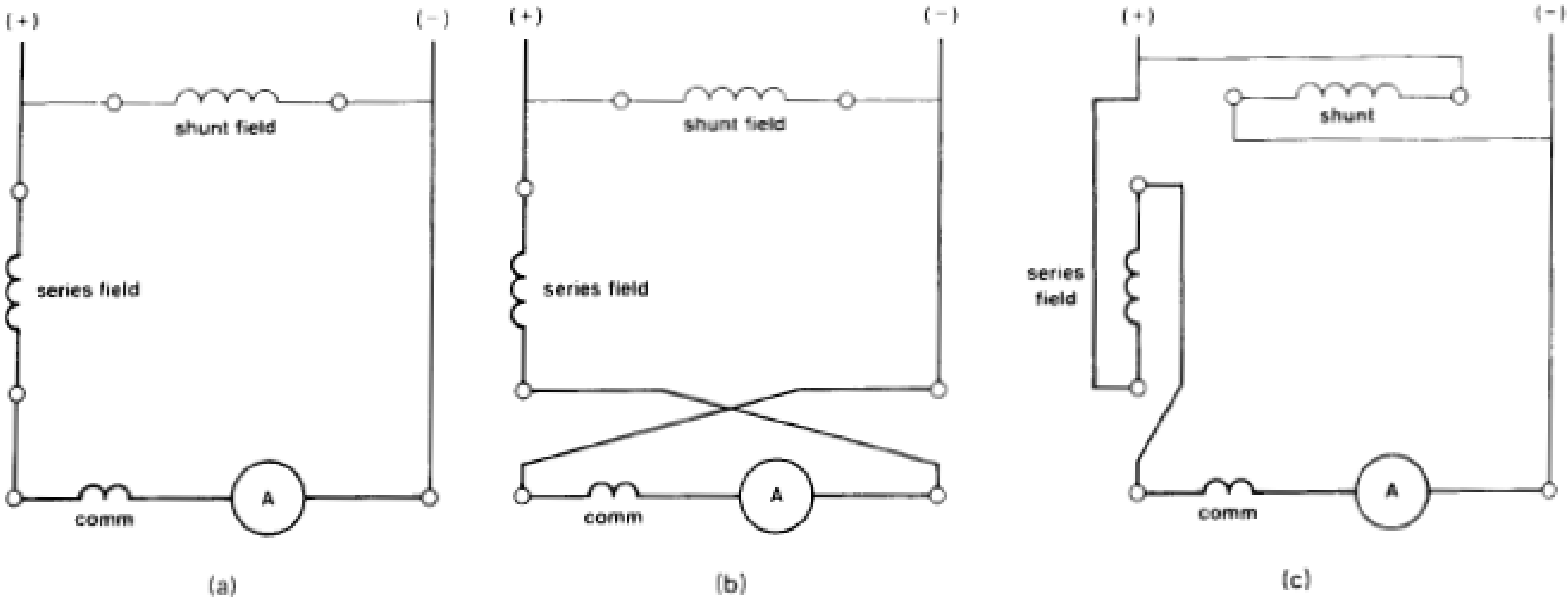


Figure 5.15

a. Original connections of a compound motor.
b. Reversing the armature connections to reverse the direction of rotation.
c. Reversing the field connections to reverse the direction of rotation.

Starting the motor

- Ketika kita langsung menghubungkan sumber tegangan pada dc motor maka arus akan sangat tinggi, dan ini berbahaya
- Perlu adanya limiter untuk membatasi arus, biasanya nilainya 1.5 – 2 kali arus full load
- Salah satu solusinya dengan menambahkan rheostat secara seri. Ketika motor sudah start, untuk menaikkan speed dengan cara menurunkan resistansi rheostat

Stopping a motor

- Ketika sumber tegangan diputus, motor masih berputar karena sisa inersianya
- Agar motor segera berhenti diperlukan metode pengereman

  1) Mechanical brake

     Dengan friction seperti pada mobil

  2) Electromechanical brake

     dynamic braking, plugging

- Dynamical braking

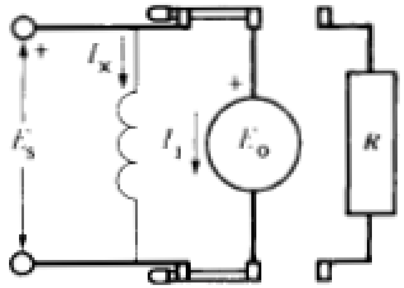


Figure 5.17a
Armature connected to a dc source E_s.

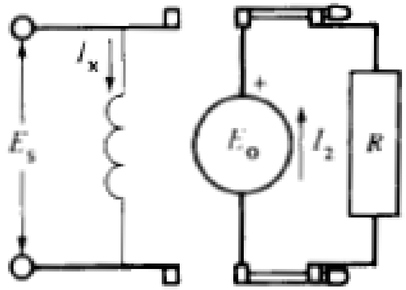


Figure 5.17c
Dynamic braking.

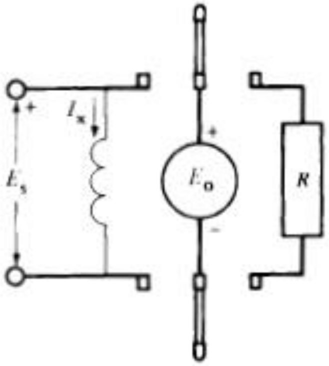


Figure 5.17b
Armature on open circuit generating a voltage E_o.

- Plungging dilakukan dengan membalik arus armature dengan cara membalik koneksi pada terminal motor
- Berbahaya karena dapat menimbulkan arus balik sebesar 50x full load
- Digabung dengan dynamic brake dengan menambahkan resistor untuk membatasi arus balik
- Ketika motor berhenti, tegangan terminal harus diputus agar motor tidak berputar berbalik arah

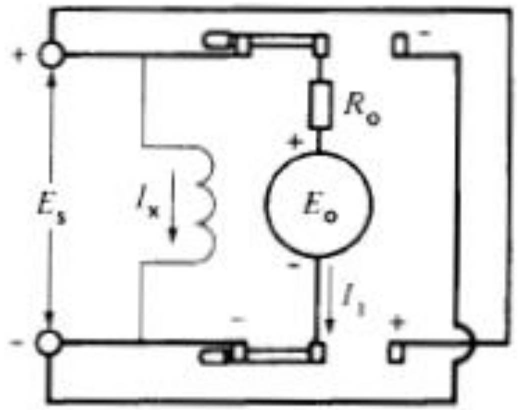


Figure 5.19a
Armature connected to dc source E_s.

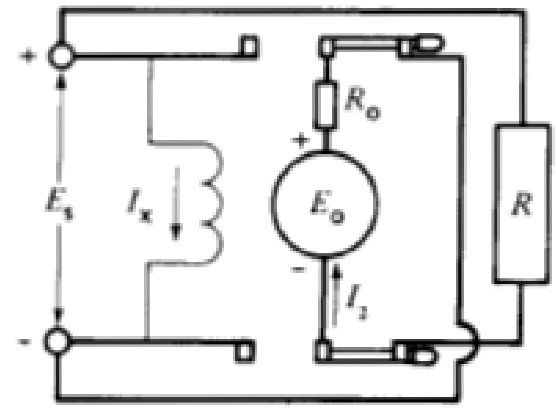


Figure 5.19b
Plugging.

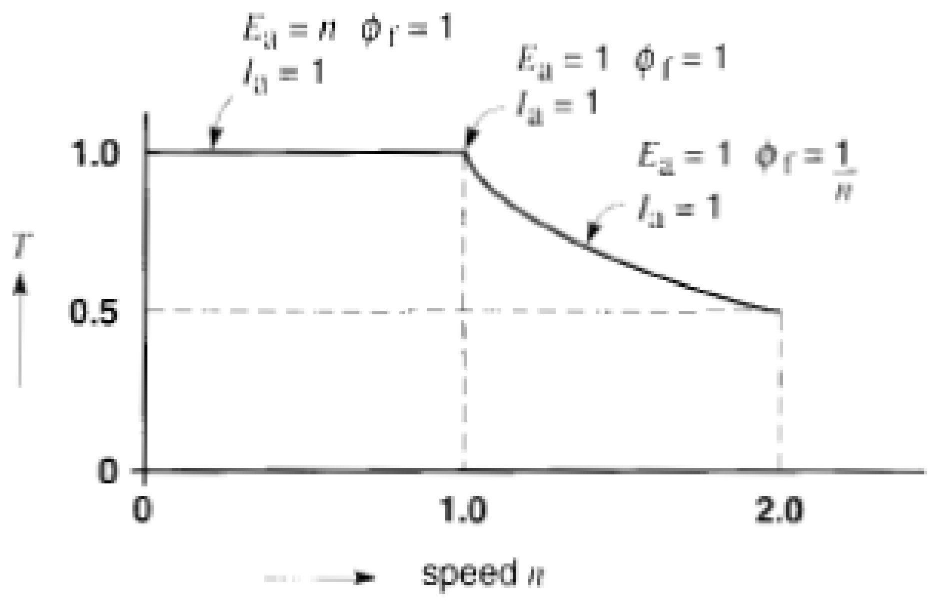
- Plugging lebih cepat menghentikan motor tetapi sistemnya kompleks
- Dynamical braking lebih banyak dipakai

Variable Speed Control

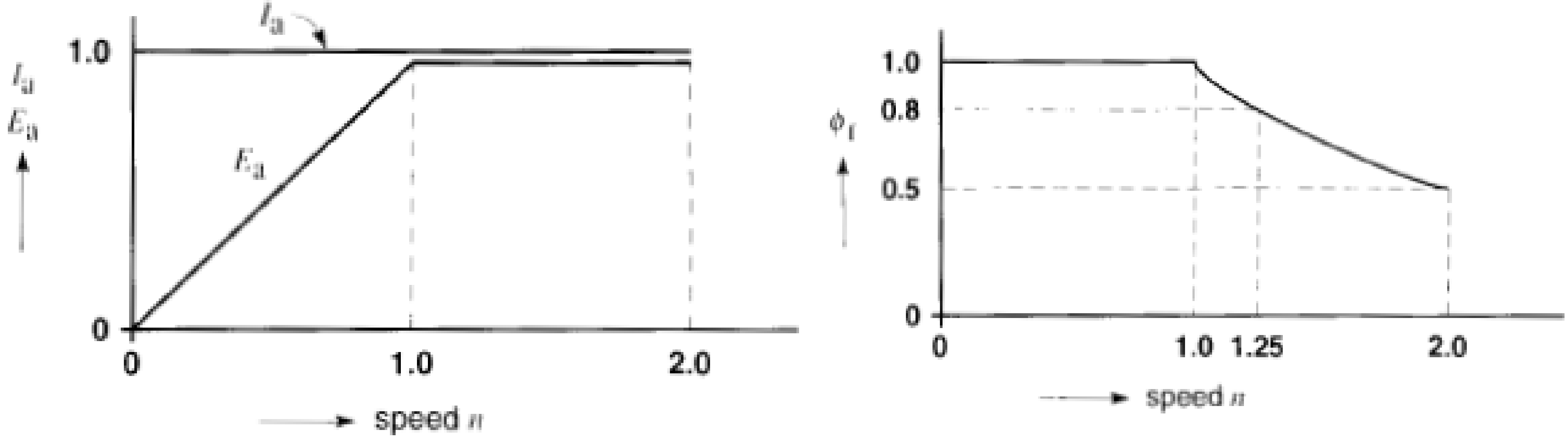
- Output utama dari motor DC yg dapat dimanfaatkan adalah speed dan torsi
- Constant torque, constant power

$$T = \Phi_f I_a$$

$$E_a = n \Phi_f$$



- Voltage and flux pada constant torque dan constant power



Permanent Magnet Motor

- Field coil diganti dengan magnet permanen, dimensi motor dapat lebih kecil, efisiensi meningkat karena tidak ada loses panas di field coil
- Air gap dapat dibuat lebih besar dan armature reaction dapat dihindari
- Kelemahan:
  - Harga permanen magnet mahal
  - Tidak bisa kontrol field weakening

Detail DC Motor Control

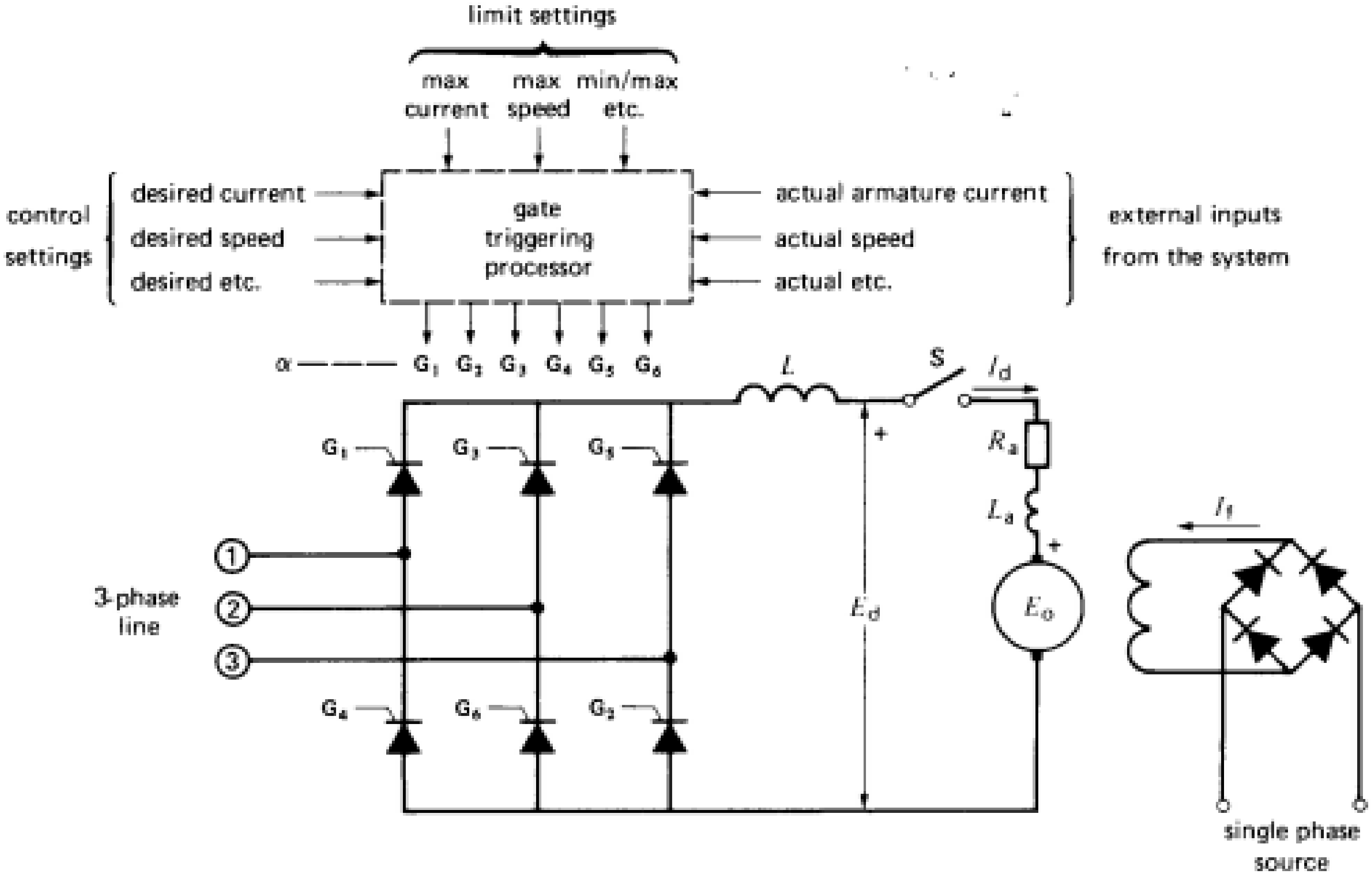
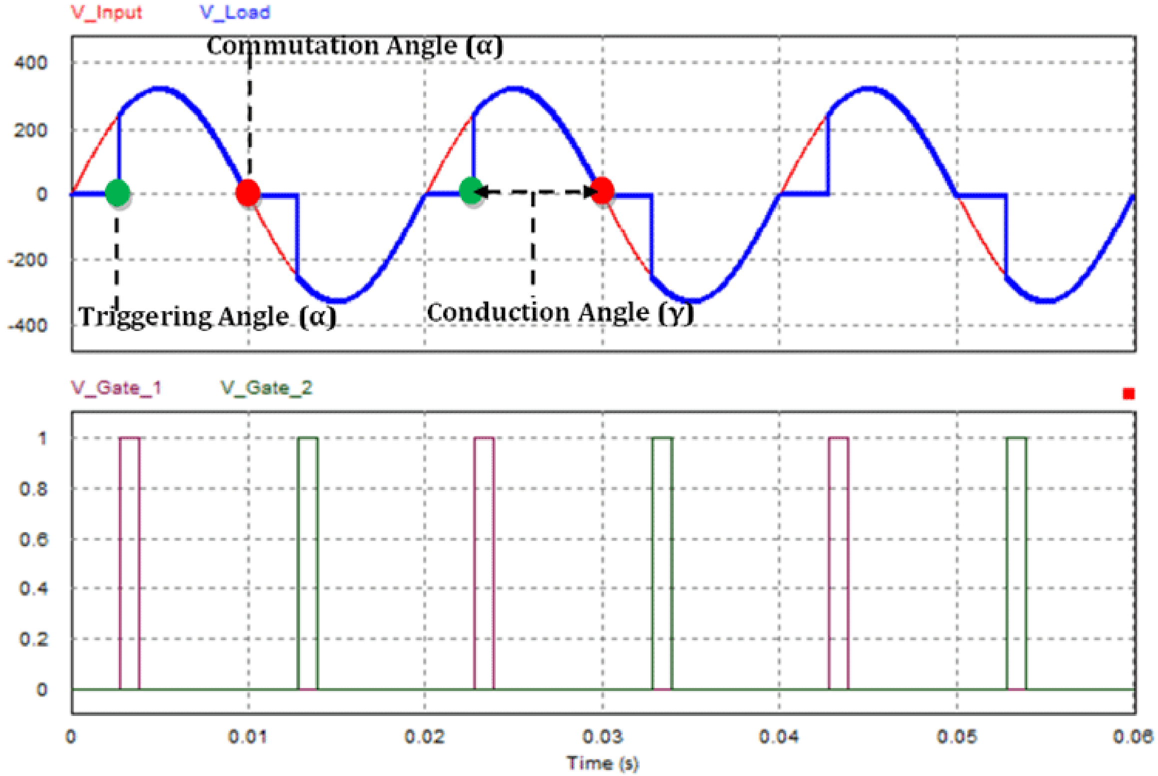


Figure 22.1
Armature torque and speed control of a dc motor using a thyristor converter.

- To control the speed of the DC motor, the firing angle of thyristor is controlled

- At the full speed, the firing angle is 15 and 20, to stop the motor, the firing angle is 90



$$E_d = 1.35\, E \cos \alpha$$

Example 22-1

A 750 hp, 250 V, 1200 r/min dc motor is connected to a 208 V, 3-phase, 60 Hz line using a 3-phase bridge converter (Fig. 22.2a). The full-load armature current is 2500 A and the armature resistance is 4 mΩ.

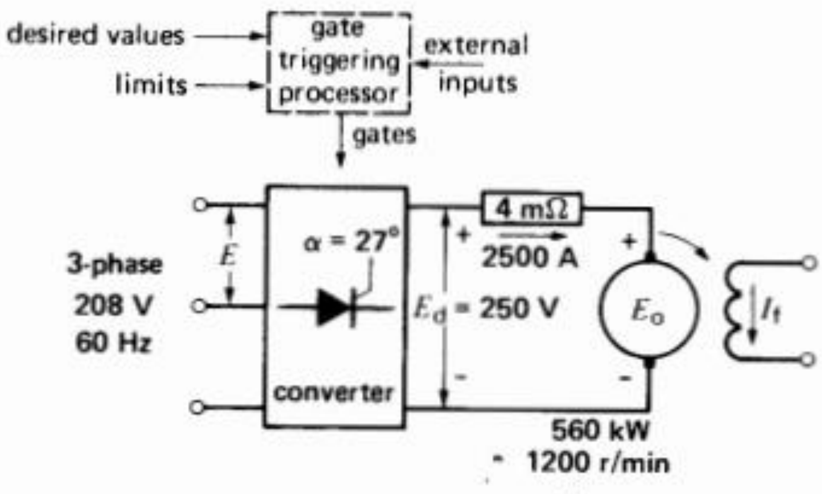


Figure 22.2a
See Example 22-1.

Calculate

a. The required firing angle α under rated full-load conditions

b. The firing angle required so that the motor develops its rated torque at 400 r/min

Solution

a. At full-load the converter must develop a dc output of 250 V:

$$E_d = 1.35\, E \cos\alpha \qquad (21.14)$$

$$250 = 1.35 \times 208 \cos\alpha$$

$$\cos\alpha = 0.89$$

$$\alpha = 27°$$

Armature *IR* drop at rated current:

$$IR = 2500\text{ A} \times 0.004\ \Omega = 10\text{ V}$$

Counter-emf (cemf) at 1200 r/min:

$$E_0 = 250 - 10 = 240\text{ V}$$

b. To develop rated torque at 400 r/min, the armature current must still be 2500 A. The cemf at 400 r/min is

$$E_0 = (400/1200) \times 240 = 80\ \text{V}$$

Armature *IR* drop = 10 V
Armature terminal voltage is

$$E_d = 80 + 10 = 90\ \text{V}$$

The converter must, therefore, generate 90 V. To determine the firing angle, we have

$$E_d = 1.35\, E \cos\alpha \qquad (21.14)$$

$$90 = 1.35 \times 208 \cos\alpha$$

$$\alpha = 71^\circ \text{ (see Fig. 22.2b)}$$

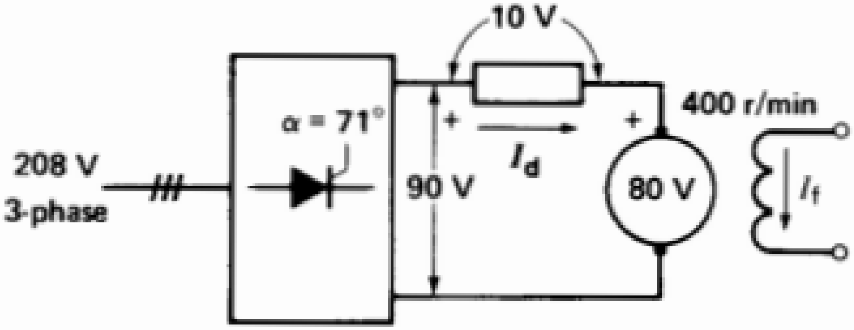


Figure 22.2b
Rated torque at 400 r/min.

Two-quadrant control - reverse

- Two quadrant control: Motor – Generator
- Ketika pengereman, supply diputus maka motor lama-kelamaan akan diam. Untuk mempercepat motor berhenti harus ada mekanisme pengereman
- Electric braking: rheostatic braking & regenerative braking
- Rheostatic braking: energi hasil pengeremen dibuang menjadi panas di kapasitor
- Regenerative braking: energi hasil pengereman disalurkan Kembali/ dimanfaatkan

Two-quadrant: reverse field

To make the converter act as an inverter, the polarity of E_d must be reversed, as shown in Fig. 22.3. This means we must also reverse the polarity of E_0. Finally, E_d must be adjusted to be slightly less than E_0, to obtain the desired braking current I_d (Fig. 22.3).

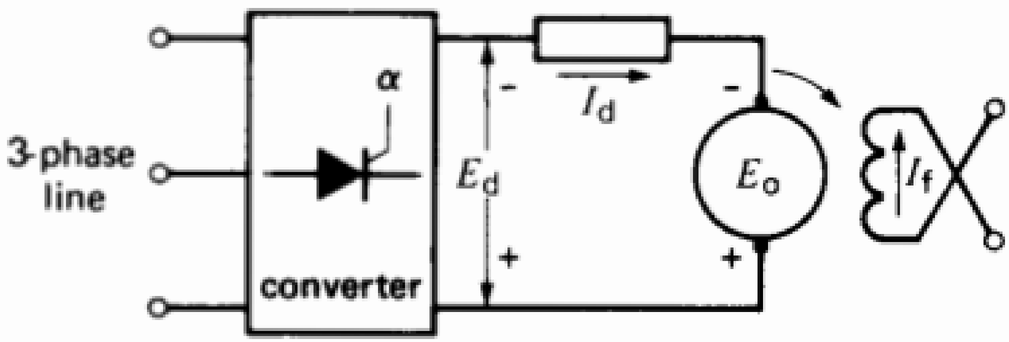


Figure 22.3
Motor control by field reversal.

- Untuk mengubah polaritas Eo, perlu reverse koneksi jangkar atau medan
- Ilustrasi berikut utk reverse medan
- Ketika kecepatan pelan, koneksi reverse harus dikembalikan seperti semula

Two-quadrant: reverse armature

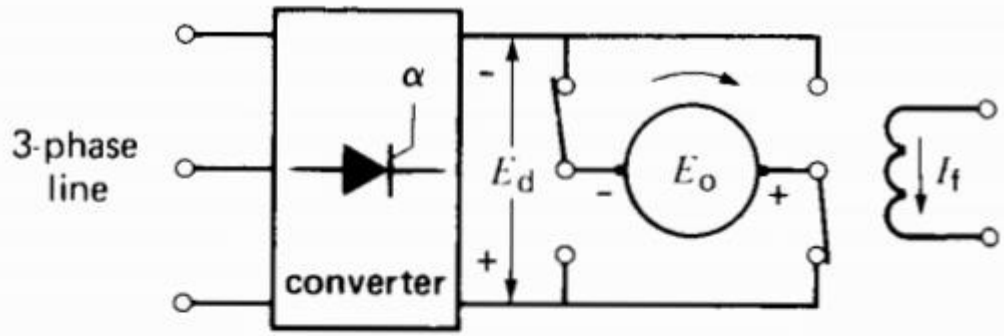


Figure 22.4
Motor control by armature reversal.

- Reverse armature/jangkar
- Reaksi lebih cepat, tapi switch harus mampu menahan arus hingga ribuan ampere
- Memerlukan high speed switch

Two-quadrant: two converter

- Converter 1: sbg motor driver
- Converter 2: sbg inverter untuk pengereman shg tidak perlu ganti koneksi seperti pada reverse field/ armature
- Complex dan mahal

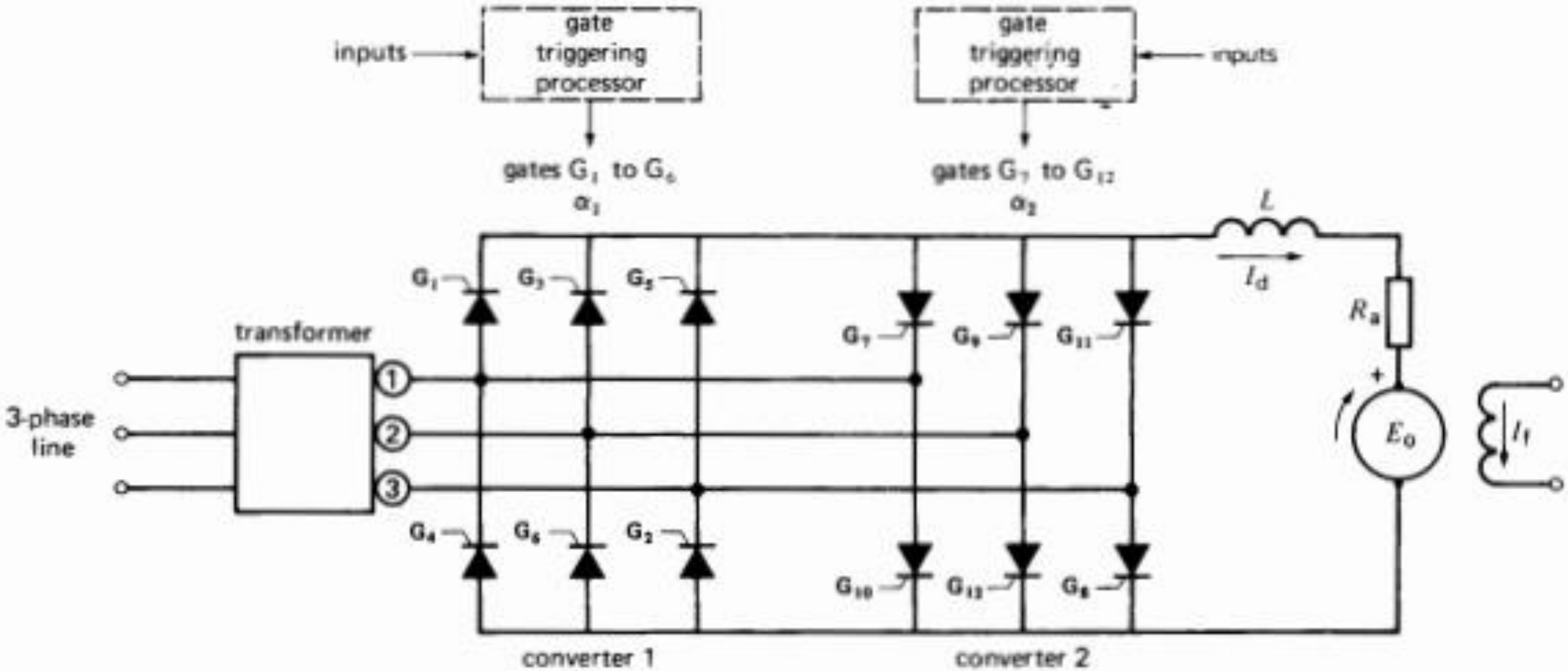


Figure 22.5
Two-quadrant control using two converters without circulating currents.

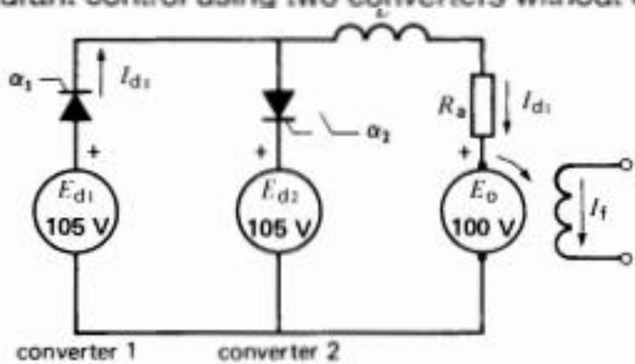


Figure 22.6a
Converter 1 in operation; converter 2 blocked.

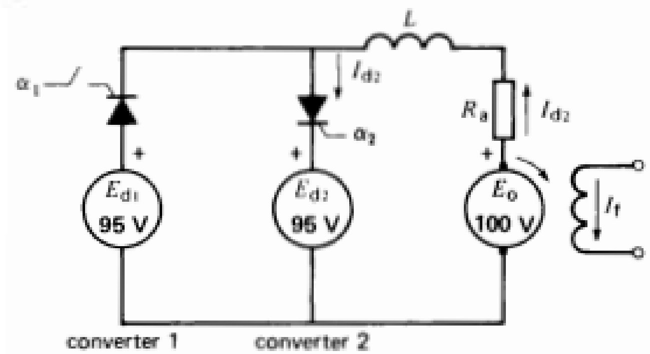


Figure 22.6b
Converter 2 in operation; converter 1 blocked.

Four-quadrant control

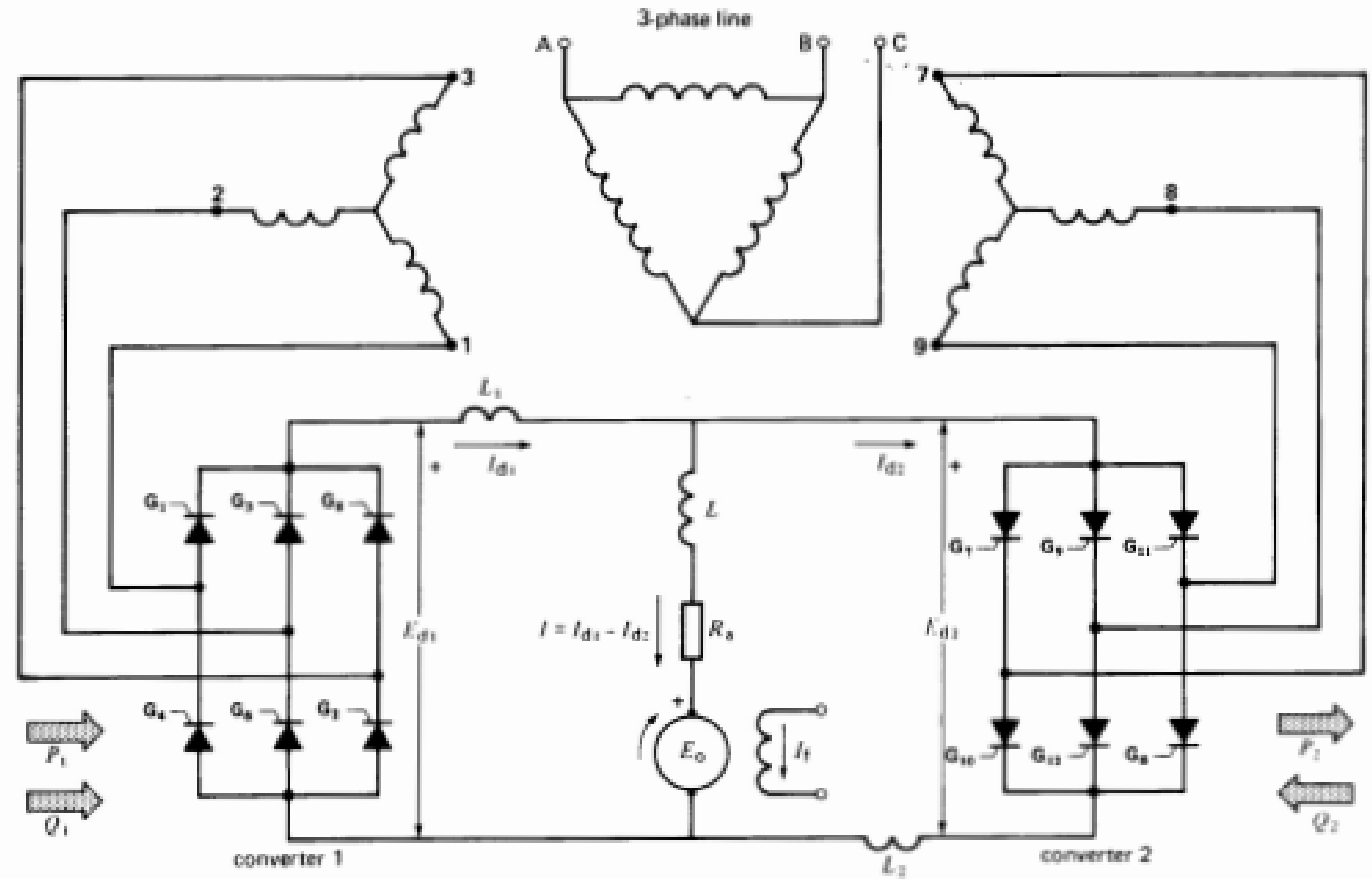


Figure 22.8
Two-quadrant control of a dc motor using two converters with circulating currents.

Contoh Soal

Example 22-3

The dc motor in Fig. 22.8 has an armature voltage of 450 V while drawing a current of 1500 A. Converter 1 delivers a current I_{d1} of 1800 A, and converter 2 absorbs 300 A. If the ac line voltage for each converter is 360 V, calculate the following:

a. The dc power associated with converters 1 and 2
b. The active power drawn from the incoming 3-phase line
c. The firing angles for converters 1 and 2
d. The reactive power drawn from the incoming 3-phase line

Solution

a. The dc power delivered by converter 1 is

$$P_1 = E_{d1} I_{d1}$$
$$= 450 \times 1800$$
$$= 810 \text{ kW}$$

The power absorbed by converter 2 (operating as an inverter) is

$$P_2 = E_{d2} I_{d2}$$
$$= 450 \times 300$$
$$= 135 \text{ kW}$$

b. The active power drawn from the incoming ac line is

$$P = P_1 - P_2$$
$$= 810 - 135$$
$$= 675 \text{ kW}$$

Secondary winding 1, 2, 3 delivers 810 kW while secondary winding 7, 8, 9 receives 135 kW. It follows that the net active power drawn from the line (neglecting losses) is 675 kW.

c. The approximate firing angle for converter 1 can be found from Eq. 21.13:

$$E_{d1} = 1.35\, E \cos \alpha_1$$
$$450 = 1.35 \times 360 \cos \alpha_1$$
$$\cos \alpha_1 = 0.926$$
$$\alpha_1 = 22.2°$$

Because E_{d2} is nearly equal to E_{d1}, the firing angle for converter 2 is found to have the same approximate value. However, because it operates as an inverter, the angle is

$$\alpha_2 = 180 - \alpha_1$$
$$= 180 - 22.2$$
$$= 157.8°$$

d. The reactive power drawn by converter 1 is

$$Q_1 = P_1 \tan \alpha_1$$
$$= 810 \tan 22.2^\circ$$
$$= 331 \text{ kvar}$$

The reactive power drawn by converter 2 is

$$Q_2 = P_2 \tan \alpha_2$$
$$= -135 \tan 157.8^\circ$$
$$= 55 \text{ kvar}$$

Consequently, the reactive power drawn from the incoming 3-phase line is

$$Q = Q_1 + Q_2$$
$$= 331 + 55$$
$$= 386 \text{ kvar}$$

It is interesting to note that whereas the active powers subtract ($P = P_1 - P_2$), the reactive powers add: ($Q = Q_1 + Q_2$). The reason is that a line-commutated converter always absorbs reactive power, whether it functions as a rectifier or inverter.

- Coba baca dan pahami contoh soal berikut