Electrical Drives

Lecture 10 (30-01-2024)

Rijil Ramchand

CONVERTERS IN ELECTRIC DRIVE SYSTEMS using DC Motors

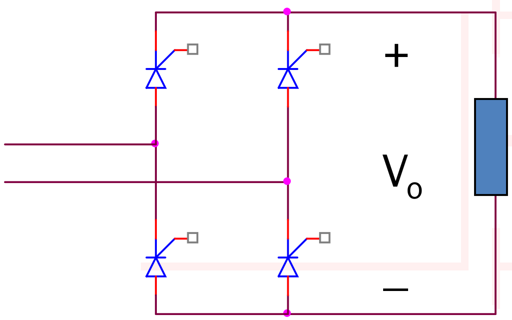
AC-DC controlled rectifier
- approximate model
- SIMULINK examples
  - open-loop
  - closed-loop

Switch Mode DC-DC converter
- 2-Q and 4-Q converters
  - Small signal modeling
    - unipolar
    - bipolar
- SIMULINK example

Courtesy: Dr. Nik Rumzi Nik Idris, Dept. of Energy Conversion, UTM

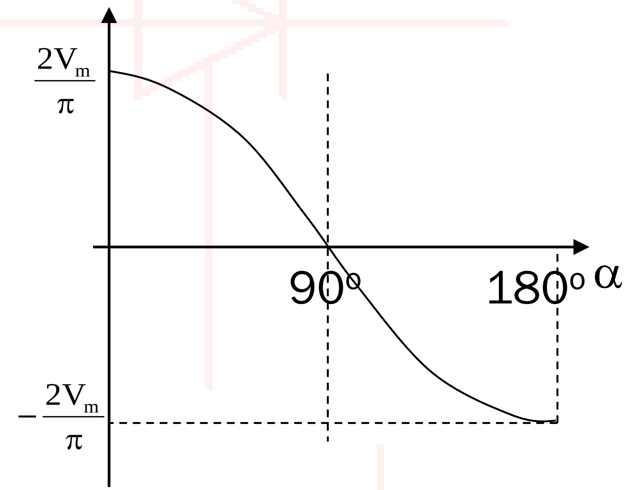
AC-DC controlled rectifier

50Hz
1-phase

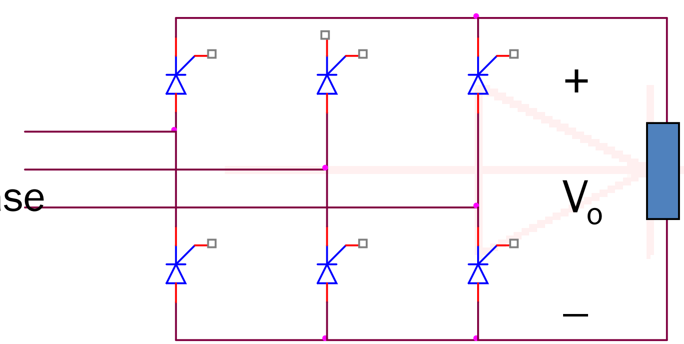


$$V_o = \frac{2V_m}{\pi}\cos\alpha$$

Average voltage over 10ms

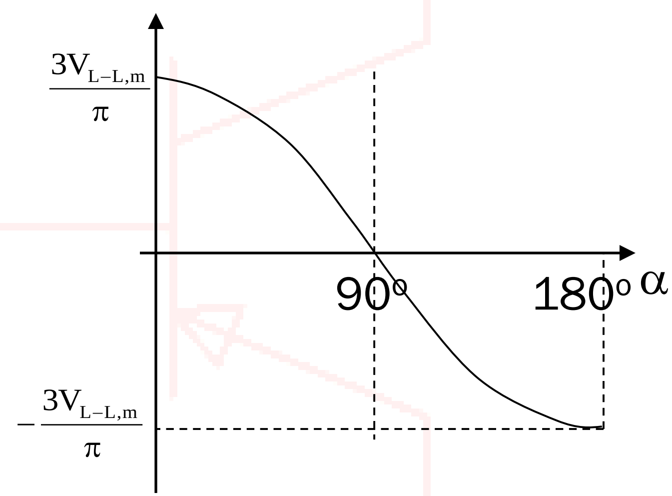


50Hz
3-phase



$$V_o = \frac{3V_{L-L,m}}{\pi}\cos\alpha$$

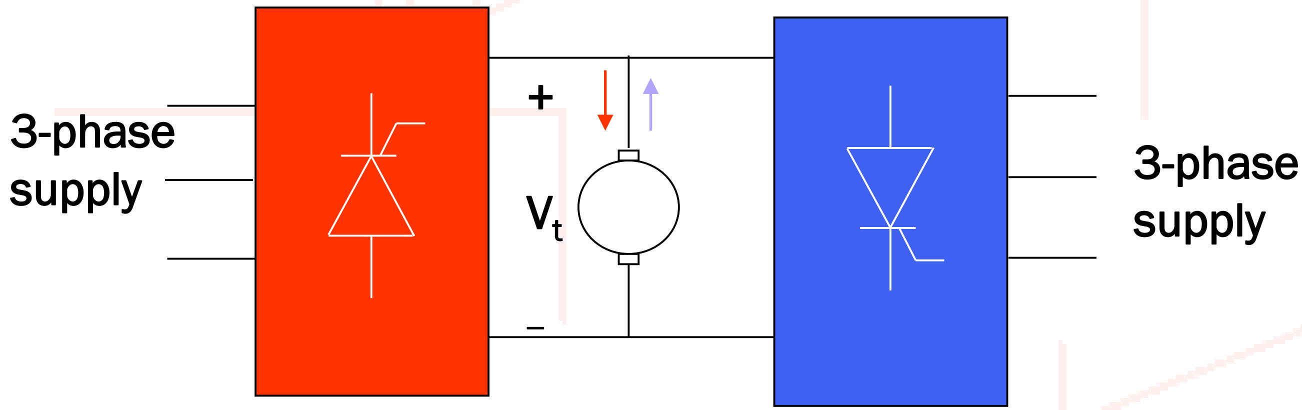
Average voltage over 3.33 ms



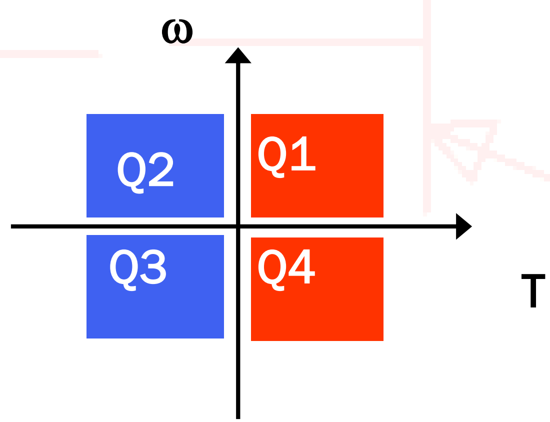
For steady state continuous current flow

AC-DC controlled rectifier

Dual Converter – 4Q operation



(i) Non-simultaneous operation
(ii) Simultaneous operation



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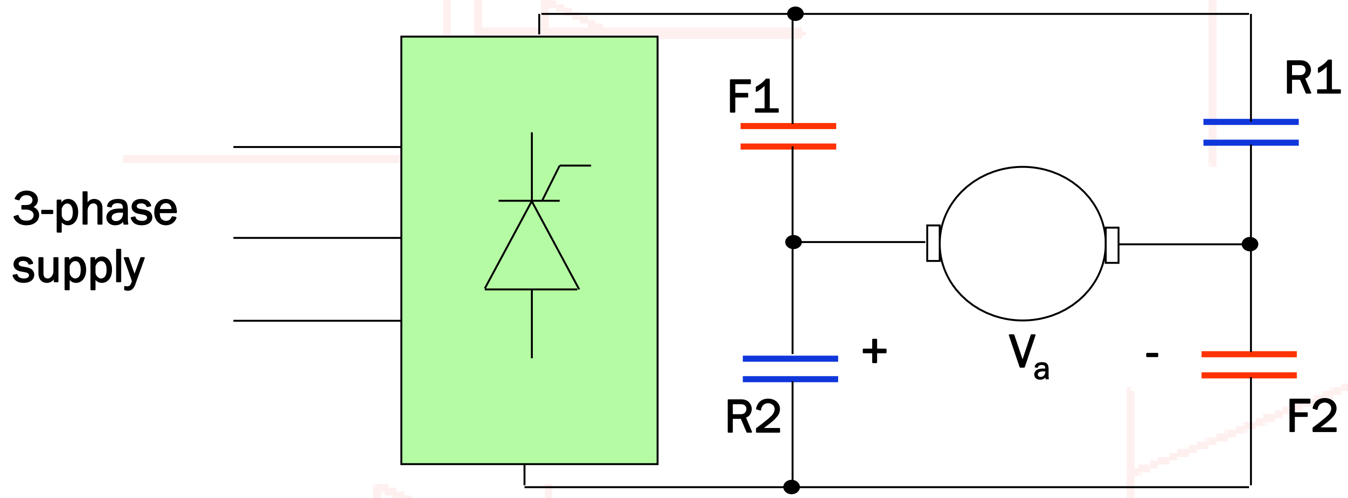
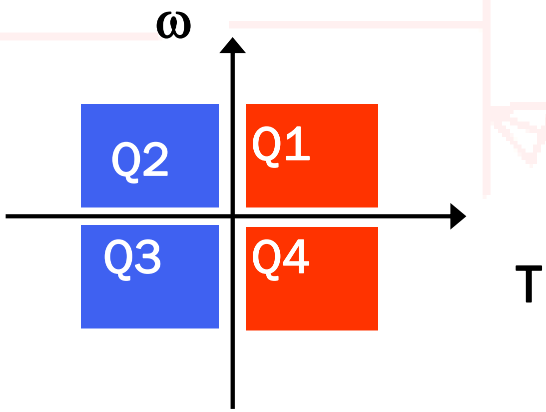
AC-DC controlled rectifier

Single Converter – 4Q operation



(i) F1 and F2 → quadrants 1 and 4
(ii) R1 and R2 → quadrants 2 and 3



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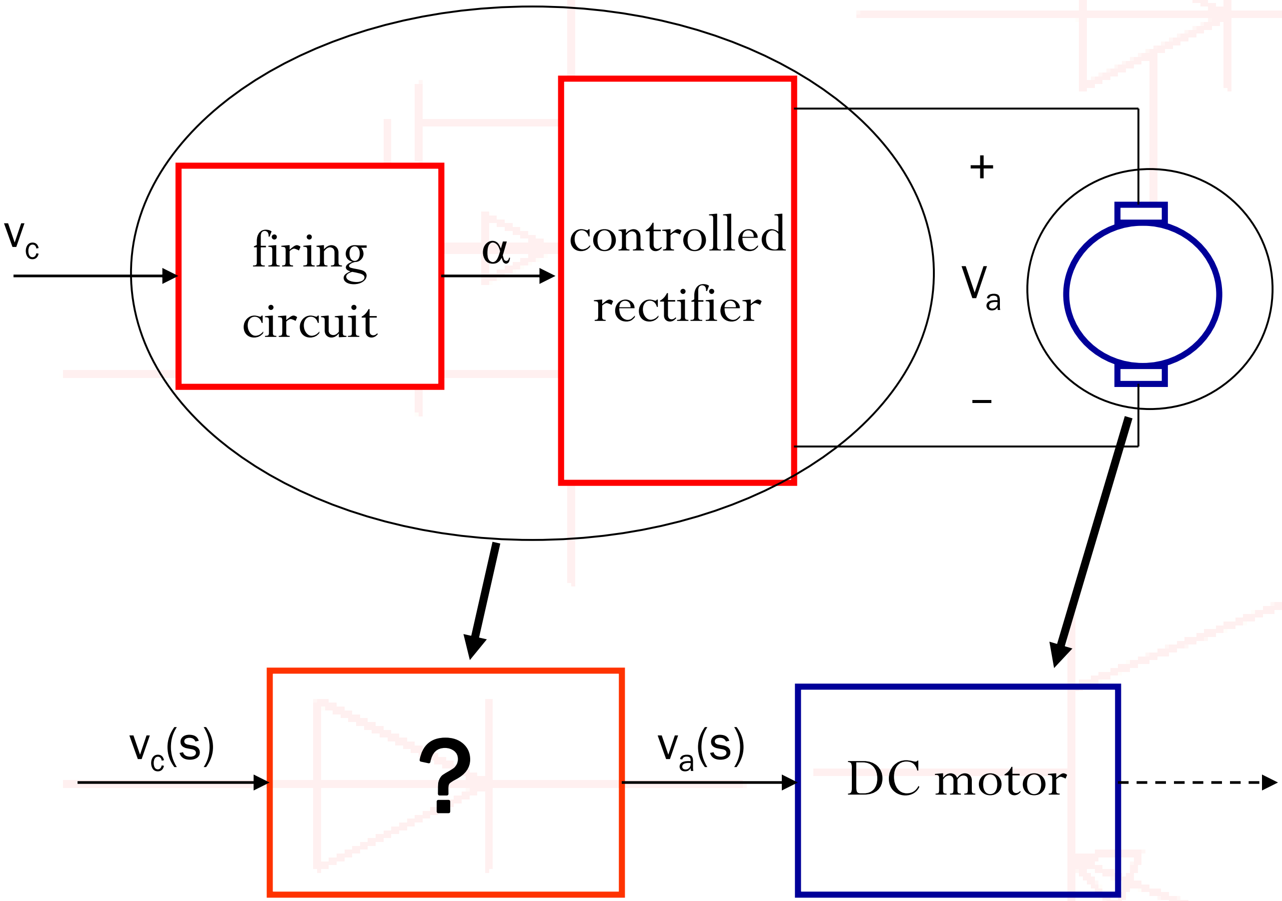
AC-DC controlled rectifier



The relation between v_c and v_a is determined by the **firing circuit**

It is desirable to have a **linear** relation between v_c and v_a

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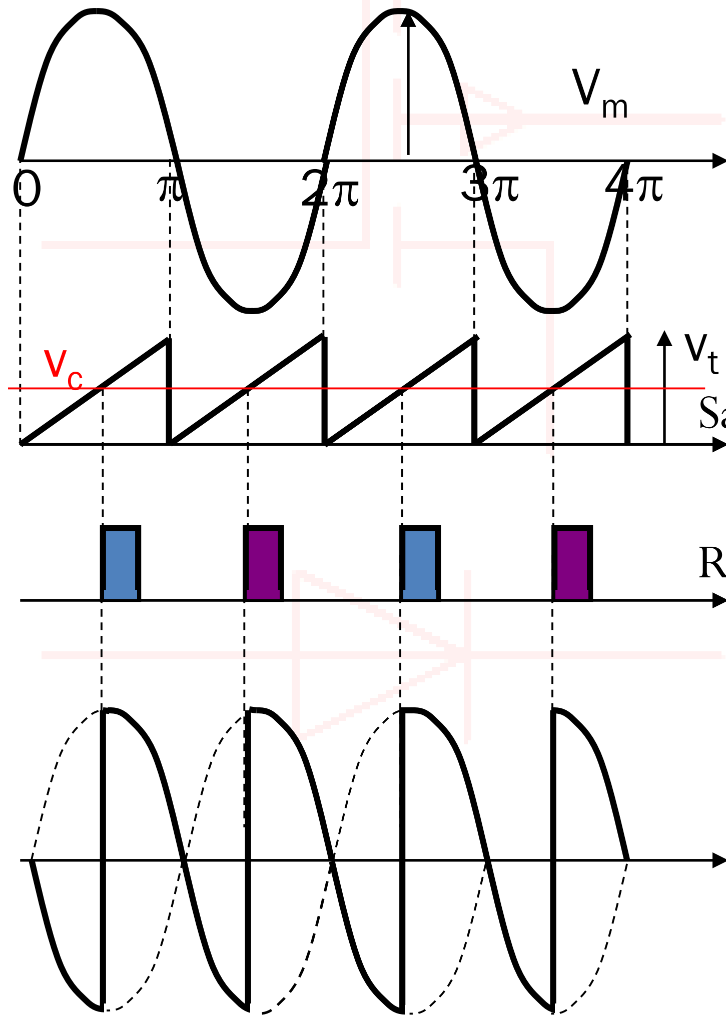
AC-DC controlled rectifier

linear firing angle control



Input voltage

Sawtooth compared with control signal

Results of comparison to trigger SCRs

Output voltage

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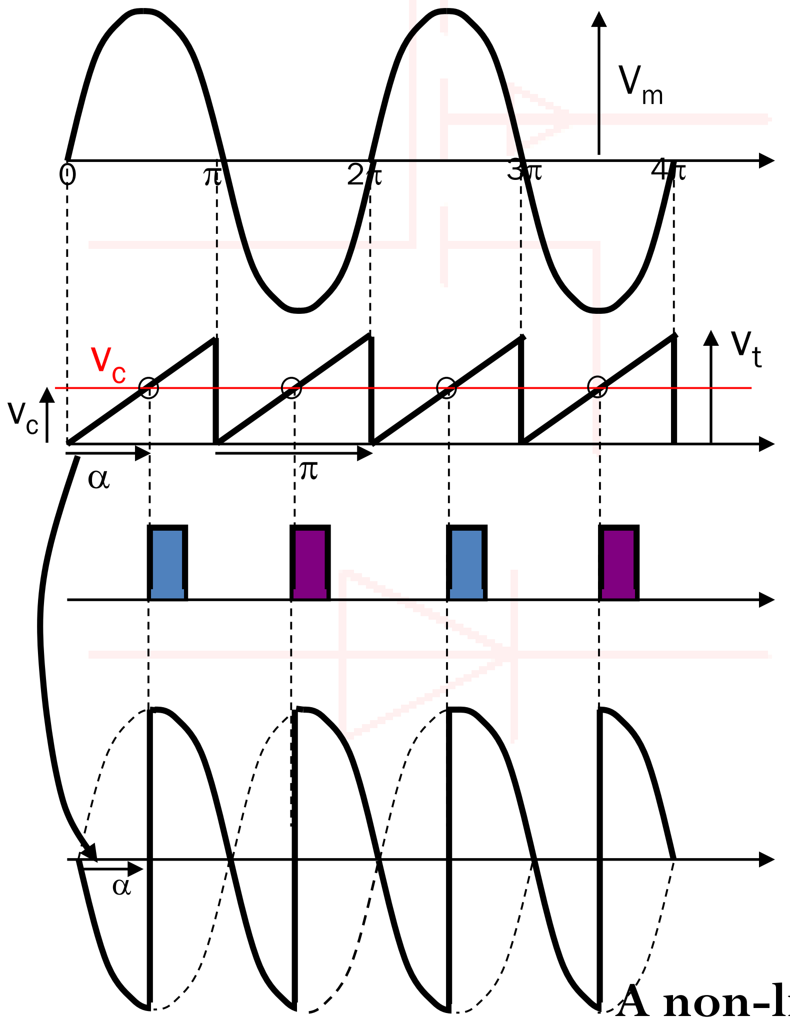
AC-DC controlled rectifier

linear firing angle control



$$\frac{V_t}{\pi} = \frac{V_c}{\alpha}$$

$$\alpha = \frac{V_c}{V_t}\pi$$

$$V_a = \frac{2V_m}{\pi}\cos\left(\frac{V_c}{V_t}\pi\right)$$

A non-linear relation between V_a and v_c

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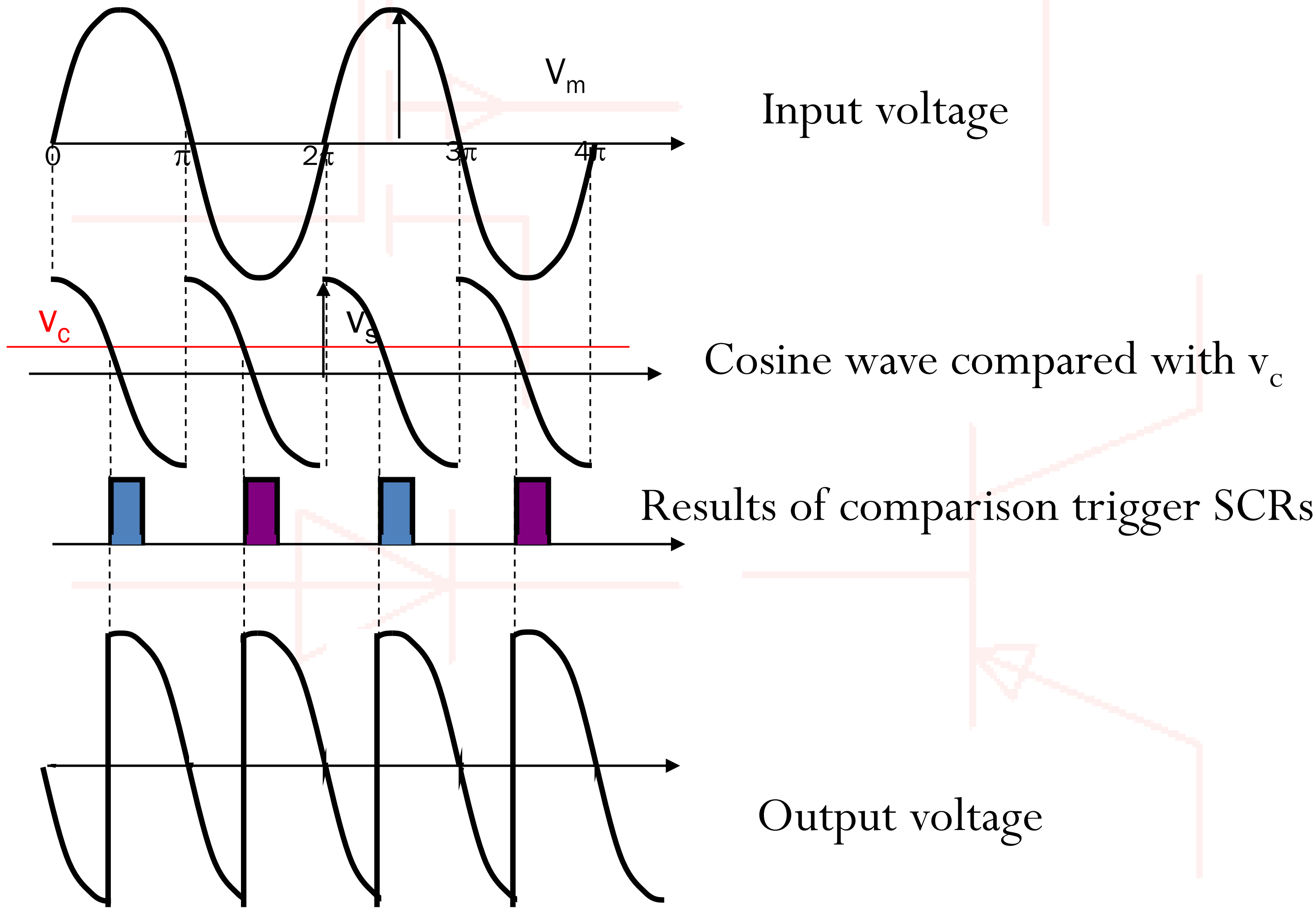
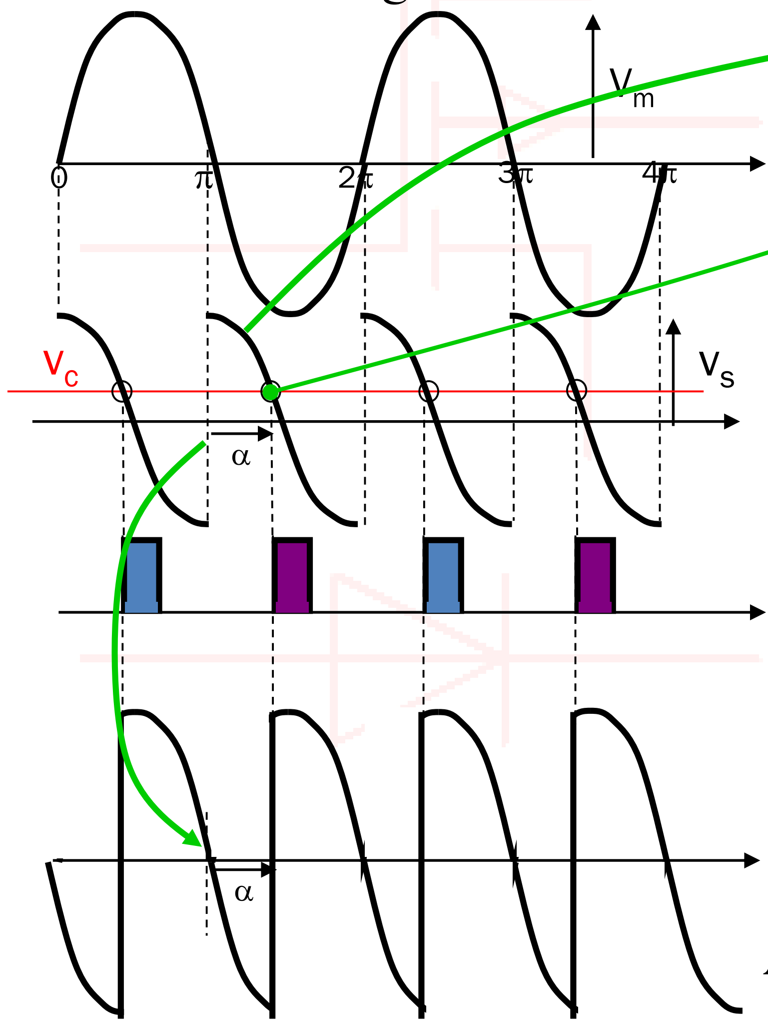
AC-DC controlled rectifier

Cosine-wave crossing control



AC-DC controlled rectifier

Cosine-wave crossing control



$$V_s\cos(\omega t) = v_c$$

$$\alpha = \cos^{-1}\left(\frac{v_c}{V_s}\right)$$

$$V_a = \frac{2V_m}{\pi}\cos\left(\cos^{-1}\left(\frac{v_c}{V_s}\right)\right)$$

A linear relation between v_c and V_a

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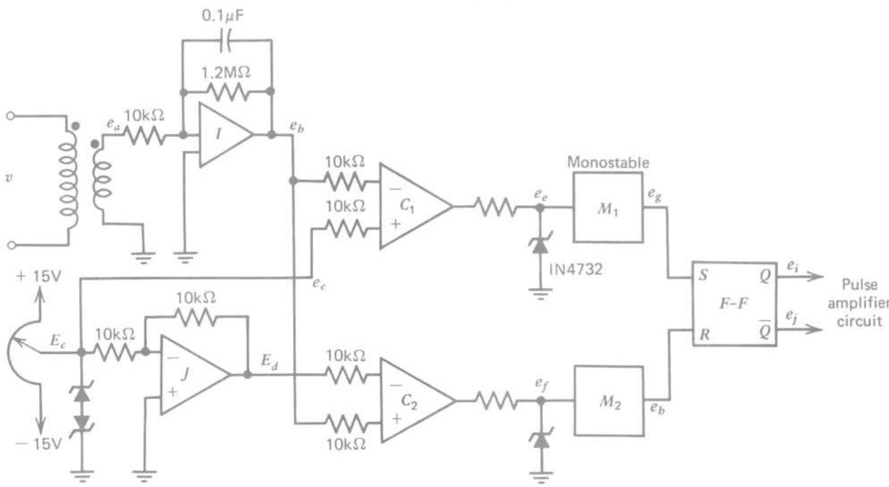
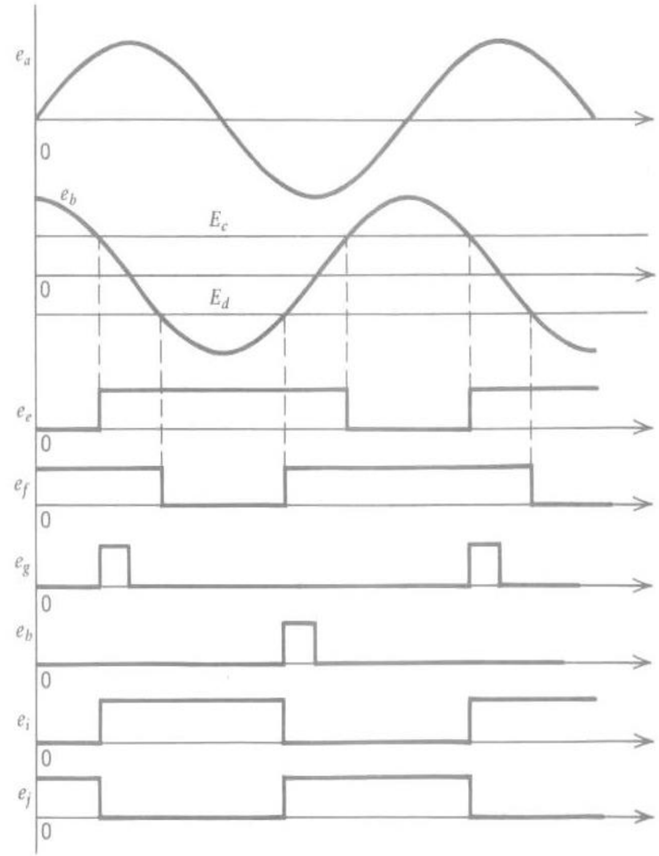
AC-DC controlled rectifier

e.g. cosine wave crossing control





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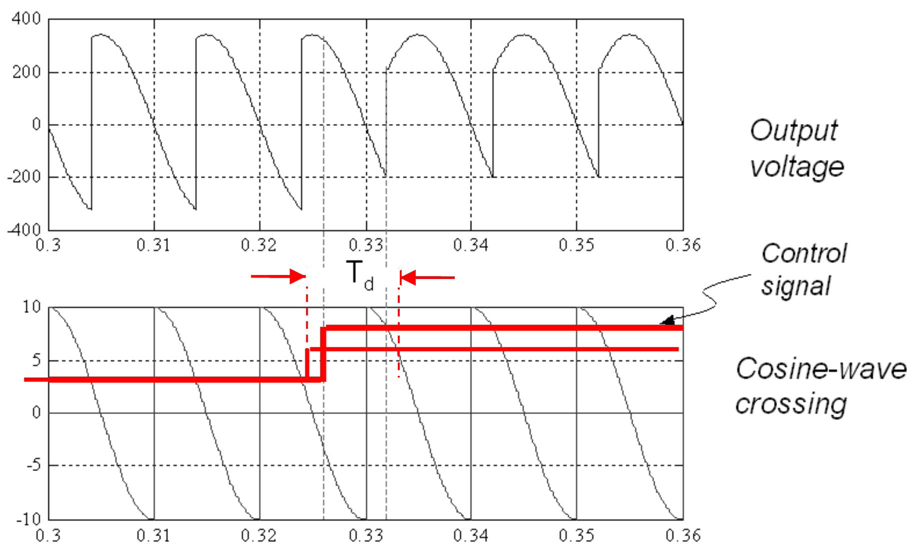
Control model

V_a is the average voltage over one period of the waveform
- sampled data system

Delays depending on when the control signal changes – normally taken as half of sampling period



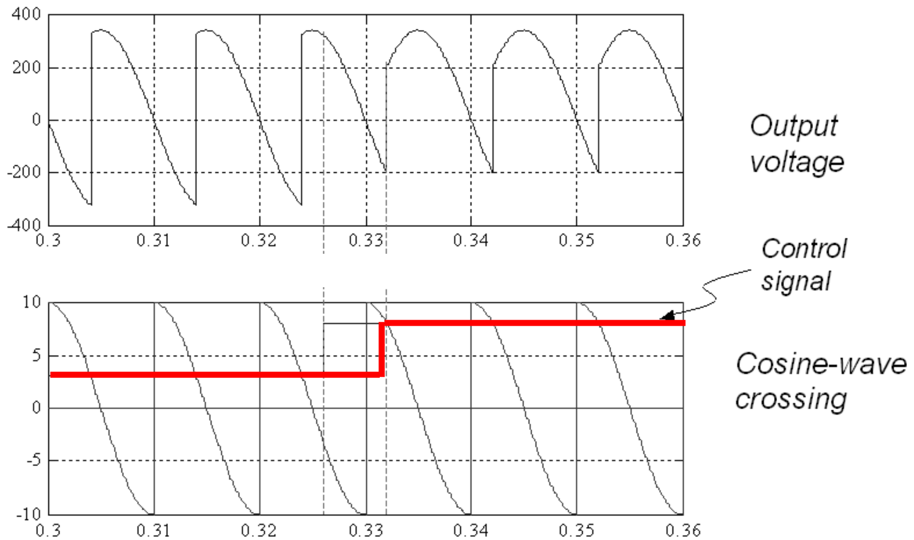
T_d – Delay in average output voltage generation
0 – 10 ms for 50 Hz single phase system

AC-DC controlled rectifier
Control model

V_a is the average voltage over one period of the waveform

- sampled data system

Delays depending on when the control signal changes – normally taken as half of sampling period



T_d – Delay in average output voltage generation
0 – 10 ms for 50 Hz single phase system

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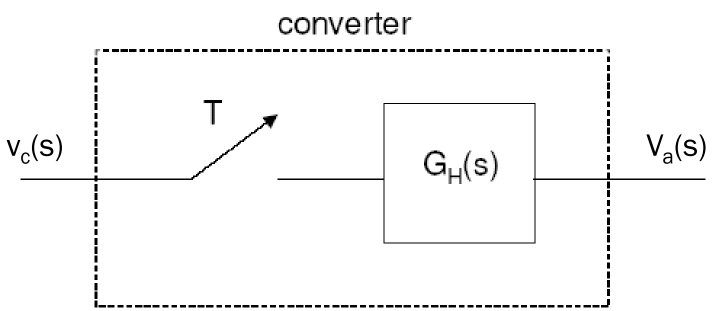
AC-DC controlled rectifier

Control model



$$G_H(s) = Ke^{-\frac{T}{2}s}$$

<u>Single phase, 50Hz</u>

$$K = \frac{2V_m}{\pi V_s} \qquad T=10\text{ms}$$

<u>Three phase, 50Hz</u>

$$K = \frac{3V_{L-L,m}}{\pi V_s} \qquad T=3.33\text{ms}$$

Many processes involve transport delays or time lags. Controlling such processes is challenging because delays cause linear phase shifts that limit the control bandwidth and affect closed-loop stability.

Courtesy: Dr. Nik Rumzi Nik Idris, Dept. of Energy Conversion, UTM

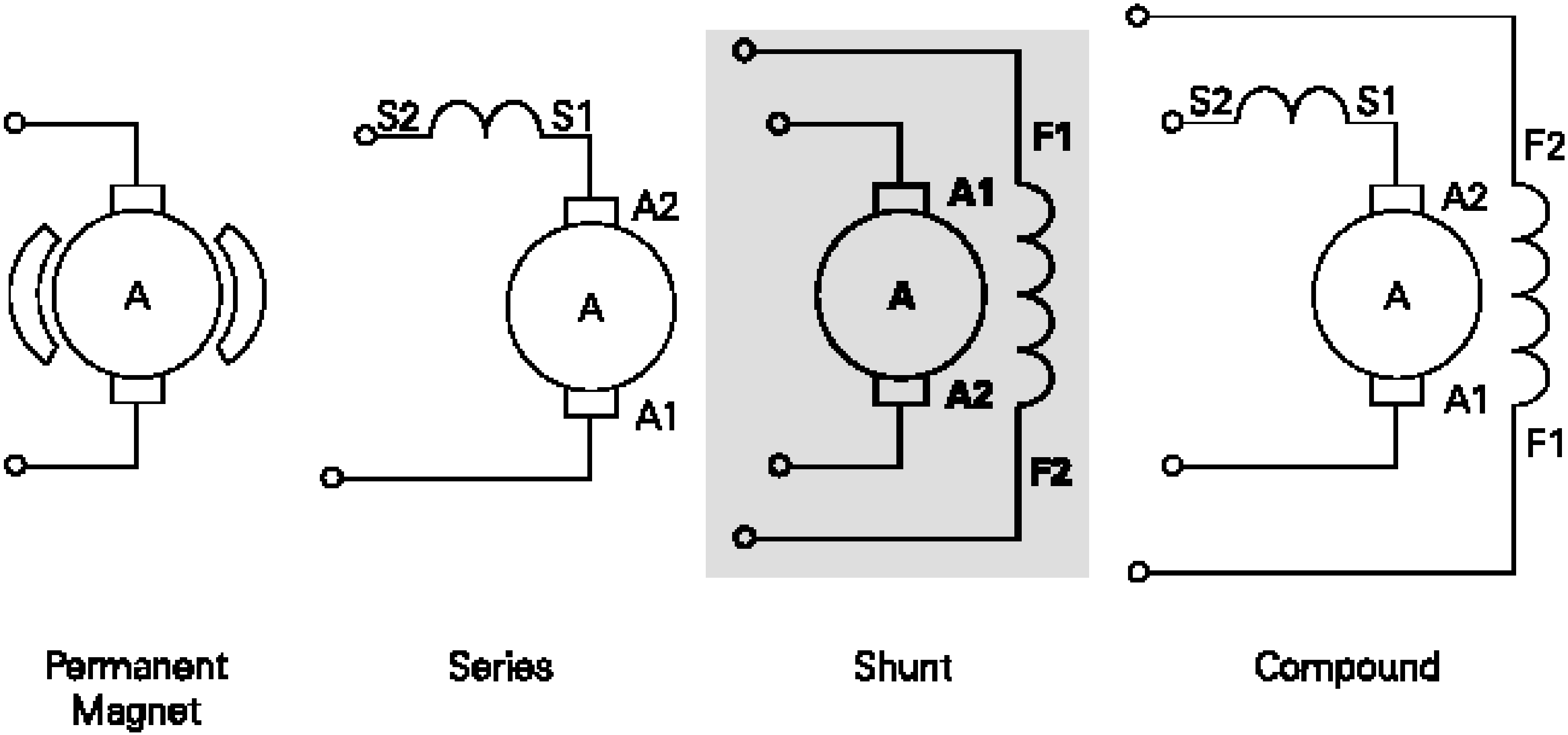
Measurement of Motor Constants

Armature Resistance:

Armature Inductance:

EMF Constant:

DC Motors


A
S2
S1
A2
A
A1
A1
A
A2
F1
F2
S2
S1
A2
A
A1
F2
F1
Permanent Magnet
Series
Shunt
Compound

Steady State Speed Torque Relations

$$E = K_e \phi \omega_m \qquad V = E + I_a R_a \qquad T = K_e \phi I_a$$

$$V = K_e \phi \omega_m + I_a R_a$$

$$\omega_m = \frac{V}{K_e \phi} - \frac{R_a}{K_e \phi} I_a \qquad I_a = \frac{T}{K_e \phi}$$

$$\omega_m = \frac{V}{K_e \phi} - \frac{R_a}{(K_e \phi)^2} T$$

Separately Excited DC Motor

$$K = K_e \phi$$

$$\underbrace{E = K\omega_m \qquad V = E + I_a R_a}_{V = K\omega_m + I_a R_a} \qquad T = K I_a$$

$$\underbrace{\omega_m = \frac{V}{K} - \frac{R_a}{K} I_a \qquad\qquad I_a = \frac{T}{K}}_{}$$

$$\omega_m = \frac{V}{K} - \frac{R_a}{K^2} T$$

Series DC Motor

$$\phi = K_f I_a$$

$$E = K_e K_f I_a \omega_m \qquad V = E + I_a R_a \qquad T = K_e \phi I_a$$

$$T = K_e K_f I_a^2$$

$$V = K_e K_f I_a \omega_m + I_a R_a$$

$$\omega_m = \frac{V}{K_e K_f I_a} - \frac{R_a}{K_e K_f} \qquad I_a = \frac{\sqrt{T}}{\sqrt{K_e K_f}}$$

$$\omega_m = \frac{V}{\sqrt{K_e K_f}} \frac{1}{\sqrt{T}} - \frac{R_a}{K_e K_f}$$

Methods of Speed Control

Armature Voltage Control

$$\omega_m = \frac{V}{K_e\phi} - \frac{R_a}{(K_e\phi)^2}T$$

Field Flux Control

Armature Resistance Control

Armature Voltage Control

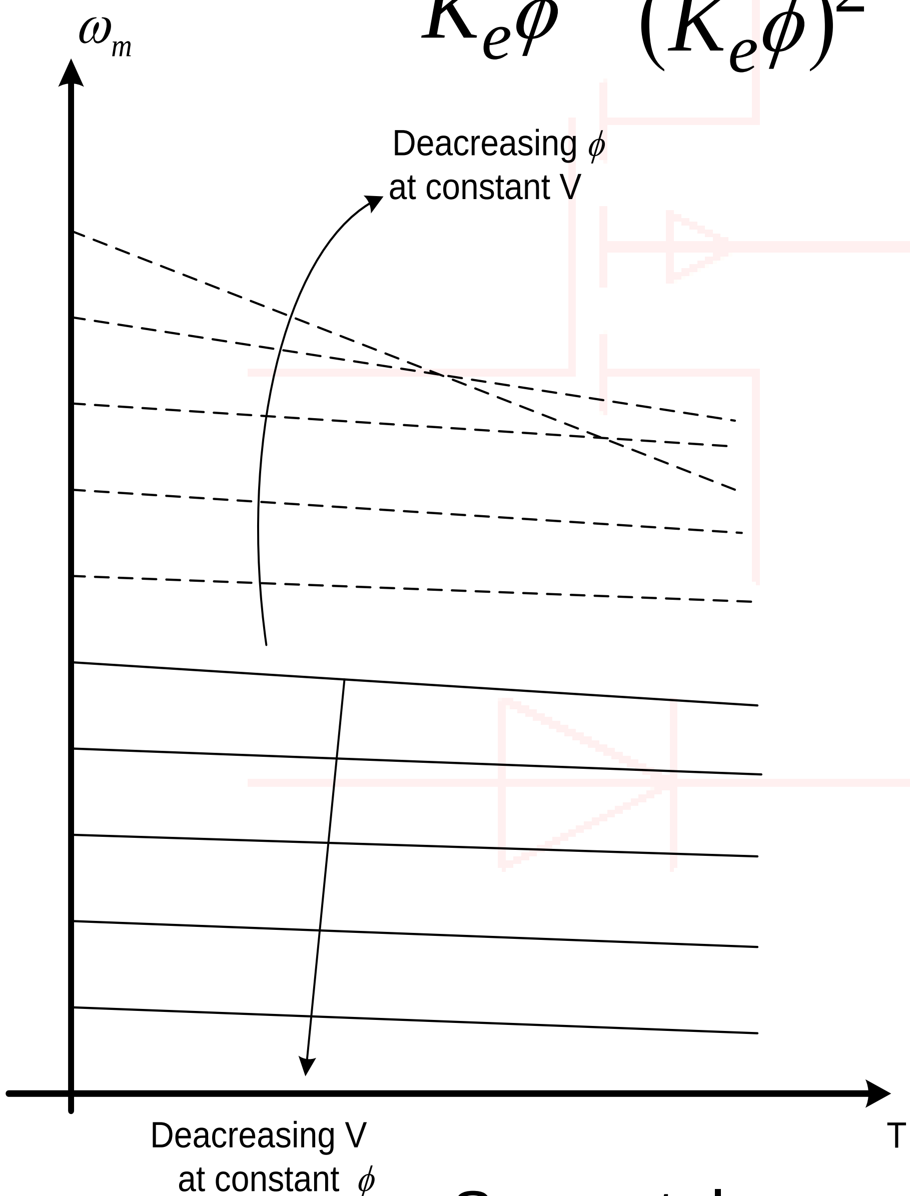
1.Controlled Rectfier

$$\omega_m = \frac{V}{K_e\phi} - \frac{R_a}{(K_e\phi)^2}T$$

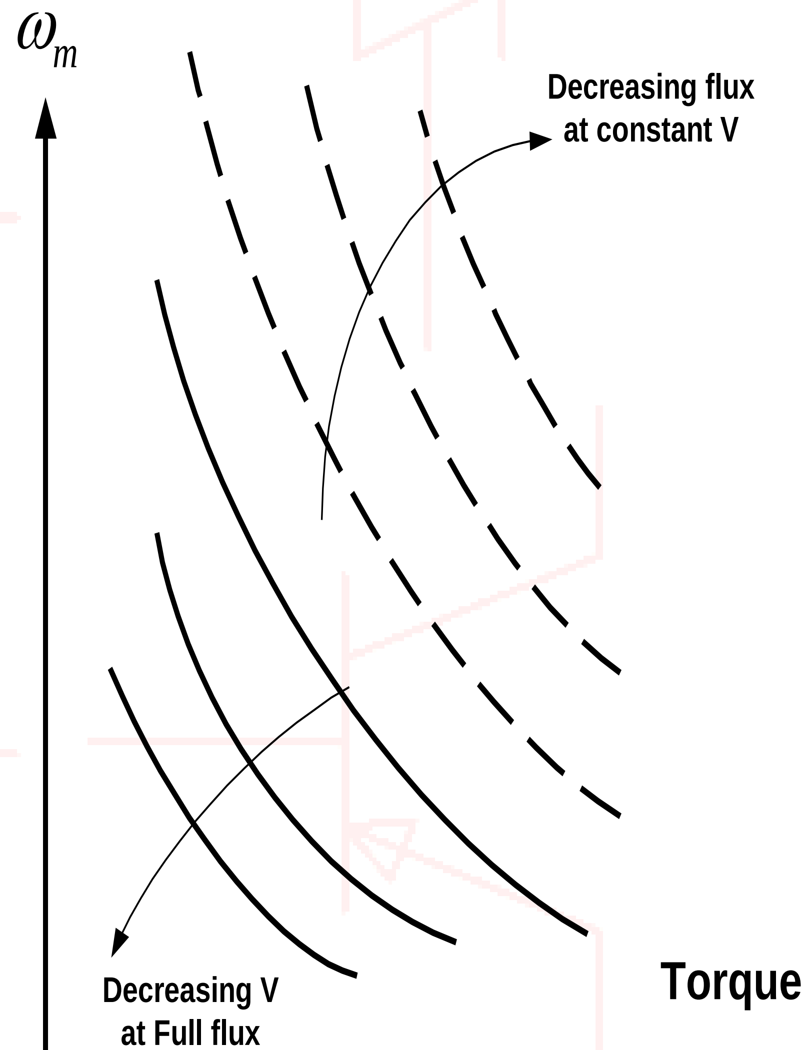
2. Chopper (DC-DC Converter)

Field Flux Control

$$\omega_m = \frac{V}{K_e\phi} - \frac{R_a}{(K_e\phi)^2}T$$

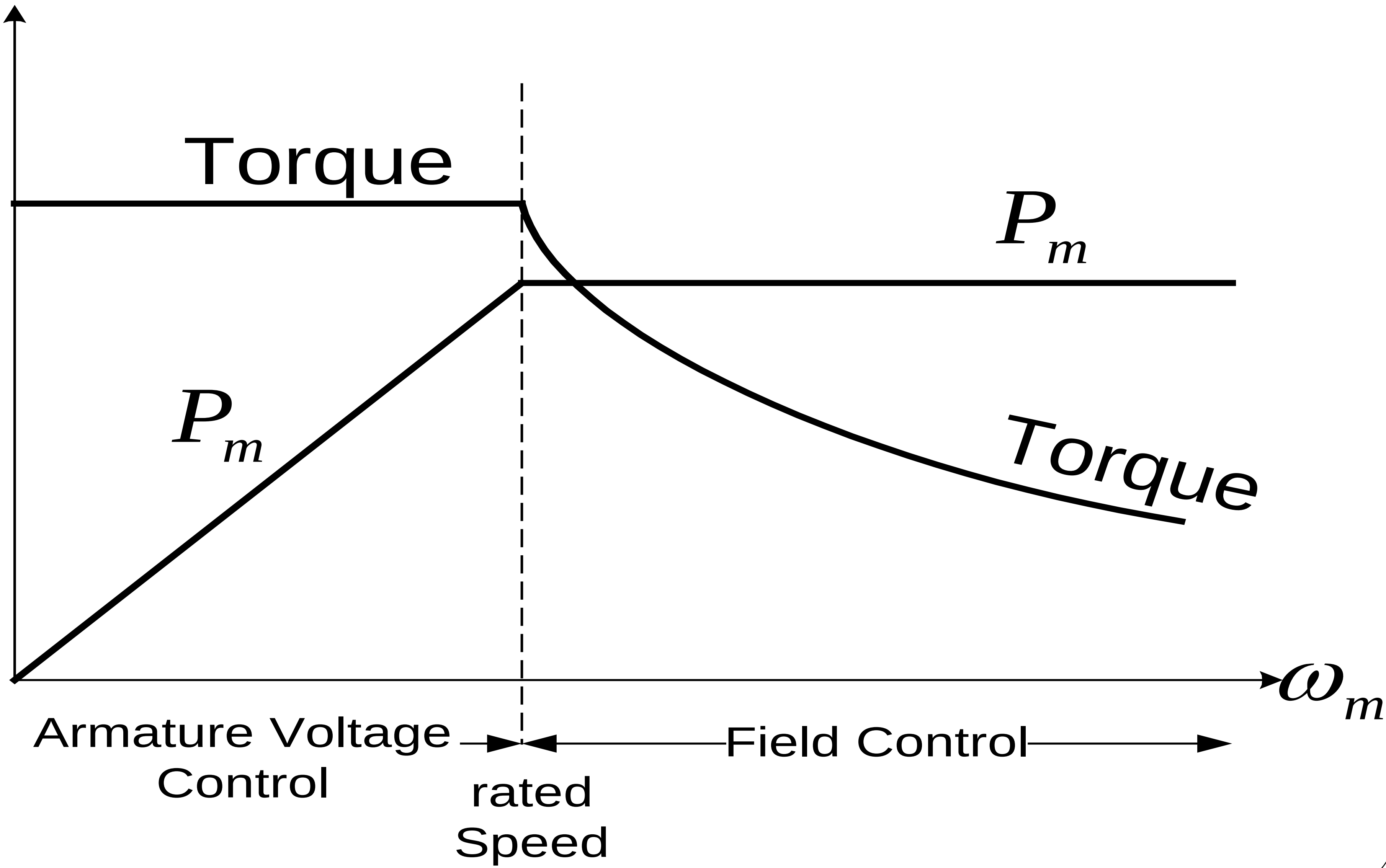


Separately



Series

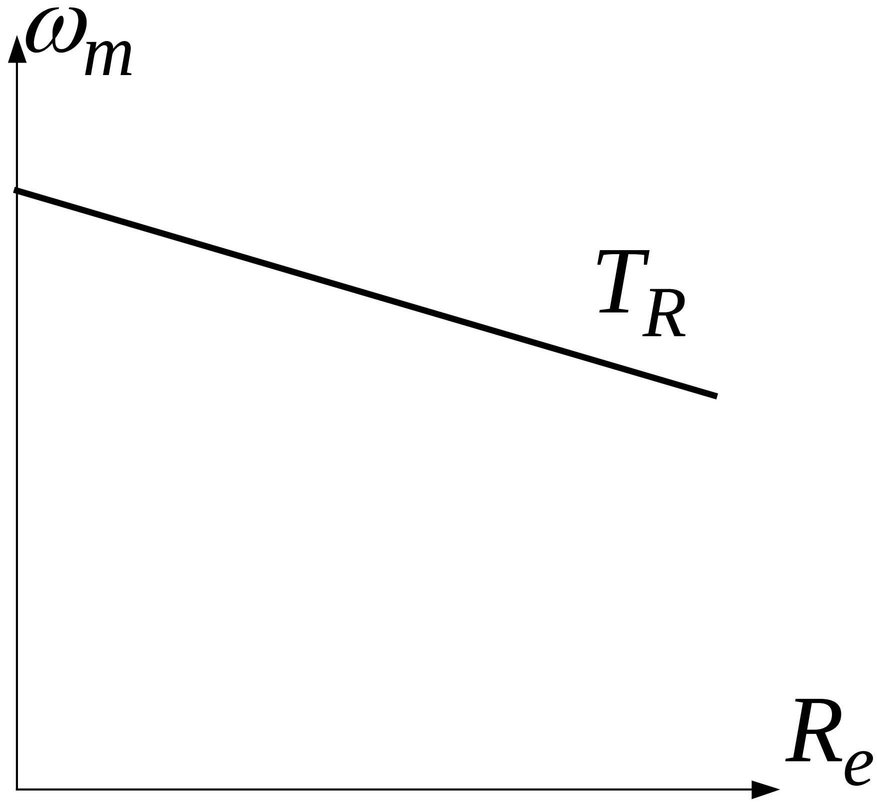
Torque & Power Limitations in Combined armature Voltage and Field Control

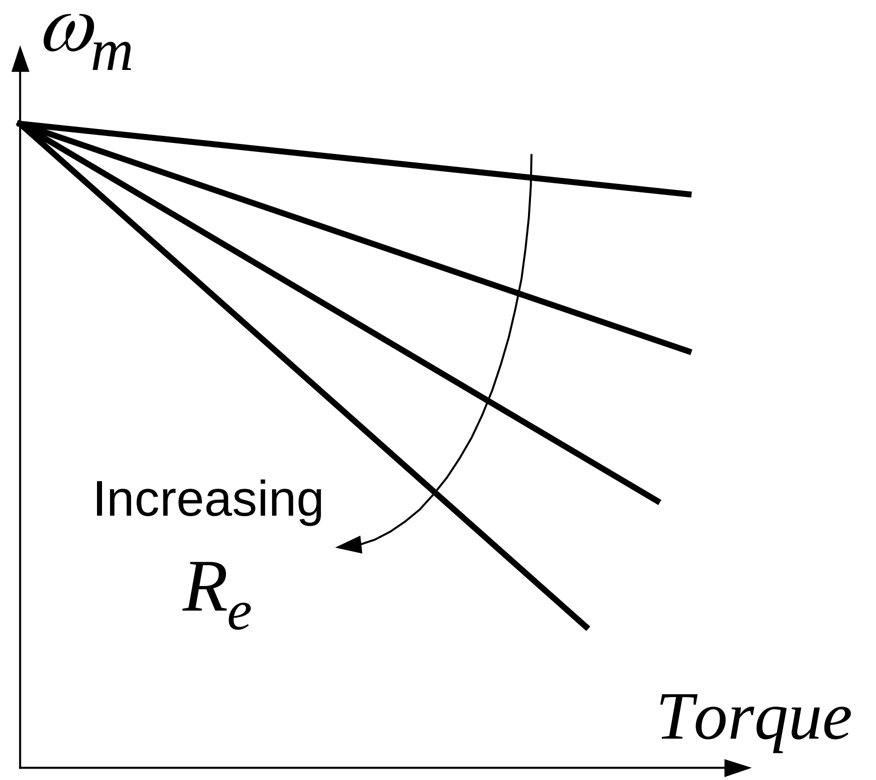


Armature Resistance Control

Separately or shunt field

$$\omega_m = \frac{V}{K_e\phi} - \frac{R_a + R_{ext}}{(K_e\phi)^2} T$$

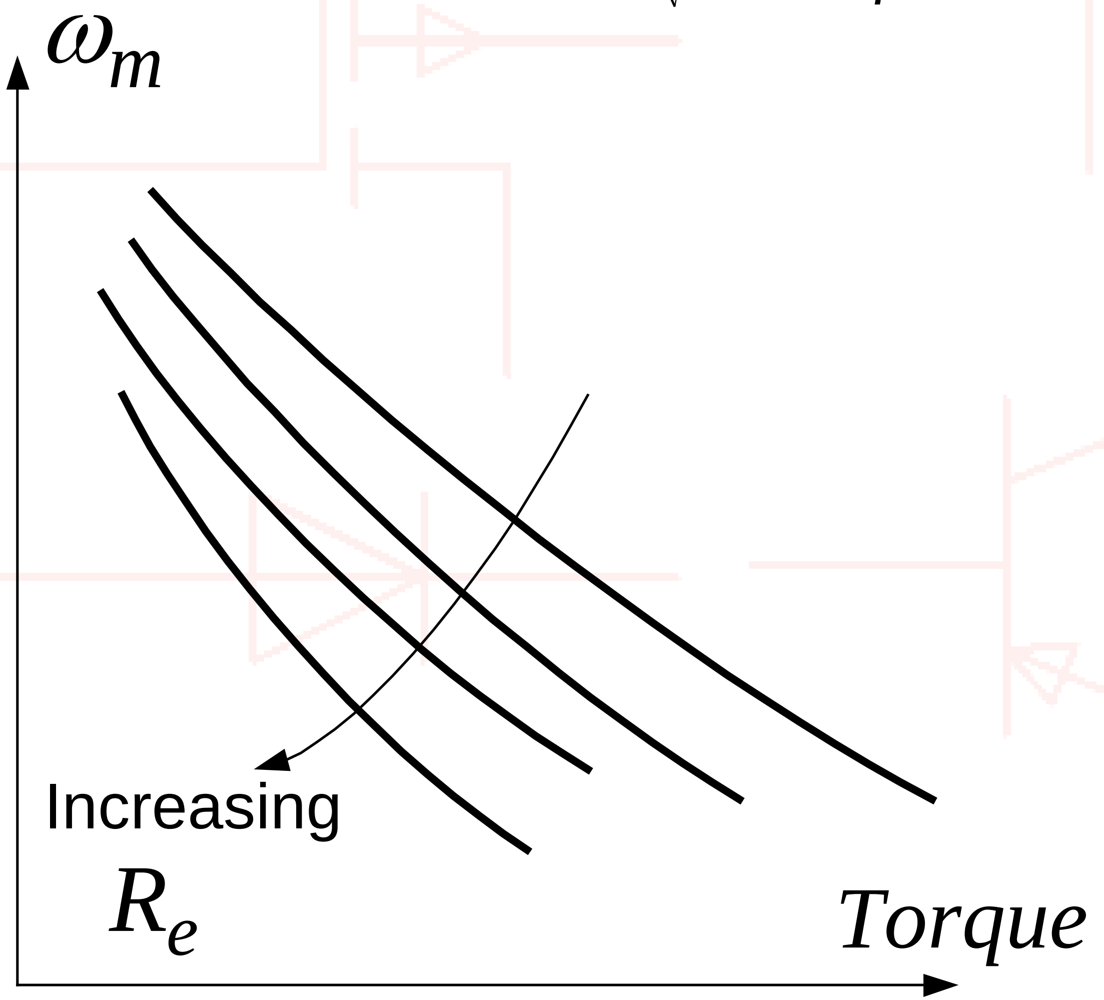




Armature Resistance Control

Series field

$$\omega_m = \frac{V}{\sqrt{K_e K_f}} \frac{1}{\sqrt{T}} - \frac{R_a}{K_e K_f}$$



(b) A DC series motor drives an elevator load that requires a constant torque of 200 N.m. The DC supply voltage is 400 V and the combined resistance of the armature and series field winding is 0.75 ohm. Neglect rotational losses and armature reaction effect.

(i) The speed of the elevator is controlled by variating the supply DC voltage. At 220V input voltage and 40A motor current, determine the speed and the horsepower output of the motor and the efficiency of the system.

(ii) The elevator is controlled by inserting resistance in series with the armature of the series motor. For the speed of part (i), determine the values of the series resistance, horsepower output of the motor, and efficiency of the system.