SMJE 1103
Electrical Power System

3-Phase Power Apparatus

References & Circuit Simulator

Can be downloaded from;

1. http://elearning.utm.my/22232/
2. https://people.utm.my/rasli1/

Circuit simulator: Matlab

Observation

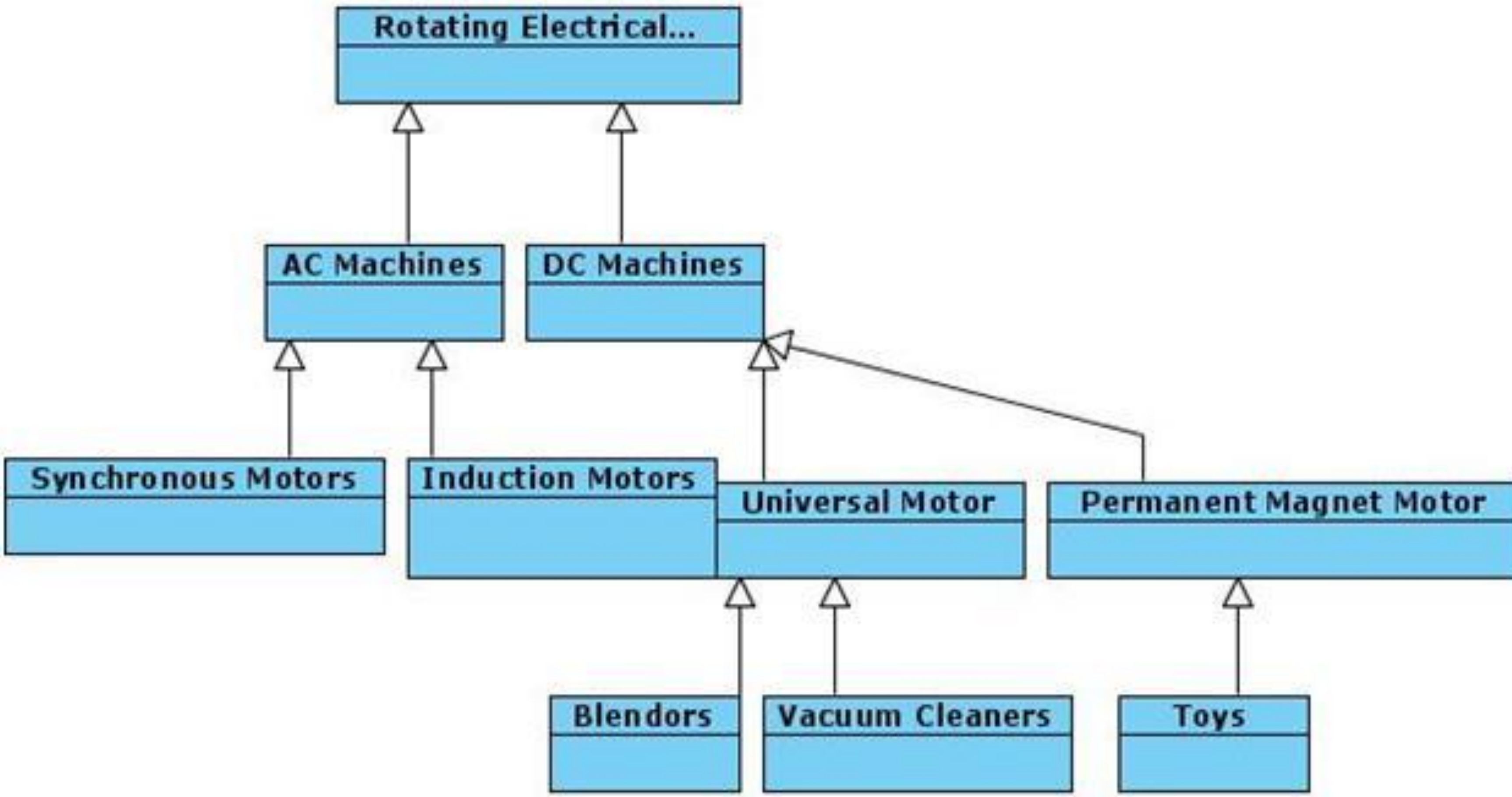
- [4]p677 – p694

Rotating Machine

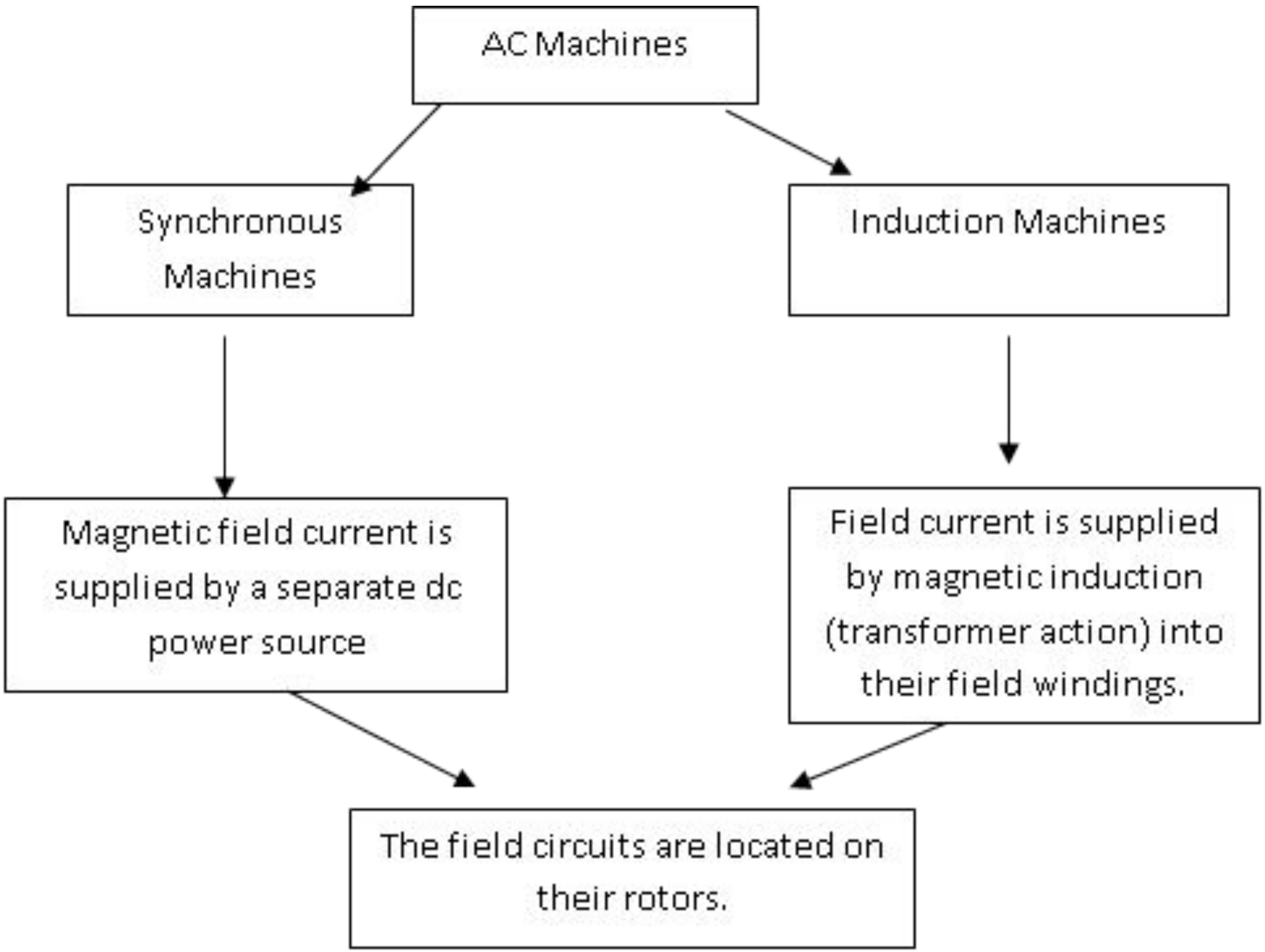
- Discussion outline

✔ Basic concept
✔ Application
✔ Structure
✔ Operational
✔ Specification
✔ Equivalent Circuit
✔ Testing

General



Rotating Electrical...
AC Machines
DC Machines
Synchronous Motors
Induction Motors
Universal Motor
Permanent Magnet Motor
Blendors
Vacuum Cleaners
Toys


AC Machines
Synchronous Machines
Induction Machines
Magnetic field current is supplied by a separate dc power source
Field current is supplied by magnetic induction (transformer action) into their field windings.
The field circuits are located on their rotors.

Application

- Could be

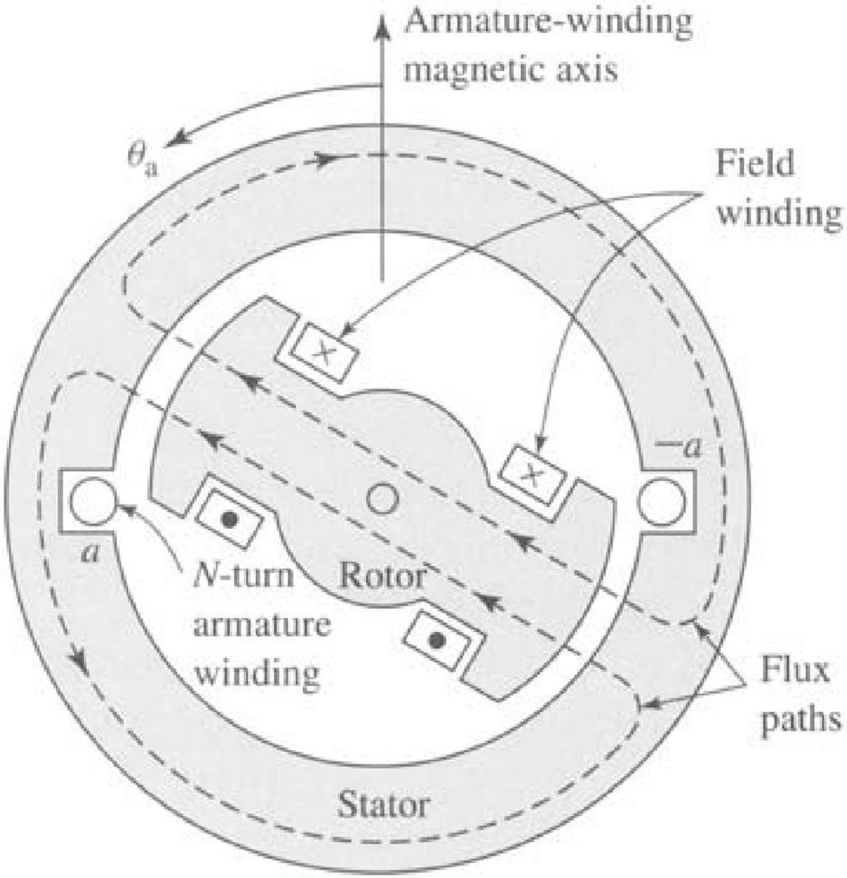
✔ Generators

✔ Alternator

✔ Motors

✔ Transmission gears

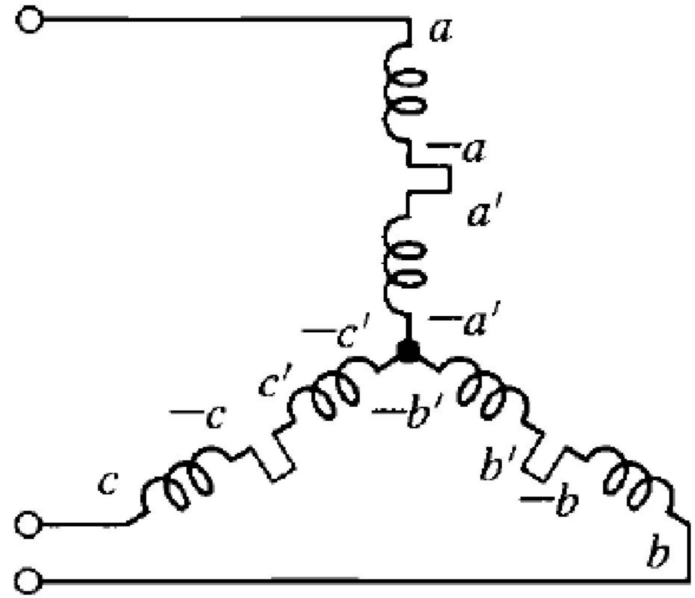
Structure


Armature-winding
magnetic axis
θ_a
Field
winding
$-a$
a
N-turn
armature
winding
Rotor
Flux
paths
Stator

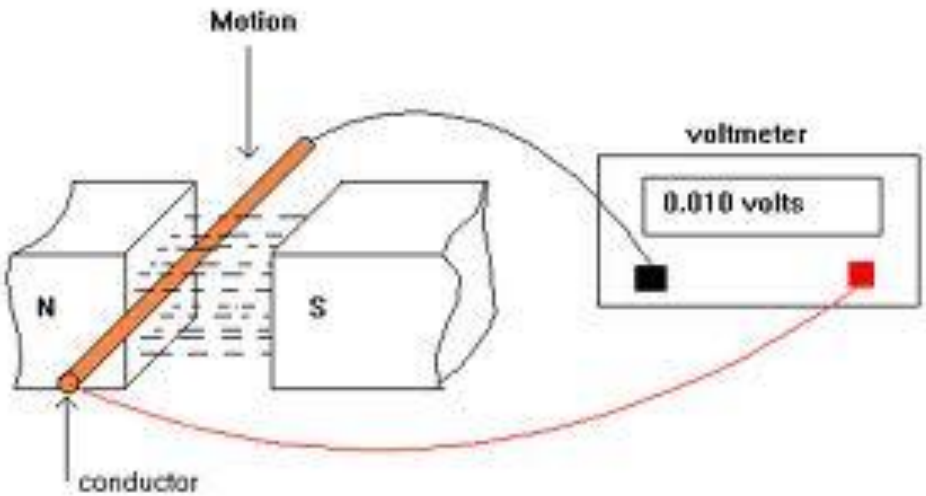
3-Phase Structure

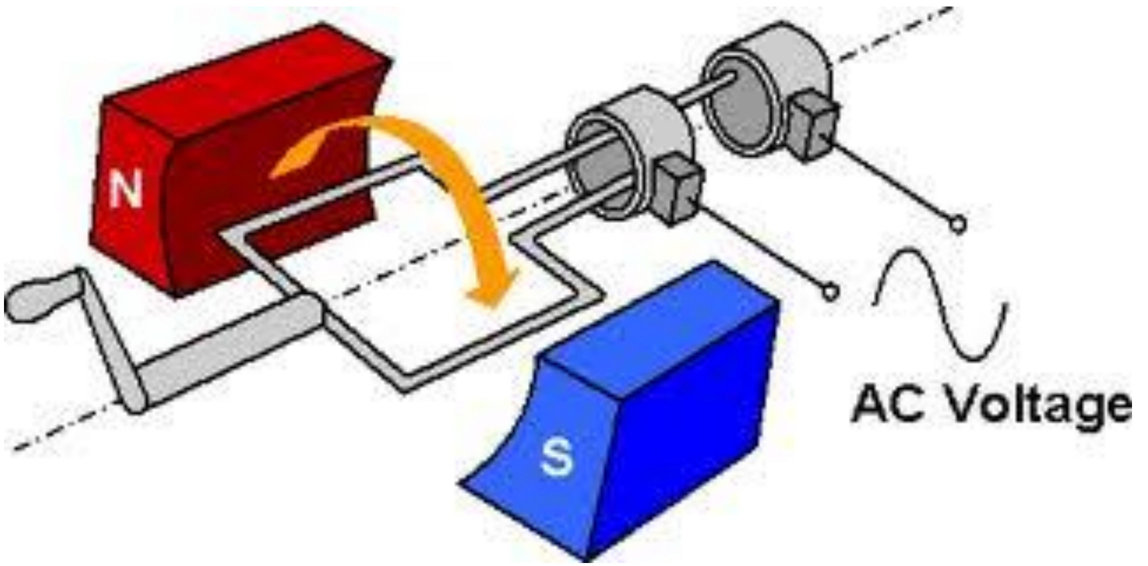
(a)

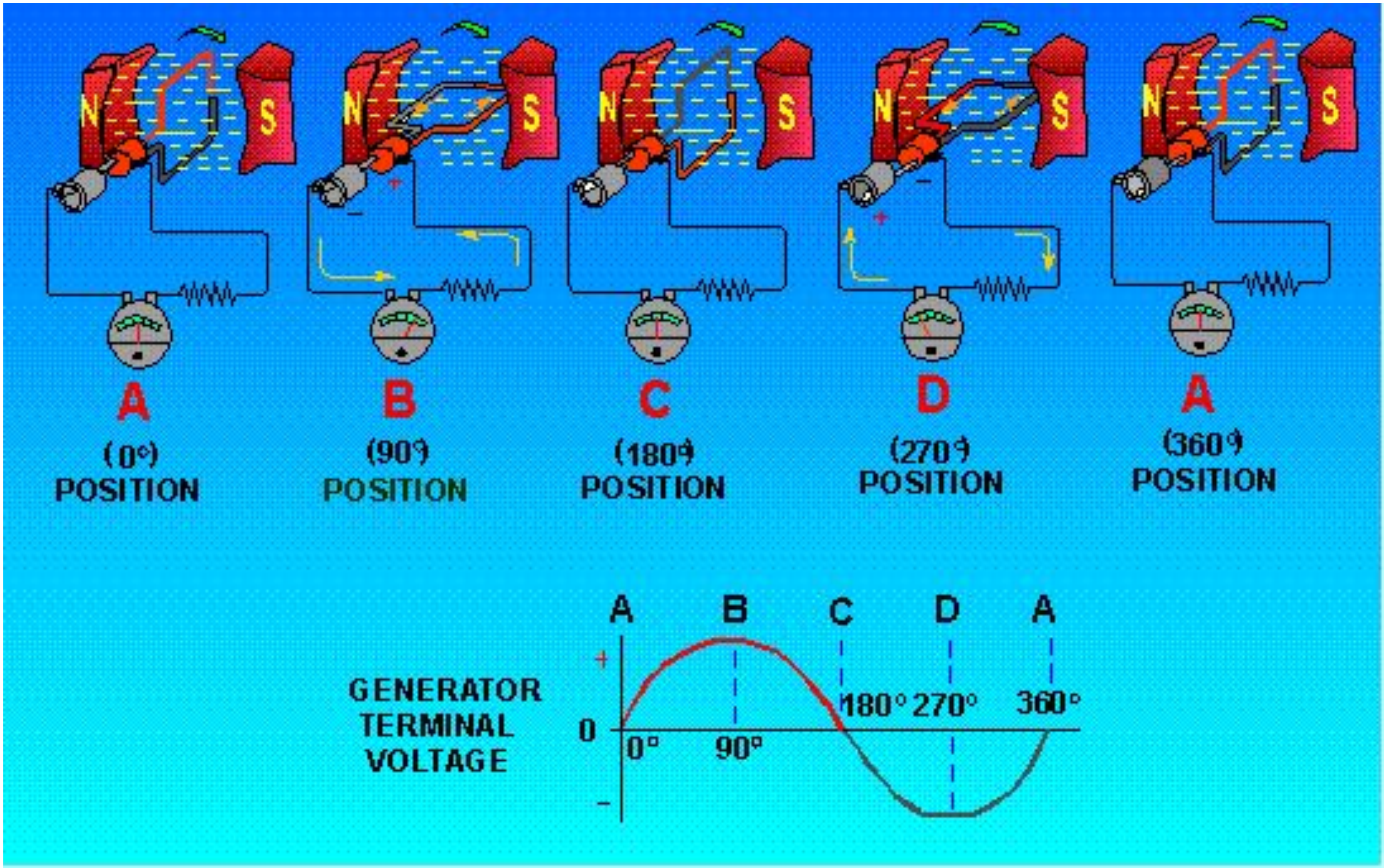
(b)



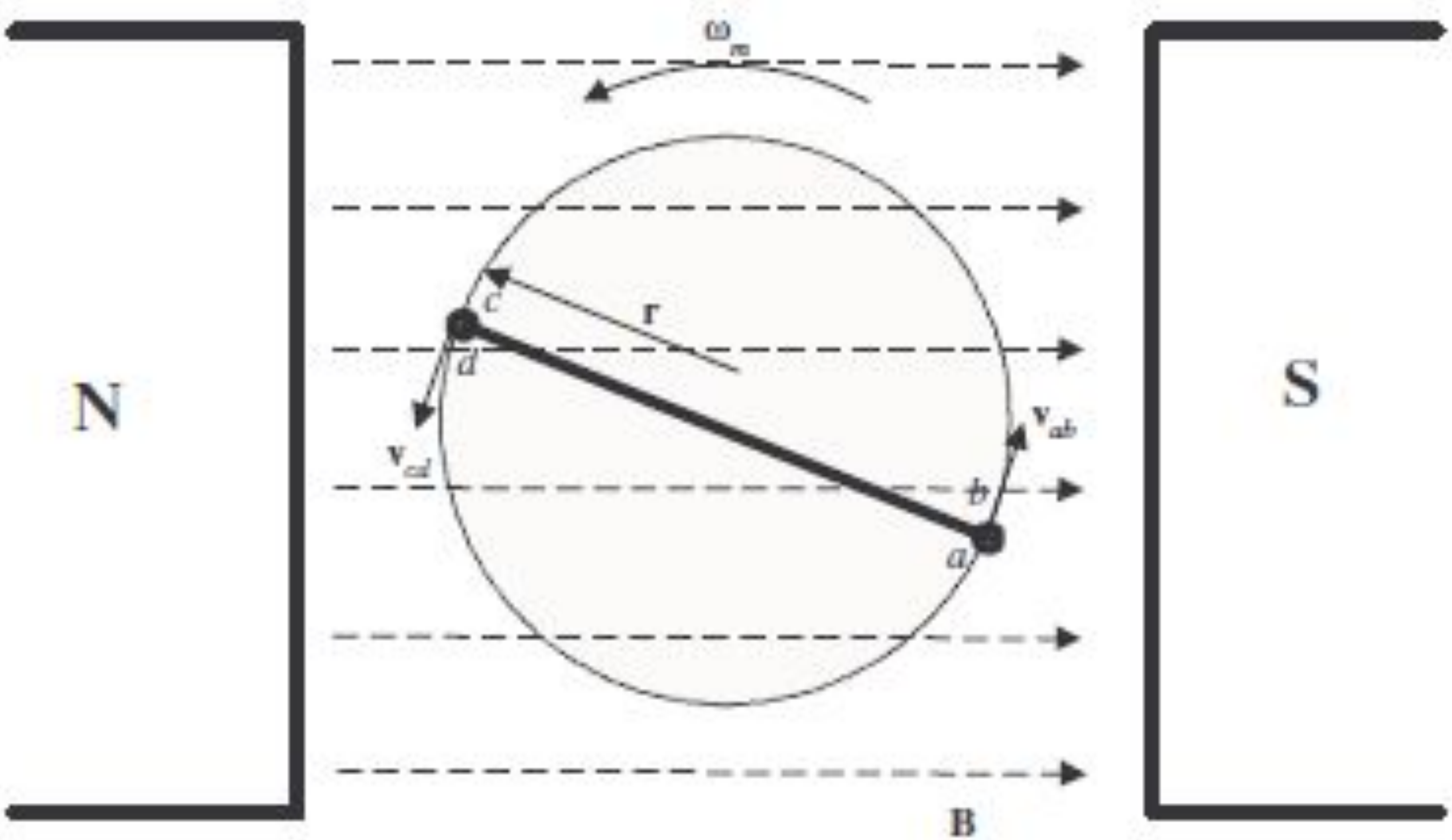
Operational (Generator)





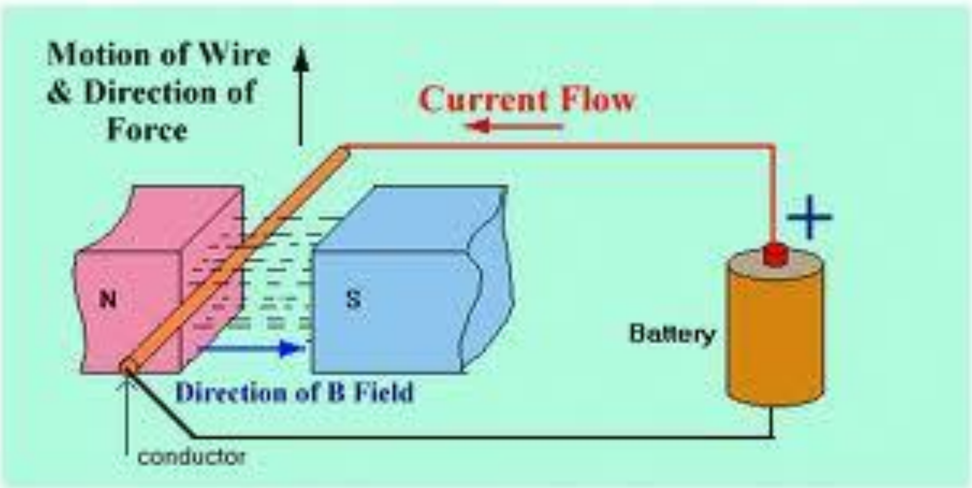


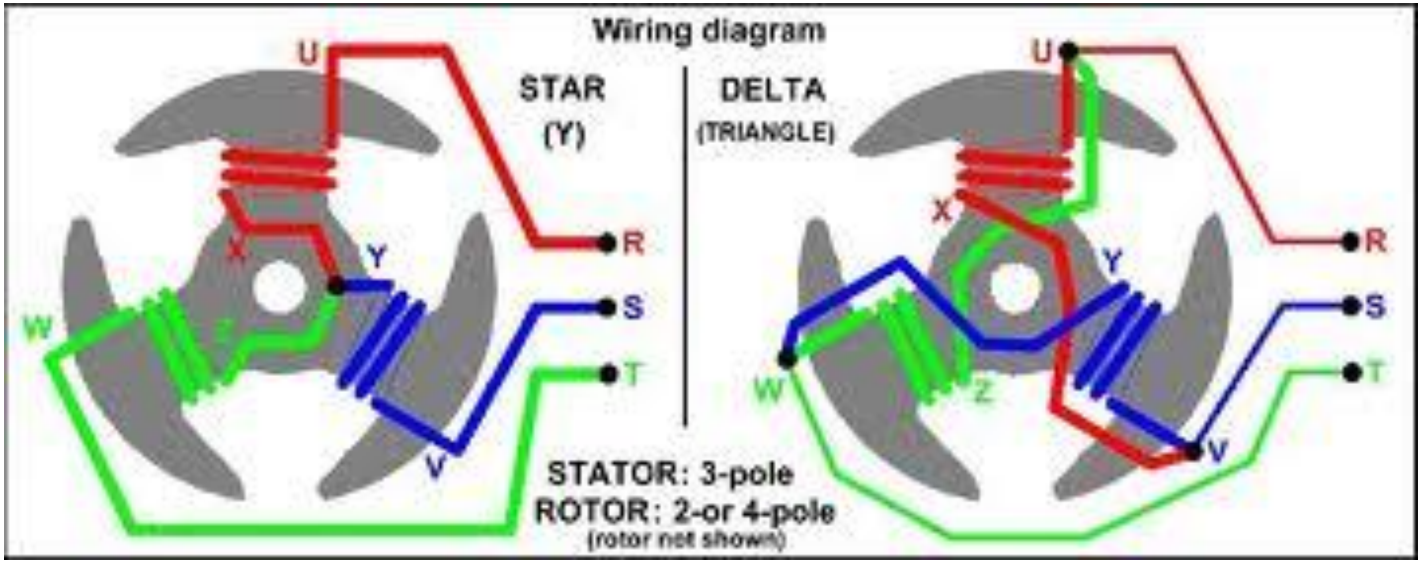
N
S
A
(0°)
POSITION
B
(90°)
POSITION
C
(180°)
POSITION
D
(270°)
POSITION
A
(360°)
POSITION
GENERATOR
TERMINAL
VOLTAGE
A
B
C
D
A
+
0
-
0°
90°
180°
270°
360°



B is a uniform magnetic
field, aligned as shown.

Operational (Motor)





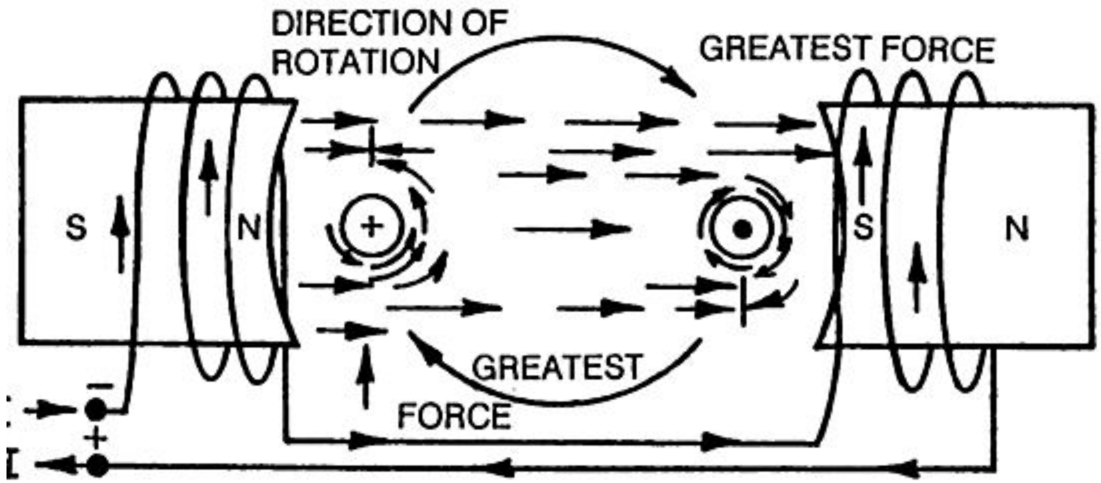


FIGURE 19-4. Combined Armature and Field Magnetic Lines of Force.

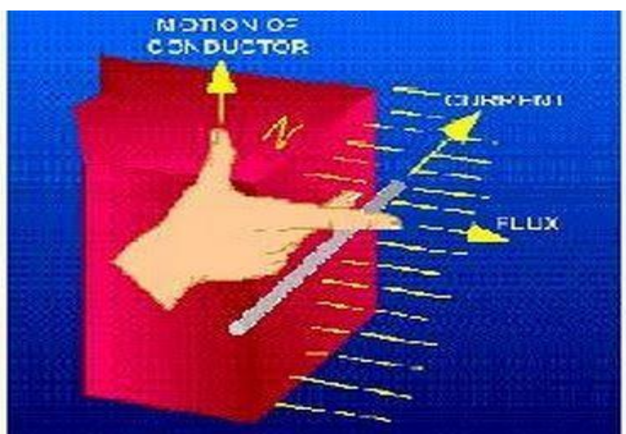
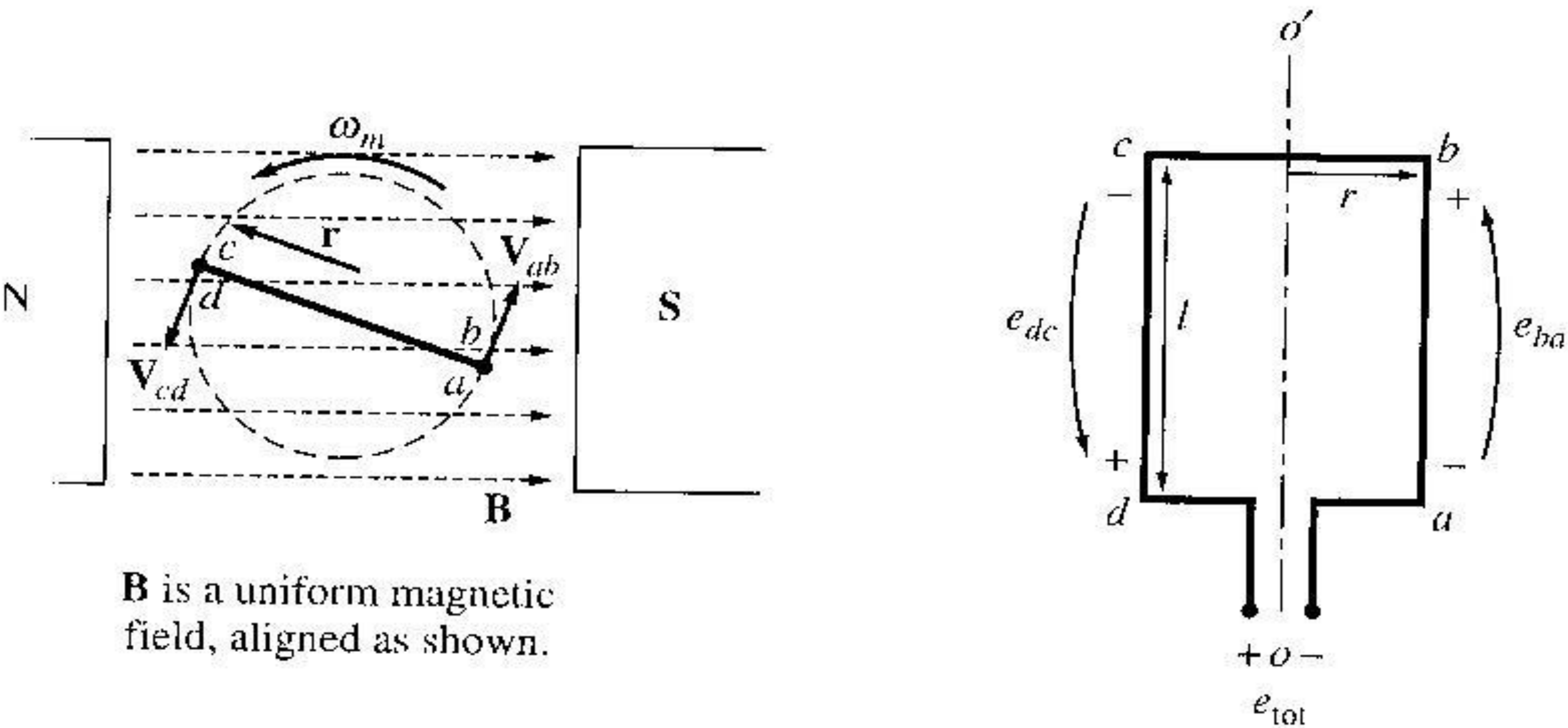


Figure 1: Right-hand rule for motors (1)

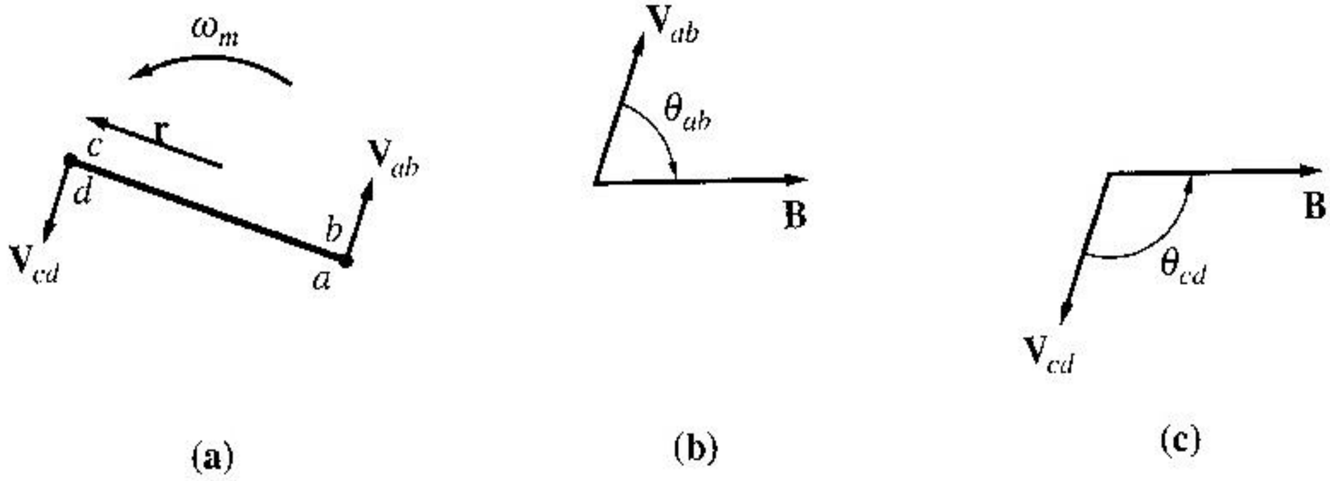
Induced Voltage (Generator)



B is a uniform magnetic field, aligned as shown.

(a)

(b)



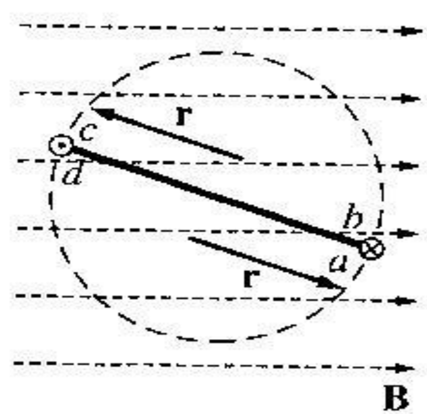
Total induced voltage on the loop

$$e_{ind} = e_{ba} + e_{cb} + e_{dc} + e_{ad}$$

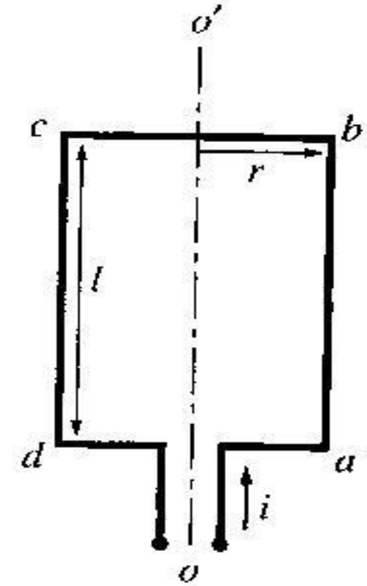
$$= vBl \sin \theta_{ab} + vBl \sin \theta_{cd}$$

$$= 2\, vBL \sin\theta$$

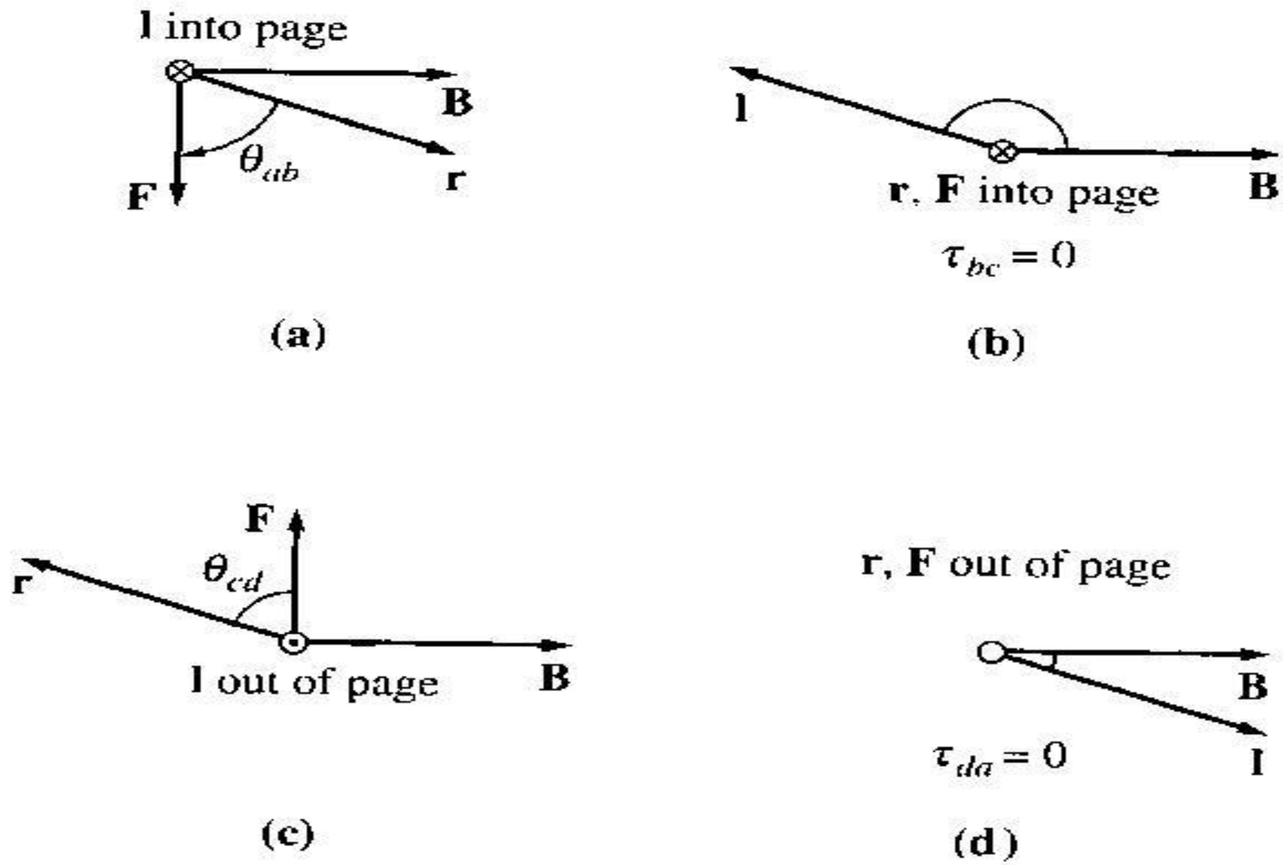
Induced Torque (Motor)



(a)



(b)



The total induced torque on the loop:

$$\tau_{ind} = \tau_{ab} + \tau_{bc} + \tau_{cd} + \tau_{da}$$

$$= rilB\sin\theta_{ab} + rilB\sin\theta_{cd}$$

$$= 2rilB\sin\theta$$

Induced Voltage and Torque

As a conclusion, the induced voltage is dependent upon:
a. Flux level (**the B component**)
b. Speed of Rotation (**the v component**)
c. Machine Constants (**the l component and machine materials**)

Also for the torque is dependent upon:
a. Strength of rotor magnetic field
b. Strength of stator magnetic field
c. Angle between the 2 fields
d. Machine constants

Induced Voltage in 3-Phase

The induced voltages at each phase will be as follows:

$$e_{aa'} = N\phi\omega \sin \omega t \quad V$$

$$e_{bb'} = N\phi\omega \sin(\omega t - 120^o) \quad V$$

$$e_{cc'} = N\phi\omega \sin(\omega t - 240^o) \quad V$$

The maximum induced voltage is when sin has a value of 1, hence,

$$E_{\max} = N\phi\omega \qquad , \qquad \text{since } \omega = 2\pi f,$$

$$\therefore E_{\max} = 2\pi N\phi f$$

Induced Torque in 3-Phase

Therefore the torque equation may be represented in the following form:

$$\tau_{ind} = KH_r B_s \sin\alpha = KH_r \times B_s$$

Note that K is a constant value.
Since $B_R = \mu H_R$,

$$\tau_{ind} = kB_r \times B_s$$

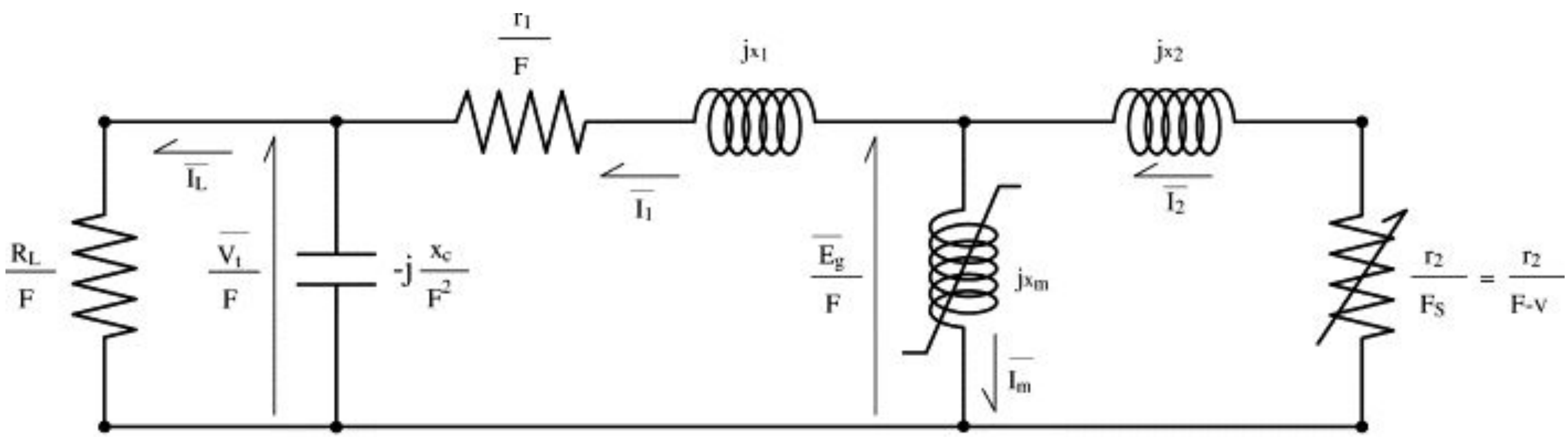
The constant k is a value which will be dependent upon the permeability of the machine's material. Since the total magnetic field density will be the summation of the B_S and B_R, hence:

$$\tau_{ind} = kB_r \times \left(B_{net} - B_r\right) = kB_r \times B_{net}$$

If there is an angle δ between B_{net} and B_R,

$$\tau_{ind} = kB_r B_{net} \sin\delta$$

Equivalent Circuit (Generator)

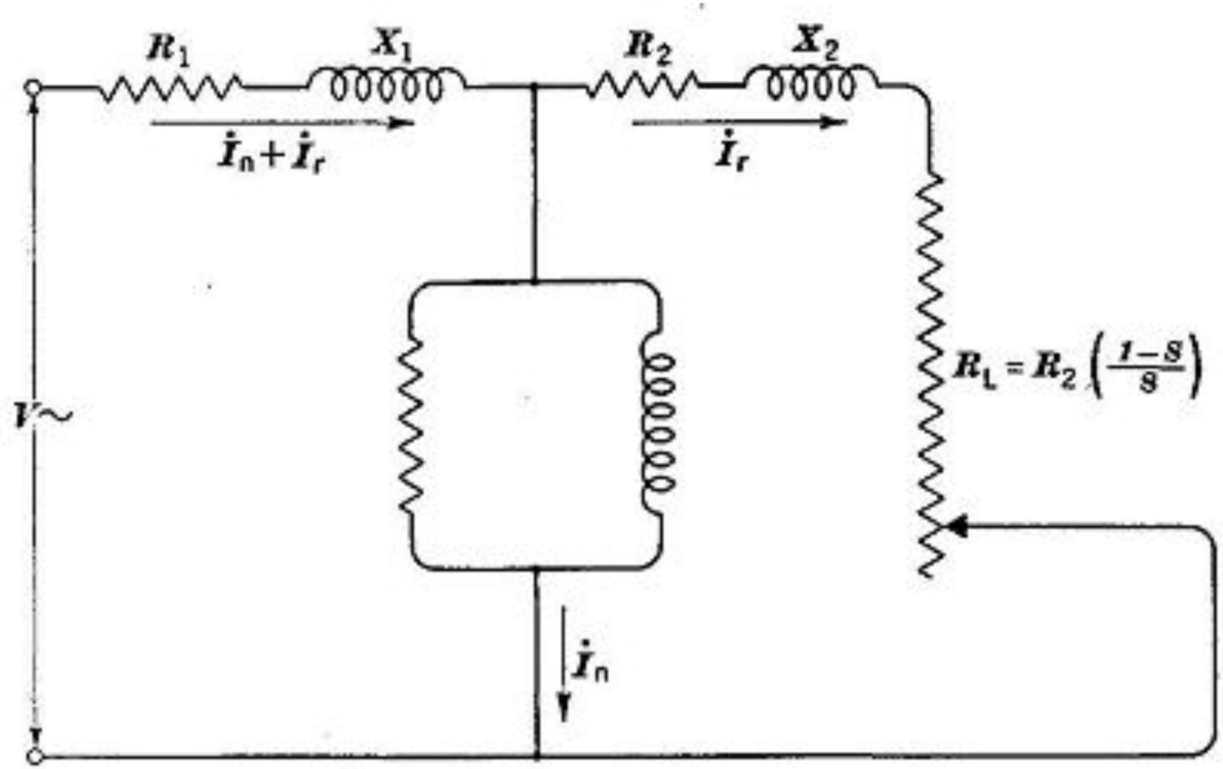


r_1, r_2	: per phase stator and rotor resistance
x_1, x_2	: per phase stator and rotor leakage reactance
x_m	: magnetizing reactance
x_c	: per phase capacitive reactance of the terminal capacitor C
R_L	: load resistance (all reactance referred to above relate to the base frequency f)
F, v	: p.u. frequency and speed
I_s, I_r, I_L	: stator, rotor and load current per phase
V_t, E_g	: terminal and gap voltage

$r_1 = 0.447\Omega$, $r_2 = 0.484\Omega$, $x_1 = x_2 = 0.640\Omega$

$x_c = 12.732\Omega$ ($C = 250\mu F$)

Equivalent Circuit (Motor)



$\dot{I}_n$ = equivalent of no-load current.
$\dot{I}_r$ = equivalent of rotor current.
$\dot{I}_n + \dot{I}_r$ = equivalent of stator current at any load.
R_1 = resistance of stator.
R_2 = equivalent resistance of rotor.
R_L = resistance equivalent to shaft loading.
S = rotor slip, expressed as fraction of synchronous speed.

Testing (Generator)

- Insulation test
- Test of dielectric withstanding voltage (DWV)
- Impulse test
- Partial discharge test

Testing (Motor)

- Insulation test
- Voltage test
- Current test
- Impulse test
- Continuity test
- Impedance test