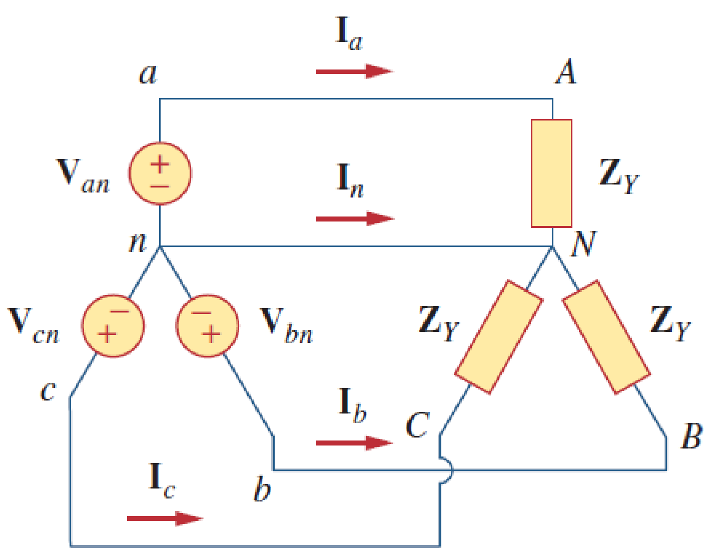
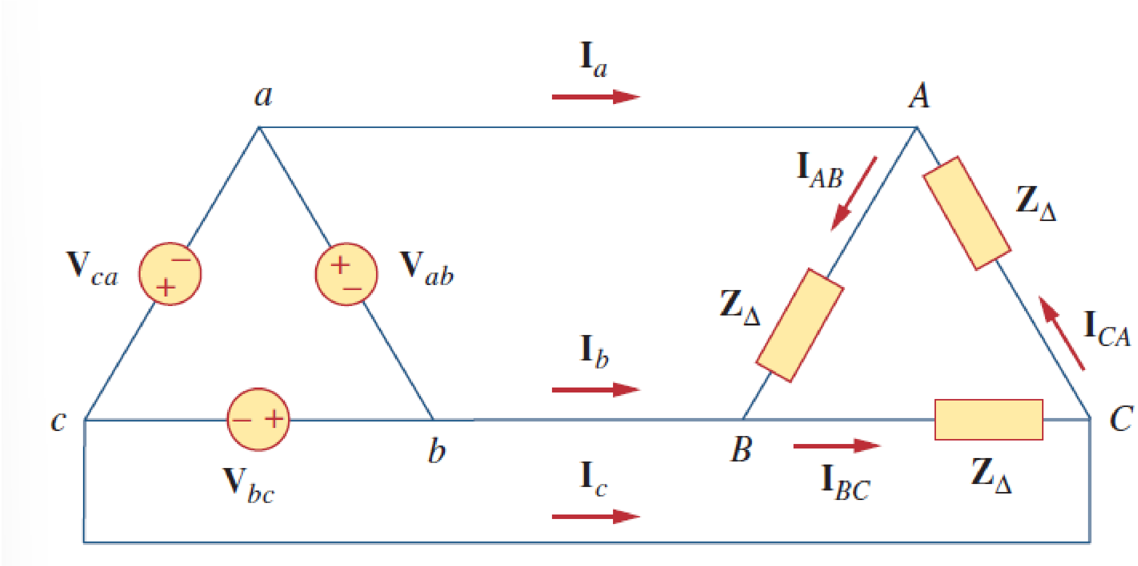
1. Three phase
    a. By default, line current
    b. $kVA = kV \times A$
    c. $kW = kV \times A \times PF$
    d. Capacitor → Leading PF
    e. Inductor → Lagging PF
    f. Power $= 3V_p I_p \cos\theta = \sqrt{3} V_L I_L \cos\theta$
    g. Wye:
        i. $V_L = \sqrt{3} V_P \angle 30°, I_L = I_P$
    h. Delta:
        i. $V_L = V_P, I_L = \sqrt{3} I_P \angle -30°$
    i. $R_Y = \frac{R_\Delta}{3}, R_\Delta = 3R_Y$
    j. If we convert a wye connected load to delta, power consumption and line current will be the same. Resistance will be three times.
    k. If we want to keep resistance same, and convert, then , the current in the line and the power consumption are smaller (one third, to be more specific).
    l. For a given 3 phase voltage, less current flows through wye connections than delta connections.
    m. So, in delta connection light will be bright.
    n. For the same load, the current in the line and the power consumption are smaller (one third, to be more specific) if the load is connected in wye rather than delta.
    o. By the same token, a generator can deliver more power if the windings are delta connected.





Connection	Phase voltages/currents	Line voltages/currents
Y-Y	$\mathbf{V}_{an} = V_p\angle 0^\circ$	$\mathbf{V}_{ab} = \sqrt{3}V_p\angle 30^\circ$
	$\mathbf{V}_{bn} = V_p\angle -120^\circ$	$\mathbf{V}_{bc} = \mathbf{V}_{ab}\angle -120^\circ$
	$\mathbf{V}_{cn} = V_p\angle +120^\circ$	$\mathbf{V}_{ca} = \mathbf{V}_{ab}\angle +120^\circ$
	Same as line currents	$\mathbf{I}_a = \mathbf{V}_{an}/\mathbf{Z}_Y$
		$\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$
		$\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$
Y-Δ	$\mathbf{V}_{an} = V_p\angle 0^\circ$	$\mathbf{V}_{ab} = \mathbf{V}_{AB} = \sqrt{3}V_p\angle 30^\circ$
	$\mathbf{V}_{bn} = V_p\angle -120^\circ$	$\mathbf{V}_{bc} = \mathbf{V}_{BC} = \mathbf{V}_{ab}\angle -120^\circ$
	$\mathbf{V}_{cn} = V_p\angle +120^\circ$	$\mathbf{V}_{ca} = \mathbf{V}_{CA} = \mathbf{V}_{ab}\angle +120^\circ$
	$\mathbf{I}_{AB} = \mathbf{V}_{AB}/\mathbf{Z}_\Delta$	$\mathbf{I}_a = \mathbf{I}_{AB}\sqrt{3}\angle -30^\circ$
	$\mathbf{I}_{BC} = \mathbf{V}_{BC}/\mathbf{Z}_\Delta$	$\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$
	$\mathbf{I}_{CA} = \mathbf{V}_{CA}/\mathbf{Z}_\Delta$	$\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$
Δ-Δ	$\mathbf{V}_{ab} = V_p\angle 0^\circ$	Same as phase voltages
	$\mathbf{V}_{bc} = V_p\angle -120^\circ$	
	$\mathbf{V}_{ca} = V_p\angle +120^\circ$	
	$\mathbf{I}_{AB} = \mathbf{V}_{ab}/\mathbf{Z}_\Delta$	$\mathbf{I}_a = \mathbf{I}_{AB}\sqrt{3}\angle -30^\circ$
	$\mathbf{I}_{BC} = \mathbf{V}_{bc}/\mathbf{Z}_\Delta$	$\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$
	$\mathbf{I}_{CA} = \mathbf{V}_{ca}/\mathbf{Z}_\Delta$	$\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$
Δ-Y	$\mathbf{V}_{ab} = V_p\angle 0^\circ$	Same as phase voltages
	$\mathbf{V}_{bc} = V_p\angle -120^\circ$	
	$\mathbf{V}_{ca} = V_p\angle +120^\circ$	
	Same as line currents	$\mathbf{I}_a = \dfrac{V_p\angle -30^\circ}{\sqrt{3}\mathbf{Z}_Y}$
		$\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$
		$\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$

2. Ideal Transformer
    a. $a = \frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$
3. Real Transformer
    a. Power factor is always lagging for real transformer.
    b. V_P = Input Voltage
    c. V_S = Supply Voltage
    d. Copper loss (I^2R)
    e. Flux

        i. Mutual flux, ϕ_M
        ii. Leakage flux
            1. Primary Leakage flux, ϕ_{LP}
            2. Secondary Leakage flux, ϕ_{LS}
    f. No load current / Excitation current, $i_{ex} = i_m + i_{h+e}$
        i. Core loss
            1. Hysteresis loss
            2. Eddy current loss
        ii. Magnetization current
            1. Current lags
    g. Equivalent circuit
        i. Copper loss → R_P, R_S
        ii. Leakage flux → X_P, X_S
        iii. Core loss → R_C
        iv. Magnetization current → X_M

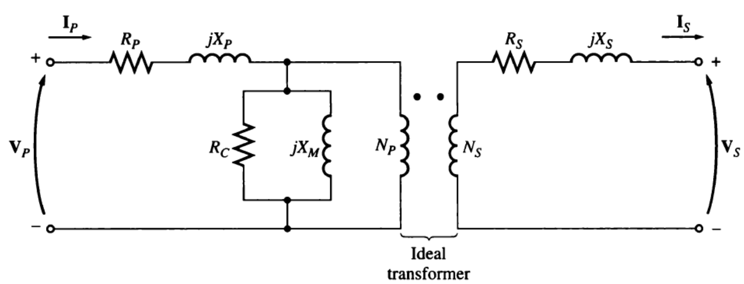


FIGURE 2–16
The model of a real transformer.

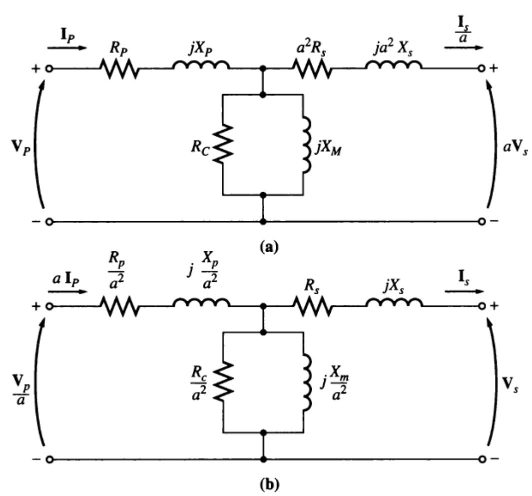


FIGURE 2–17
(a) The transformer model referred to its primary voltage level. (b) The transformer model referred to its secondary voltage level.

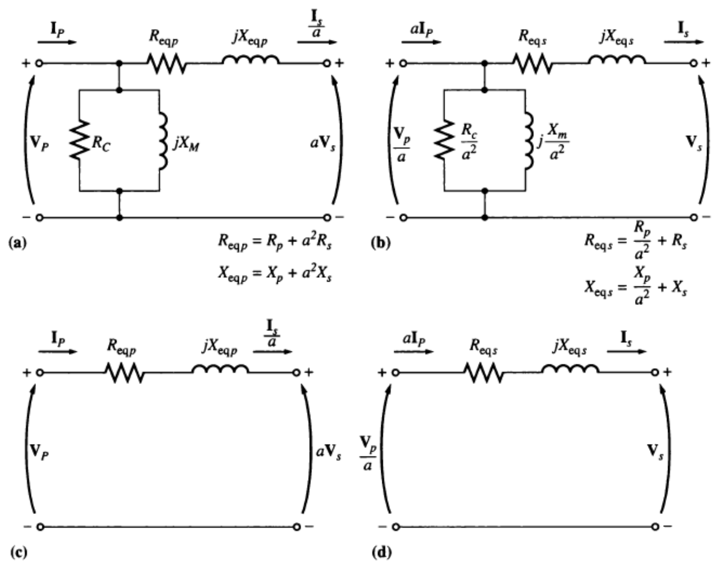
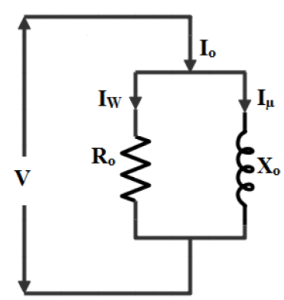
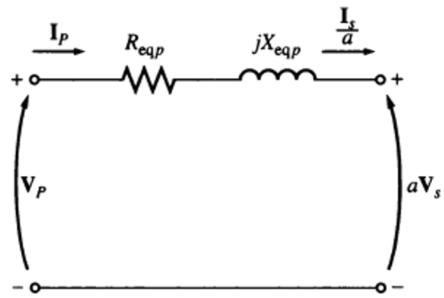


FIGURE 2–18
Approximate transformer models. (a) Referred to the primary side; (b) referred to the secondary side; (c) with no excitation branch, referred to the primary side; (d) with no excitation branch, referred to the secondary side.

4. Determining components
   a. Value of $R_P, X_P, R_S, X_S, R_C, X_M$ doesn't depend on connected load.
   b. Open circuit test



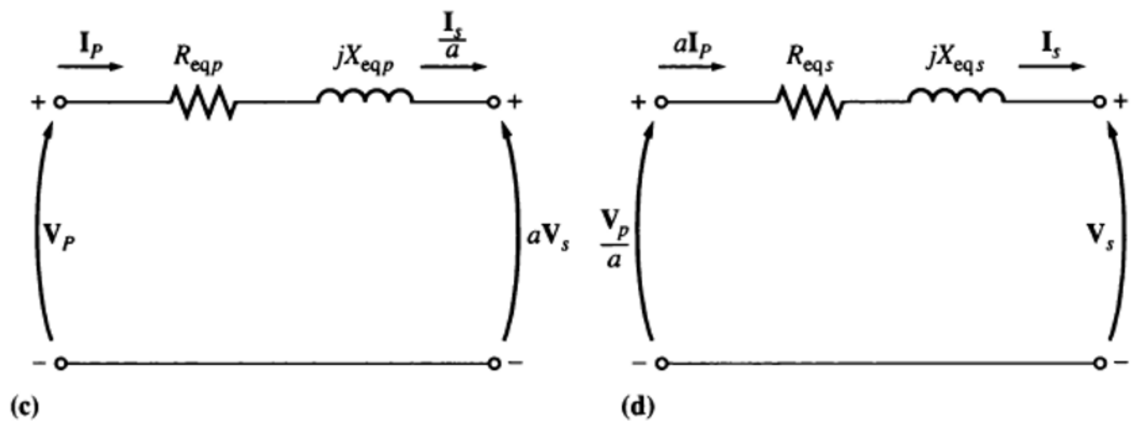
      i. Find R_C and X_M referred to low voltage side
      ii. Performed on low voltage side
      iii. High voltage terminal open circuit
      iv. Performed in rated voltage
      v. $Y_E = \frac{I_{OC}}{V_{OC}} \angle - \cos^{-1} PF = \frac{1}{R_C} - j\frac{1}{X_M}$
      vi. $PF = \frac{P_{OC}}{V_{OC} I_{OC}}$
      vii. This measurement is normally done on the low-voltage side of the transformer, since lower voltages are easier to work with.
   c. Short circuit test



i. Find R_{eq} and X_{eq} referred to high voltage side
ii. Performed on high voltage side
iii. Low voltage terminal short circuit
iv. Performed in rated current
v. $Z_{SE} = \frac{V_{SC}}{I_{SC}} \angle \cos^{-1} PF = R_{eq} + jX_{eq}$
vi. $PF = \frac{P_{SC}}{V_{SC} I_{SC}}$
vii. Voltage high and current low. Low current will not harm the ammeter. This measurement is normally done on the high-voltage side of the transformer, since currents will be lower on that side, and lower currents are easier to work with.
viii. Also because we cannot short circuit high voltage side, as, if we short circuit high voltage side, voltage of high voltage side essentially falls to zero and since VI=constant, so the high voltage side current will be very high and will burn the winding.

d. $R_{eq,p} = R_P + a^2 R_S = a^2 R_{eq,s}$
e. $X_{eq,p} = X_P + a^2 X_S = a^2 X_{eq,s}$
f. $R_{eq,s} = \frac{R_P}{a^2} + R_S = \frac{R_{eq,p}}{a^2}$
g. $X_{eq,s} = \frac{X_P}{a^2} + X_S = \frac{X_{eq,p}}{a^2}$
h. $Z_{eq,p} = a^2 Z_{eq,s}$
i. $R_{eq,p} = a^2 R_{eq,s}$
j. $X_{eq,p} = a^2 X_{eq,s}$
k. For a transformer with primary high voltage side and secondary low voltage side, we have to find R_C,X_M referred to secondary side and R_{eq},X_{eq} referred to primary side. Which means we have to perform open circuit test on secondary side and short circuit test on primary side. All of the elements must be referred to the same side to create the final equivalent circuit. Usually, we take $a^2 R_C, a^2 X_M$ to create equivalent circuit referred to primary side. So, we will create equivalent circuit referred to <The side referred in short circuit test>.

5. Voltage regulation



a. For voltage regulation and transformer efficiency use referred to secondary.
b. To find VR either we need to know V_P or V_S.
c. When we ignore excitation branch $I_P = \frac{I_S}{a}$.
d. $VR = \frac{V_{S,nl} - V_{S,fl}}{V_{S,fl}} \times 100\%$
   i. $V_{S,nl} = Output\ voltage\ at\ No\ load$
   ii. $V_{S,fl} = Output\ voltage\ at\ full\ load$
e. $VR = \frac{\left|\frac{V_P}{a}\right| - |V_{S,fl}|}{|V_{S,fl}|} \times 100\%\ [Referred\ to\ secondary]$
   i. $\frac{V_P}{a} = V_S + \left(R_{eq,s} + jX_{eq,s}\right) \times I_S$
f. $VR = \frac{V_P - aV_{S,fl}}{aV_{S,fl}} \times 100\%\ [Referred\ to\ primary]$
   i. $V_P = aV_S + \left(R_{eq,p} + jX_{eq,p}\right) \times \frac{I_S}{a}$
g. For ideal transformer, $VR = 0$
h. Ideal transformer, $\frac{V_P}{a} = V_S$
i. Real transformer, $\frac{V_P}{a} = V_s + \left(R_{eq,p} + jX_{eq,p}\right) \times I_S$
j. Lagging power factor
   i. $\frac{V_P}{a} > V_S$
   ii. $VR > 0$
k. Unity power factor
   i. $\frac{V_P}{a} > V_S$
   ii. $VR > 0$
l. Leading power factor
   i. $\frac{V_P}{a} < V_S$
   ii. $VR < 0$

6. Transformer efficiency

a. $\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{P_{out}}{P_{out}+P_{loss}} \times 100\% = \frac{V_S I_S \cos\theta}{P_{Cu}+P_{core}+V_S I_S \cos\theta} \times 100\% = \frac{S\cos\theta}{P_{Cu}+P_{core}+S\cos\theta} \times 100\%$
    i. $P_{Cu} = I_S^2 R_{eq,s}$
    ii. $P_{core} = \frac{\left(\frac{V_P}{a}\right)^2}{R_{c,s}} = \frac{\left(\frac{V_P}{a}\right)^2}{\frac{R_{c,p}}{a^2}} = \frac{V_P^2}{R_{c,p}}$
    iii. P_{core} doesn't depend
b. At half load,
    i. Current gets halved
    ii. $P_{core,hl} = P_{core,fl}$
    iii. $P_{Cu,hl} = \left(\frac{I_S}{2}\right)^2 R_{eq,s}$
    iv. $P_{out,hl} = \frac{1}{2} P_{out,fl}$
    v. $I_{S,HL} = \frac{1}{2} I_{S,FL}$

7. Induction motor
    a. Due to three phase current in stator magnetic field rotates. When we place the closed conductor inside the rotating magnetic field according to the Faraday's law of induction, a changing of the magnetic field will lead to the appearance of an electromotive force (EMF) in the conductor. In turn, the EMF will produce a current in the conductor. Thus, in a magnetic field there will be a closed conductor with a current on which force will act, according to Ampere's law. As a result of which the loop will begin to rotate.
    b. Synchronous speed of motor = Speed of magnetic field, $n_{sync} = \frac{120 f_{se}}{P}\ r/min$
        i. f_{se} = Stator frequency / frequency of the current provided in the stator
        ii. P = Poles in machine
    c. Types of rotor
        i. Squirrel cage rotor
        ii. Wound rotor
    d. Rotor speed, n_m
    e. $n_m < n_{sync}$
    f. $n_{slip} = n_{sync} - n_m$
        i. n_{slip} = slip speed of the machine
        ii. n_{sync} = speed of the magnetic fields
        iii. n_m = mechanical shaft speed of motor
    g. Slip, $S = \frac{n_{slip}}{n_{sync}} \times 100\% = \frac{n_{sync}-n_m}{n_{sync}} \times 100\% = \frac{\omega_{sync}-\omega_m}{\omega_{sync}} \times 100\%$
    h. Rotor speed, $n_m = (1-s) n_{sync}$
    i. Rotor frequency, $f_{re} = s f_{se} = \frac{P}{120}\left(n_{sync} - n_m\right)$
        i. $n_m = 0 \rightarrow f_{re} = f_{se}$

ii. $n_m = 1 \rightarrow f_{re} = 0$

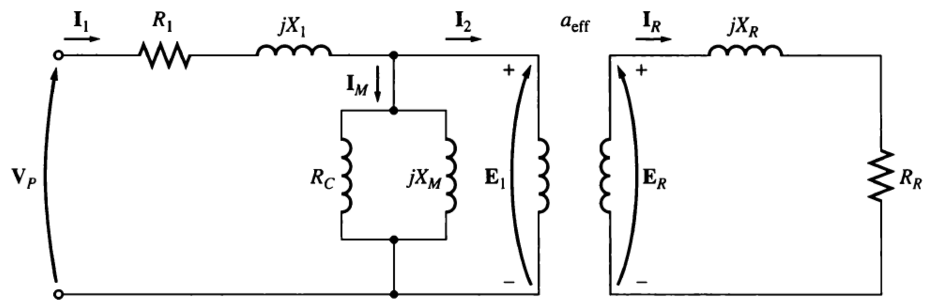
iii. f_{re} = Frequency of inducing EMF

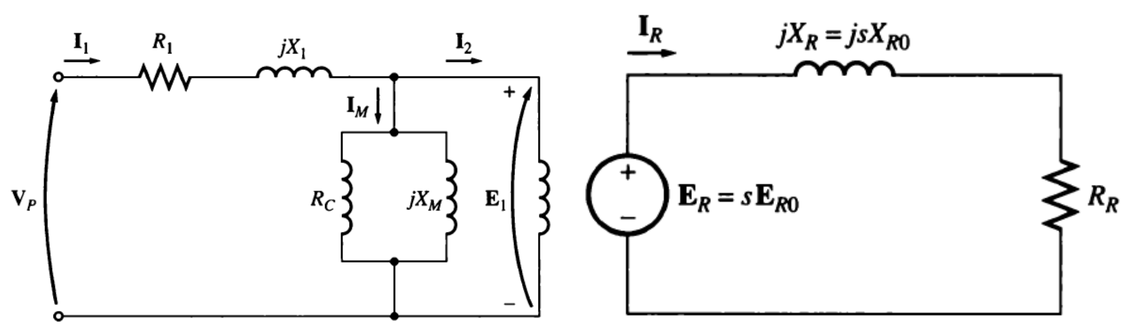
j. Stator frequency, $f_{se} = \frac{n_{sync}P}{120}$

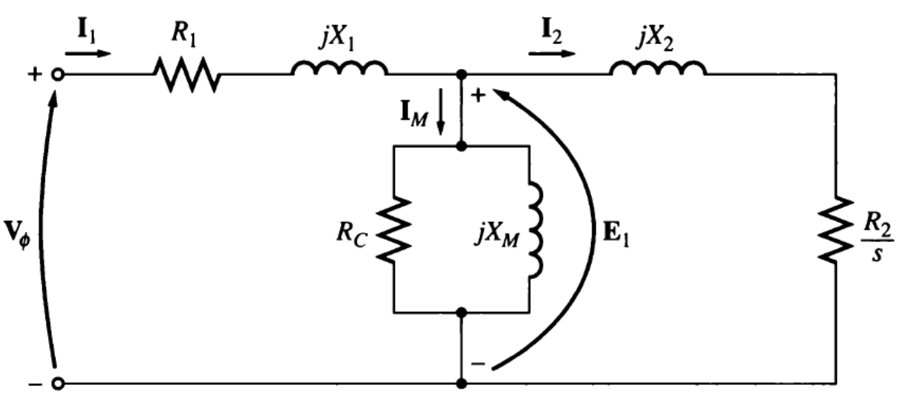
k. Shaft load torque, $\tau_{load} = \frac{P_{out}}{\omega_m}$

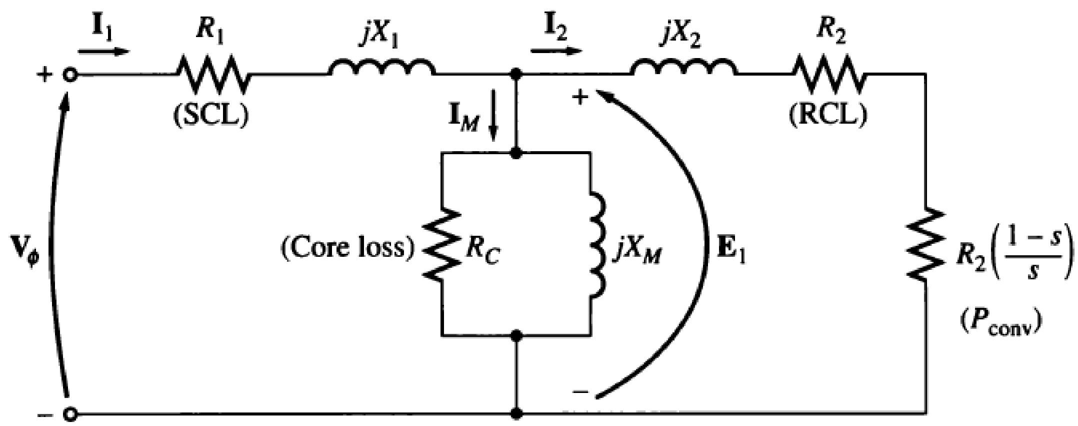
l. $\omega_m = 2\pi n_m\ rad/min = \frac{2\pi n_m}{60}\ rad/s$

8. Equivalent circuit of induction motor









a. $Z_{eq} = R_1 + jX_1 + \left(jX_M || \left(jX_2 + \frac{R_2}{s}\right)\right) = R_1 + jX_1 + \frac{1}{-\frac{j}{X_M} + \frac{1}{\frac{R_2}{S} + jX_2}}$

b. $R_2 = a_{eff}^2 R_R$

c. $X_2 = a_{eff}^2 X_{R0}$

d. Induced voltage at locked rotor $= E_{R0}$

e. Induced voltage, $E_R = sE_{R0}$

f. $P_{SCL} = 3I_1^2 R_1$

g. $P_{RCL} = 3I_2^2 R_2 = sP_{AG}$

h. $P_{rot} = P_{core} + P_{F\&W} + P_{misc}$

i. $P_{conv} = (1 - s)P_{AG}$

j. $P_{out} = P_{conv} - P_{rot}$

k. $P_{in} = V_\phi I_1$

l. P_{AG} is consumed by $\frac{R_2}{s}$

m. P_{RCL} is consumed by R_2

n. P_{conv} is consumed by $R_{conv} = R_2\left(\frac{1-s}{s}\right)$

o. Induced torque, $\tau_{ind} = \frac{P_{conv}}{\omega_m} = \frac{P_{AG}}{\omega_{sync}}$

p. Output torque, $\tau_{load} = \frac{P_{out}}{\omega_m}$

q. $V_{TH} = V_\phi \frac{X_M}{\sqrt{R_1^2 + (X_1 + X_M)^2}}$

r. $R_{TH} \approx R_1 \left(\frac{X_M}{X_1 + X_M}\right)^2$

s. $X_{TH} \approx X_1$

t. Slip at pullout torque, $s_{max} = \frac{R_2}{\sqrt{R_{TH}^2 + (X_{TH} + X_2)^2}}$

u. $\tau_{ind} = \frac{3V_{TH}^2 \frac{R_2}{s}}{\omega_{sync}\left[\left(R_{TH}+\frac{R_2}{s}\right)^2+(X_{TH}+X_2)^2\right]}$

v. For maximum toque, $\frac{R_2}{s} = \sqrt{R_{TH}^2 + (X_{TH} + X_2)^2}$

w. $\tau_{max} = \frac{3V_{TH}^2}{2\omega_{sync}\left[R_{TH}+\sqrt{R_{TH}^2+(X_{TH}+X_2)^2}\right]}$

x. $\tau_{start} = \frac{3V_{TH}^2 R_2}{\omega_{sync}[(R_{TH}+R_2)^2+(X_{TH}+X_2)^2]}$ $[\tau_{ind}(s=1)]$

y. No load test

  i. $|Z_{nl}| = \frac{V_\phi}{I_{1,nl}} \approx X_1 + X_M$

z. DC test

  i. Y connected stator, $R_1 = \frac{V_{DC}}{2I_{DC}}$

  ii. Δ connected stator, $R_1 = \frac{3V_{DC}}{2I_{DC}}$

aa. Locked rotor test

  i. $|Z_{LR}| = \frac{V_\phi}{I_1}$

  ii. $Z_{LR} = R_{LR} + jX'_{LR} = |Z_{LR}|\cos\theta + j|Z_{LR}|\sin\theta$

  iii. $R_{LR} = R_1 + R_2$

  iv. $X_{LR}' = X_1' + X_2'$

  v. $X_{LR} = \frac{f_{rated}}{f_{test}} X'_{LR}$

  vi. $\text{PF} = \cos\theta = \frac{P_{in}}{\sqrt{3}V_T I_L}$

  vii. $I_{L,av} = \frac{I_A+I_B+I_C}{3}$

bb. Circuit parameters

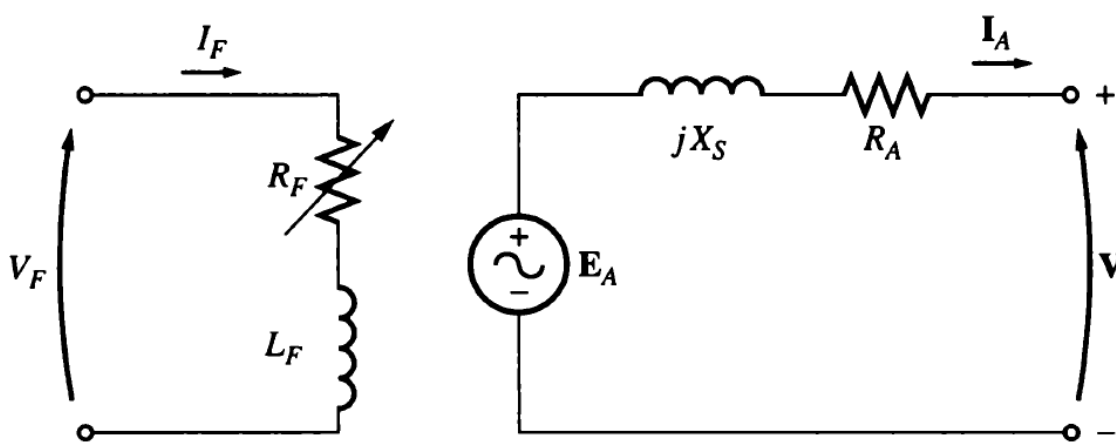
  i. R_1 from DC test

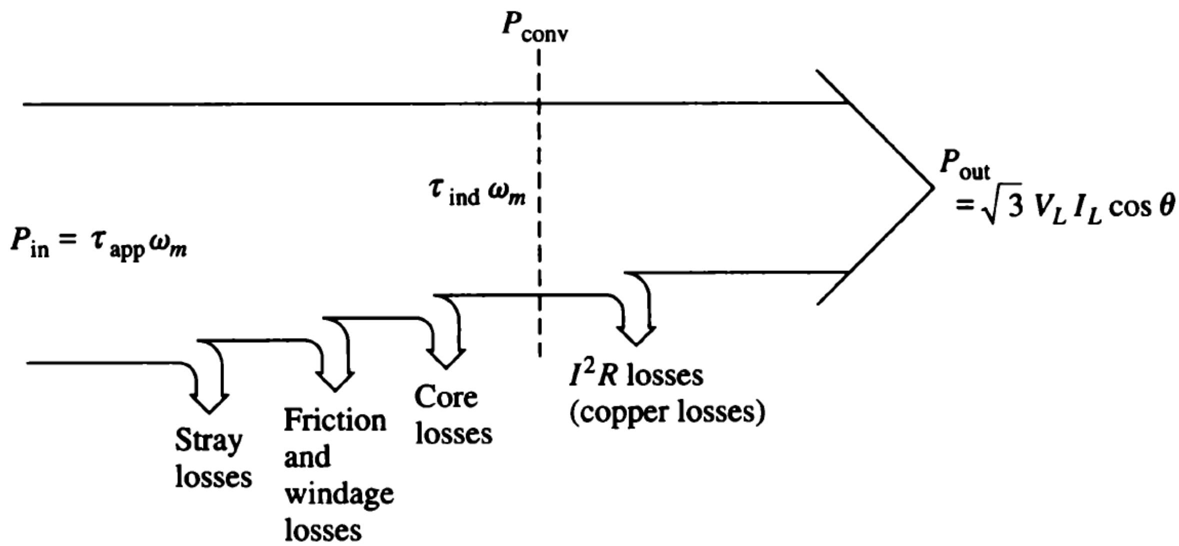
  ii. R_2, X_1, X_2 from Locked rotor test

  iii. X_M from No Load test

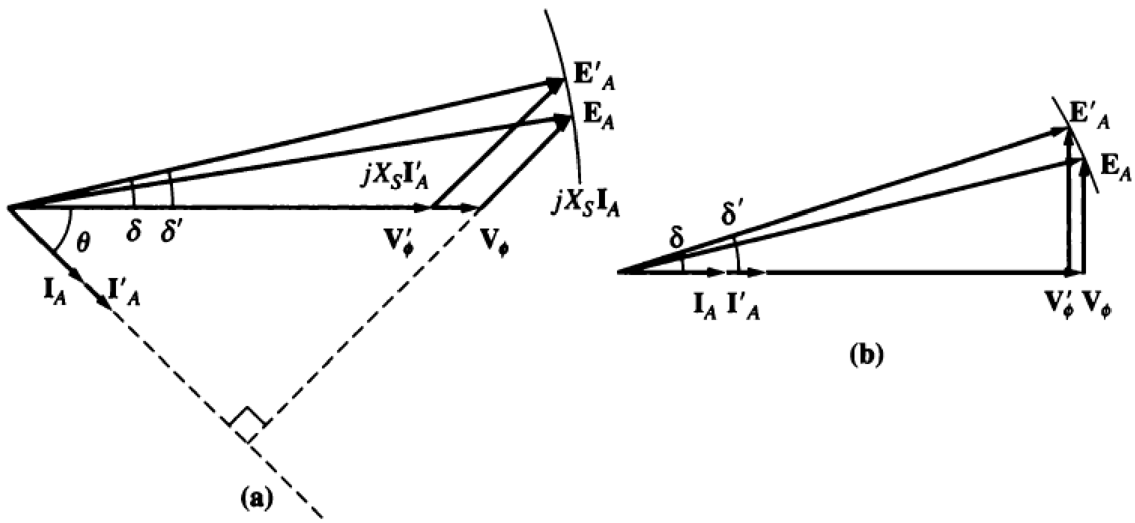
	X_1 and X_2 as functions of X_{LR}	
Rotor Design	X_1	X_2
Wound rotor	0.5 X_{LR}	0.5 X_{LR}
Design A	0.5 X_{LR}	0.5 X_{LR}
Design B	0.4 X_{LR}	0.6 X_{LR}
Design C	0.3 X_{LR}	0.7 X_{LR}
Design D	0.5 X_{LR}	0.5 X_{LR}

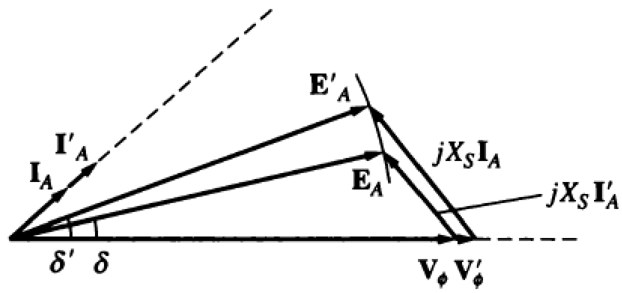
9. Synchronous generators
    a. Stator resistance $= R_A$
    b. Stator self-inductance $= L_A$
    c. Stator self-reactance $= X_A$
    d. Synchronous reactance, $X_S = X + X_A$
    e. $E_{stat} = -jXI_A$
    f. $V_\phi = E_A - jXI_A - jX_A I_A - R_A I_A = E_A - jX_S I_A - R_A I_A$
    g. $V_\phi = E_A$ [No load]
    h. $E_A = k\phi\omega$
    i. $f_{se} = \frac{n_m P}{120}$
    j. n_m = mechanical speed of magnetic field = Speed of rotor
    k. Field circuit of exciter is mounted on stator of generator.
    l. Armature circuit of exciter is mounted on rotor of generator.
    m. For exciter Field is stator and Armature is rotor.
    n. For synchronous generator Field is rotor and Armature is stator.
    o. Three phase input → Field circuit of exciter → Armature circuit of exciter → Three phase output → Field circuit of synchronous generator → Armature circuit of synchronous generator → Three phase output





p. Mechanical power input from prime mover $= P_{in}$
q. Power got in armature circuit $= P_{conv}$
r. $P_{conv} = 3E_A I_A \cos\gamma$
s. $\theta = Power\ factor\ angle$
t. $P_{out} = 3V_\phi I_A \cos\theta$
u. $Q_{out} = 3V_\phi I_A \sin\theta$
v. Internal angle/Torque angle $= \delta$
w. $V_\phi(lagging) < V_{phi}(leading)$
x. $E_A(lagging) > E_A(leading)$
y. No load voltage, E_A
z. Leading load $\rightarrow Q -$
aa. Lagging load $\rightarrow Q +$
bb. Effect of changing load
    i. Increase leading load V_ϕ increase
    ii. Increase lagging load V_ϕ decrease
cc. Ignoring R_A
    i. $P_{conv} = P_{out} = \frac{3V_\phi E_A}{X_S}\sin\delta$
    ii. Static stability limit, $P_{max} = \frac{3V_\phi E_A}{X_S}$
    iii. $E_A \sin\delta = X_S I_A \cos\theta$
    iv. $\pi_{ind} = \frac{3V_\phi E_A}{\omega_m X_S}\sin\delta$
dd. Effect of load change
    i. Single generator:





ee. Increasing governors set point increases the system frequency.
ff. Increasing generators field current increases the terminal voltage.
gg. In case of parallel generators
  i. Increasing governors set point of one generator also increases the real power supplied by that generator. But the generator starts to consume reactive power. By increasing field current we can adjust the generator to supply reactive power.
  ii. Increasing field current of generator also increases the reactive power supplied by that generator.
hh. $P = s_p(f_{nl} - f_{sys})$
ii. Generator operating alone
jj. Generator in parallel with infinite bus
kk. Generator in parallel with same size generator
ll. Δ connected, $V_T = V_\phi$
mm. Y connected, $V_T = \sqrt{3}V_\phi$
nn. 480V, 60Hz, Δ connected, four pole synchronous generator
  i. $No\ load\ terminal\ voltage = 480V$
  ii. $f_{se} = 60Hz$
  iii. $P = 4$

oo. 13.8KV, 50MVA, 0.9power-factor-lagging,60Hz, four pole,Y-connected

i. Full load(0.9pf-lagging) terminal voltage,$V_{Tfl,rated} = 13.8\text{KV}$

ii. $S_{rated} = \sqrt{3}V_{\phi,rated}I_{A,max} = 50MVA$

iii. Power factor of whole circuit(including load) at rated condition = 0.9

iv. $f_{se} = 60Hz$

v. $P = 4$

vi. $Y\ connected, V_{\phi} = \frac{V_T}{\sqrt{3}}$

pp. $S_{rated} = 3V_{\phi,rated}I_{A,max}$

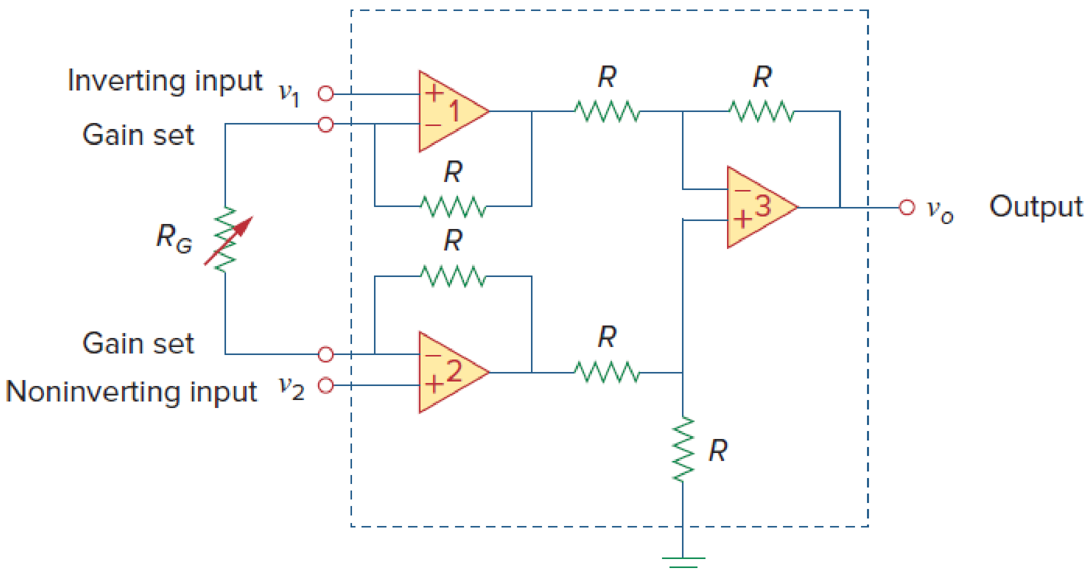
qq. OCC curve of $V_{Tnl}\ vs\ I_F$ will be given. If we can find V_{Tnl} we can also find I_F from graph.

10. Instrumentation Amplifier

a. DC, $A = \frac{V_o}{E_1 - E_2} = 1 + \frac{2}{a}$

b. AC, $A = \frac{V_o}{E_1} = 1 + \frac{2}{a}$

c. $V_{rms} = \frac{V_P}{\sqrt{2}}$



11. Shunt generator

a. $E_A = k\phi\omega_m$

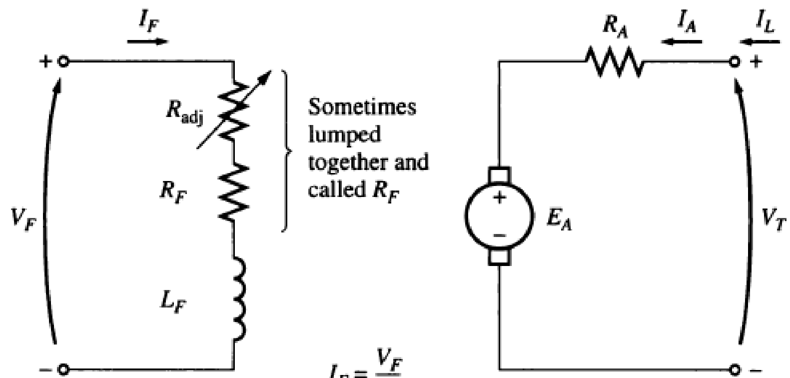
b. $\omega_m = 2\pi n_m$

12. Shunt motor

a. When the armature of the DC motor rotates under the influence of driving torque, the armature of the conductors moves through a magnetic field inducing an emf in them. The [induced emf] is in the opposite direction to the applied voltage and is known as the back emf.

b. Induced torque, $Z_{ind} = K\phi I_A$
c. $\omega_m \propto R_F$
d. $\omega_m \propto \frac{1}{R_A}$
e. $\omega_m \propto V_T$

13. DC Motor
  a. No load $I_A = 0, \tau_{ind} = 0$
  b. Separately Excited DC Motor



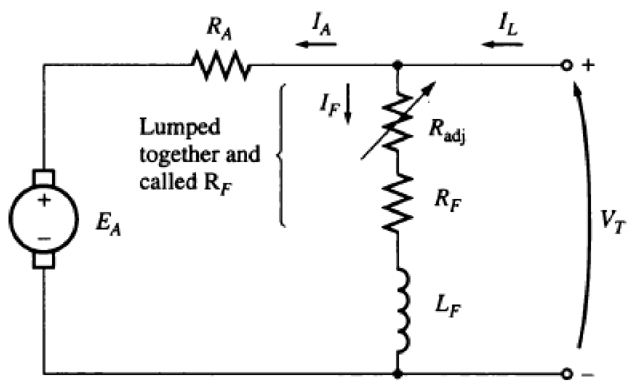
$$I_F = \frac{V_F}{R_F}$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A$$

(a)

  c. Shunt DC Motor

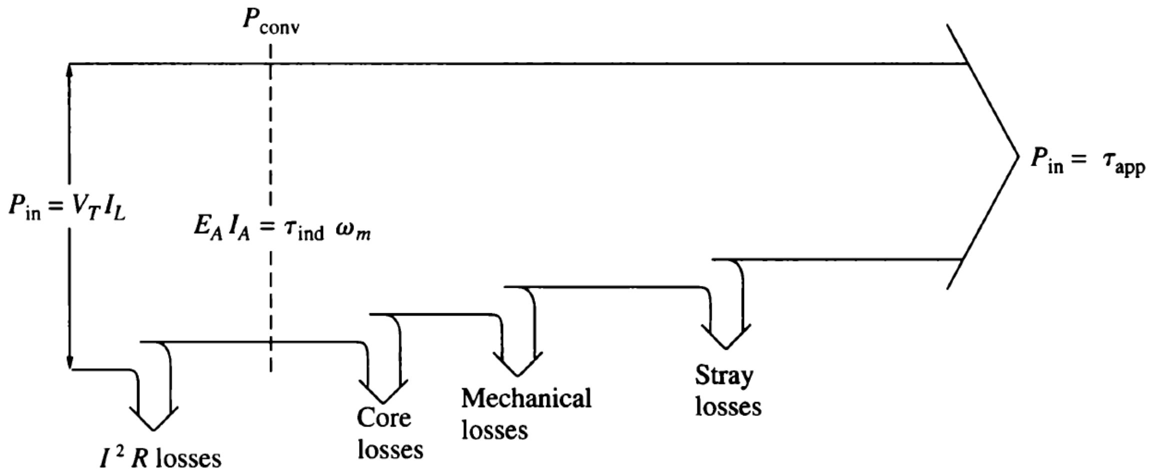


$$I_F = \frac{V_T}{R_F}$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A + I_F$$

(b)



i. $\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2}\tau_{ind}$
ii. $E_A = K\phi\omega_m$
iii. $I_A = \frac{V_T - E_A}{R_A}$
iv. $\tau_{ind} = \frac{P_{conv}}{\omega_m} = K\phi I_A$
v. $P_{conv} = \tau_{ind}\omega_m = E_A I_A$
vi. $\frac{E_{A1}}{E_{A2}} = \frac{V_T - I_{A1}R_A}{V_T - I_{A1}R_A} = \frac{K\phi_{I_{F1}} n_{m1}}{K\phi_{I_{F2}} n_{m2}} = \frac{KE_{A I_{F1}} n_{m1}}{KE_{A I_{F2}} n_{m2}}$
vii. So basically to find $\frac{E_{A1}}{E_{A2}}$ we need the value of $\frac{\phi_1}{\phi_2}$. We can rewrite this as $\frac{\phi_{I_{F1}}}{\phi_{I_{F2}}}$. We can find this from $\frac{E_{I_{F1}}}{E_{I_{F2}}}$. We will find the value of from curve.
viii. For same speed, $\frac{E_{A1}}{E_{A2}} = \frac{\phi_1}{\phi_2}$
ix. $\tau_{load} = \frac{P_{out}}{\omega_m}$
x. $P_{in} = V_T I_L$
xi. 100-hp, 250-V 1200 r/min shunt
    1. $V_T = 250$
xii. $n = \frac{E_A}{E_{Ao}} n_o\ [When\ only\ I_A\ changes]$
xiii. $E_{Ao} = From\ curve\ [Shunt, Series \rightarrow I_F\ and\ Compound \rightarrow I_F^*]$
xiv. $E_A = From\ KVL$
xv. $[Shunt = V_T - I_A R_A, Series, Compound = V_T - I_A(R_A + R_S)]$
xvi. Shunt, $E_{Ao} = V_T\ [No\ load]$
xvii. Compound, $E_{Ao} = I_{F,nl} \rightarrow I_F^* \rightarrow E_A\ [No\ load]$
xviii. Series, $E_{Ao} \rightarrow On\ load$

xix. Speed control

1. Changing the Field Resistance

    a. $\frac{\phi_{I_{F1}}}{\phi_{I_{F2}}} = \frac{E_{A,I_{F1}}}{E_{A,I_{F2}}}$

    b. $[If\ we\ know\ I_{F1}\ and\ I_{F2},$
    $we\ can\ get\ the\ value\ of\ E_{A,I_{F1}}\ and\ E_{A,I_{F2}}\ from\ curve]$

    c. Can control above base speed

    d. Minimum speed occurs when the motor's field circuit has the maximum permissible current flowing through it.

xx. The base speed of a motor is the **nameplate speed at the rated voltage and full load.**

1. **Increasing** R_F **causes** $I_F (= V_T / R_F \uparrow)$ to decrease.
2. **Decreasing** I_F decreases ϕ.
3. **Decreasing** ϕ lowers E_A $(= K\phi\downarrow\omega_m)$.
4. **Decreasing** E_A increases $I_A (= V_T - E_A \downarrow)/R_A$.
5. **Increasing** I_A increases $\tau_{ind} (= K\phi\downarrow I_A \Uparrow)$, with the change in I_A dominant over the change in flux).
6. **Increasing** τ_{ind} makes $\tau_{ind} > \tau_{load}$, and the speed ω_m increases.
7. **Increasing** ω_m increases $E_A = K\phi\omega_m\uparrow$ again.

8. **Increasing** E_A **decreases** I_A.
9. **Decreasing** I_A **decreases** τ_{ind} **until** $\tau_{ind} = \tau_{load}$ **at a higher speed** ω_m.

    a. R_F increases, I_F, ϕ decreases, $\cancel{\tau_{ind}}$ ~~constant~~, ω_m increases.

    b. $\tau_{max} = K\phi I_{A,max}$ $[\phi\ decreases, \tau_{max}\ decreases]$

    c. $P_{max} =$
    $\tau_{max}\omega_m$ $[\tau_{max}\ decreases, \omega_m\ increases, P_{max}\ constant]$

2. Changing the armature voltage

    a. Can control below base speed

    b. Maximum speed occurs when the motor's armature voltage reaches its maximum permissible level.

    c. V_A increase, ω_m increases

    d. $P_{max} = \tau_{max}\omega_m$ $[\tau_{max}$ constant,
    ω_m increases, P_{max} increases]

    e. $\tau_{max} = K\phi I_{A,max}$ $[\phi\ constant, \tau_{max}\ constant]$

1. An increase in V_A increases I_A [$= (V_A\uparrow - E_A)/R_A$].
2. Increasing I_A increases τ_{ind} ($= K\phi I_A\uparrow$).
3. Increasing τ_{ind} makes $\tau_{ind} > \tau_{load}$ increasing ω_m.
4. Increasing ω_m increases E_A($= K\phi\omega_m\uparrow$).
5. Increasing E_A decreases I_A [$= (V_A\uparrow - E_A)/R_A$].
6. Decreasing I_A decreases τ_{ind} until $\tau_{ind} = \tau_{load}$ at a higher ω_m.

3. Inserting resistor in series with armature circuit
    a. Wasteful method
    b. No load torque is always same
    c.

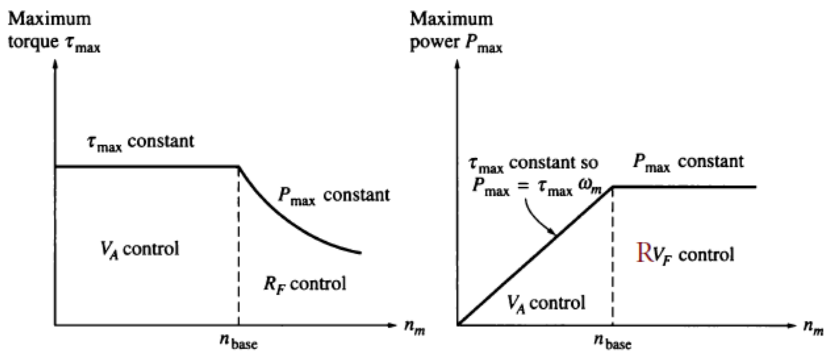
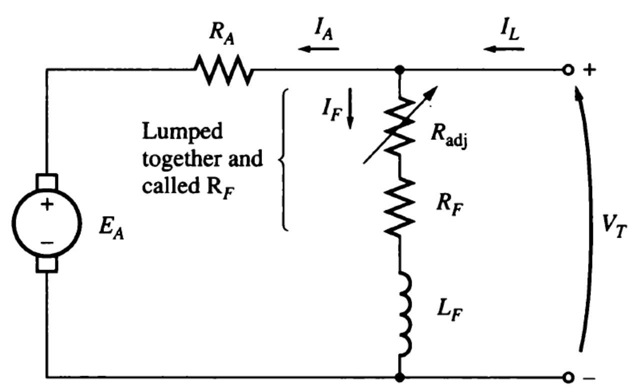


FIGURE 8–16
Power and torque limits as a function of speed for a shunt motor under armature volt and field resistance control.



$$I_F = \frac{V_T}{R_F}$$

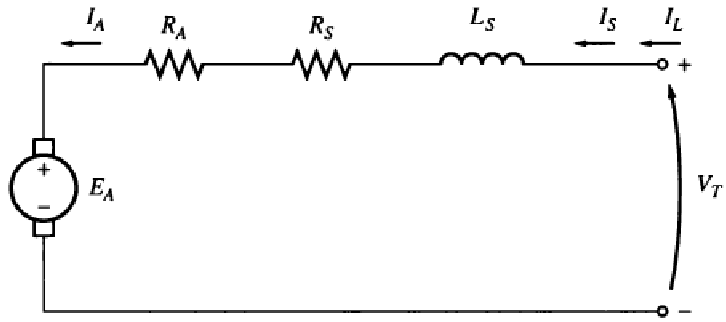
$$V_T = E_A + I_A R_A$$

$$I_L = I_A + I_F$$

(b)

d. Series DC Motor

i. $\omega_m = \frac{V_T}{\sqrt{Kc}} \frac{1}{\sqrt{\tau_{ind}}} - \frac{R_A + R_S}{Kc}$



$I_A = I_S = I_L$

$V_T = E_A + I_A (R_A + R_S)$

ii. $\phi = cI_A$

iii. $\tau_{ind} = K\phi I_a = KcI_A^2$

iv. Magnetomotive force, $\mathcal{F} = NI_F$

v. Should not be operate at no load

e. Compounded DC Motor

i. $\mathcal{F}_{net} = \mathcal{F}_{\mathrm{F}} \pm \mathcal{F}_{\mathrm{SE}} - \mathcal{F}_{\mathrm{AR}}$

ii. Effective field current, $I_F^* = I_F \pm \frac{N_{SE}}{N_F} I_A - \frac{\mathcal{F}_{\mathrm{AR}}}{N_F}$

iii. N_{SE} = Turns per pole on series winding

iv. N_F = Turns per pole on field winding

v. Cumulatively Compounded DC Motor

1.

vi. Differentially Compounded DC Motor

vii. The speed of the cumulatively compounded motor decreases with load, while the speed of the differentially compounded motor increases with load.

f. DC Motor with compensating windings doesn't have armature reaction.

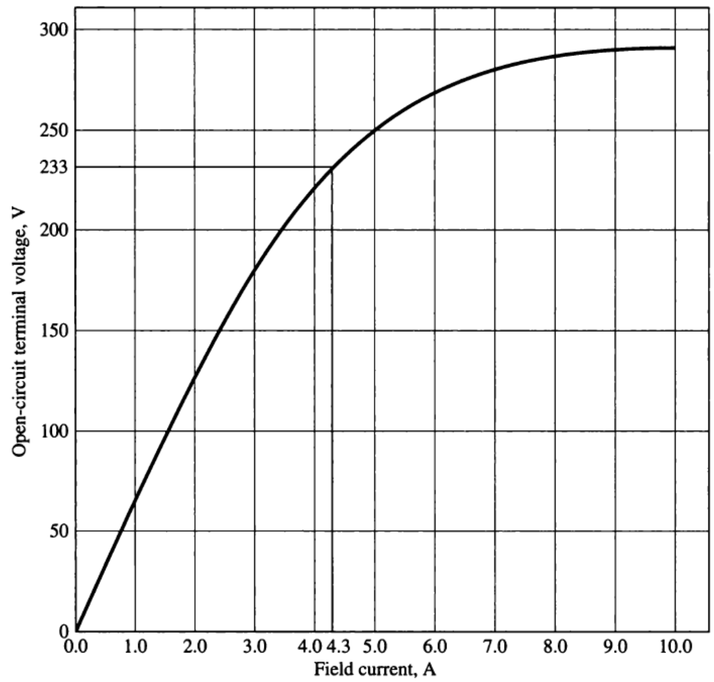


FIGURE 8–9
The magnetization curve of a typical 250-V dc motor, taken at a speed of 1200 r/min.

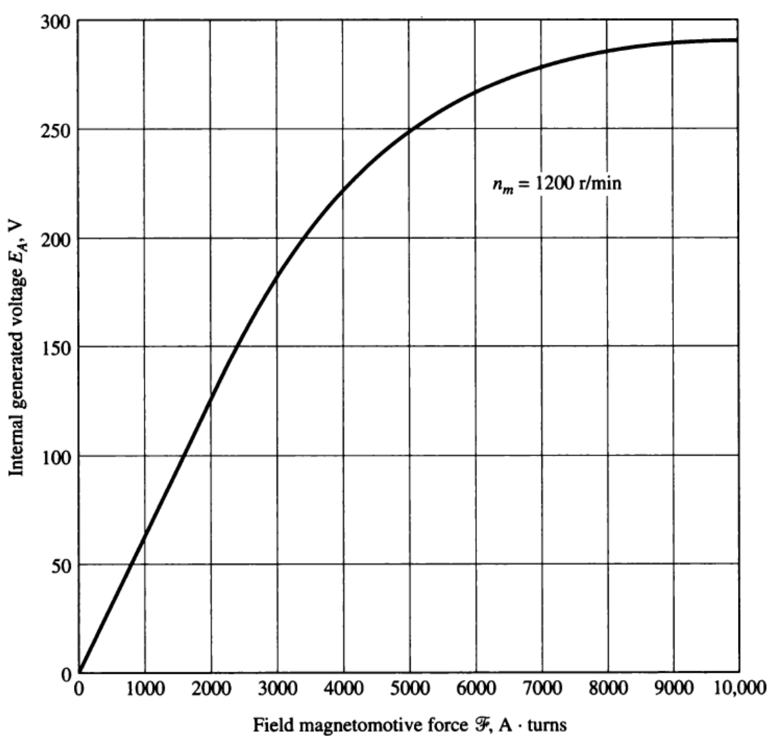


FIGURE 8–22
The magnetization curve of the motor in Example 8–5. This curve was taken at speed n_m = 1200 r/min.

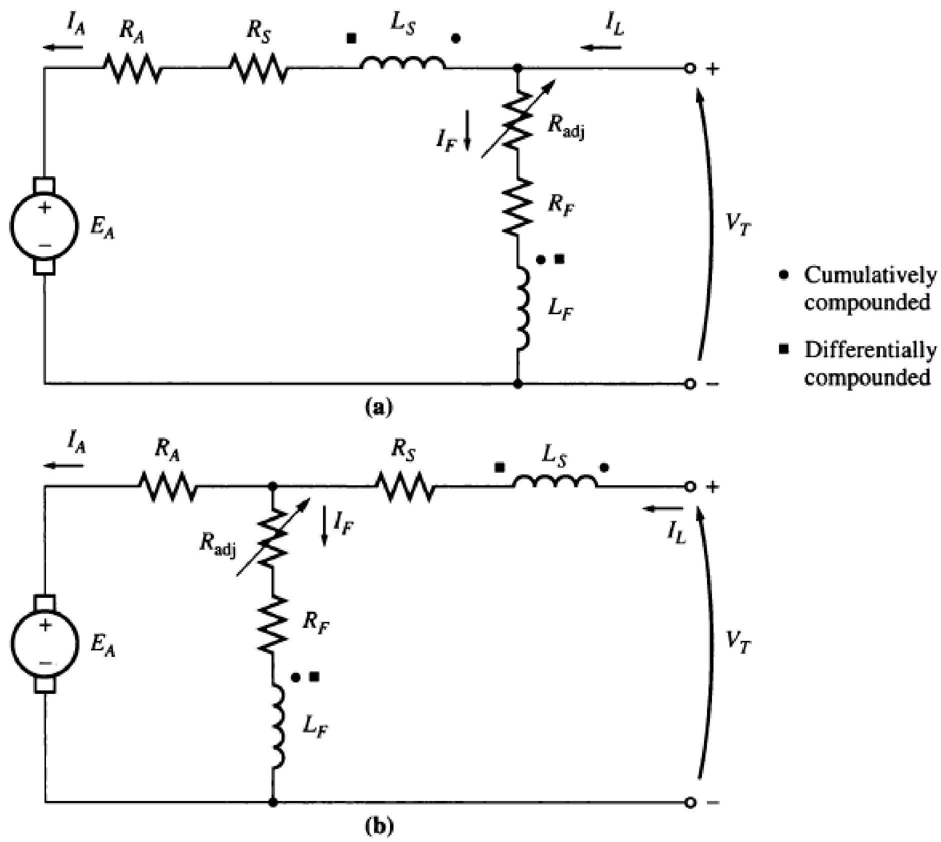


FIGURE 8–24
The equivalent circuit of compounded dc motors: (a) long-shunt connection; (b) short-shunt connection.

g. Motor starters
h. Summary
   i. 5 types of generator
   ii. 2 types of compound generator
   iii. 3 types of speed control
   iv. 1 type of starter
   v. 2 types of voltage variable