Formula Sheet

Electric Power:

$$S = V_{rms} I_{rms} \quad VA$$

$$Q = V_{rms} I_{rms} \sin(\theta_v - \theta_i) \quad VAR$$

$$P = V_{rms} I_{rms} \cos(\theta_v - \theta_i) \quad W$$

$$S = \sqrt{P^2 + Q^2}$$

Three phase power:

$$P = 3V_{\emptyset} I_{\emptyset} \cos(\theta)$$

$$Q = 3V_{\emptyset} I_{\emptyset} \sin(\theta)$$

$$S = 3V_{\emptyset} I_{\emptyset}$$

$$P = \sqrt{3} V_L I_L \cos(\theta)$$

$$Q = \sqrt{3} V_L I_L \sin(\theta)$$

$$S = \sqrt{3} V_L I_L$$

Power and impedance

$$P = I^2 Z \cos(\theta) = I^2 R$$

$$Q = I^2 Z \sin(\theta) = I^2 X$$

$$S = I^2 Z$$

$$\boldsymbol{S} = \boldsymbol{V}\boldsymbol{I}^* = V\angle\theta_v . I\angle{-\theta_i}$$

Three Phase voltage:

$V_L = V_{\emptyset}$ For Δ Connected

$I_L = \sqrt{3}\, I_{\emptyset}$ For Δ Connected

$V_L = \sqrt{3} V_{\emptyset}$ For star-Connected

$I_L = I_{\emptyset}$ For star-Connected

Three phase source conversion from Δ to star

$$V_{\phi} = \frac{V_{line}}{\sqrt{3}\angle 30°}$$

Voltage induced on a conductor in a magnetic field

$$e = (\boldsymbol{v} \times \boldsymbol{B}) . \boldsymbol{L}$$

Forces on a current carrying conductor:

$$\boldsymbol{F} = i(\boldsymbol{L} \times \boldsymbol{B})$$

Lorentz Equation:

$$\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$$

Force of attraction per unit area in a magnetic field:

$$\frac{f_m}{A} = {}^1\!/_2 \frac{B^2}{\mu_0}$$

Magnetic flux of an infinite current carrying straight conductor:

$$B = \frac{\mu_0 i}{2\pi r} \quad \mu_0 = 4\pi \times 10^{-7}$$

Magnetic flux of a finite current carrying straight conductor:

$$B = \frac{\mu_0 i}{2\pi r} (\cos\alpha_2 - \cos\alpha_1)$$

Flux intensity:

$$H = \frac{B}{\mu} \quad \mu = \mu_0 \mu_r$$

Ampere's Law (general form)

$$\oint_C \boldsymbol{H} . \boldsymbol{dl} = \int_s J \, ds$$

Ampere's Law for a toroidal coil: (H inside the core of the coil)

$$\sum i = Ni = \oint \boldsymbol{H} . \boldsymbol{dl} = H . 2\pi r$$

Flux Linkage (General Form):

$$\lambda = \sum \phi$$

Flux linkage for N identical core:

$$\lambda = N\phi$$

Inductance:

$$L = \frac{\lambda}{i}$$

Magnetic energy stored in the coil:

$$W_m = {}^1\!/_2 L i^2 = {}^1\!/_2 \lambda i$$

Faraday's Law

$$e = \frac{d\lambda}{dt} = NA \frac{dB}{dt}$$

Gauss Law:

$$\oint_s \emptyset \, ds = 0$$

Flux in the airgap

$$\phi = B_g A_g$$

Reluctance of steel core:

$$\mathcal{R}_s = \frac{l_s}{\mu_r \mu_0 A_s}$$

Reluctance of air-gap:

$$\mathcal{R}_g = \frac{l_g}{\mu_0 A_g}$$

Magneto motive force:

$$\mathcal{F} = \phi \mathcal{R}$$

Magneto motive force:

$$\mathcal{F} = Ni = Hl$$

Magneto motive force in core with airgap:

$$\mathcal{F} = Ni = H_g l_g + H_C l_C$$

Voltage of coupled coils:

$$v_1 = R_1 i_1 + L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

Force on armature in magnetic storage system:

$$f_{fld} = -\left.\frac{\partial W_{fld}}{\partial x}\right|_{\lambda}$$

Force in magnetic storage system w.r.t inductance:

$$f_{fld} = \frac{i^2}{2} \frac{dL(x)}{dx}$$

Force in magnetic storage system w.r.t reluctance:

$$f_{fld} = \frac{1}{2} \emptyset^2 \frac{\partial \mathcal{R}}{\partial x}$$

Torque in magnetic storage system w.r.t inductance and reluctance:

$$\tau = \frac{1}{2} i^2 \frac{\partial L}{\partial \theta} = \frac{1}{2} \emptyset^2 \frac{\partial \mathcal{R}}{\partial \theta}$$

Induced voltage in a linear DC machine:

$$e_{ind} = vBL$$

Force in a linear DC machine:

$$F = iBL$$

Speed in a linear DC machine:

$$v = \frac{V_B}{BL} - \frac{R}{(BL)^2} . F_{load}$$

Speed regulation:

$$SR = \frac{v_{no-load} - v_{full-load}}{v_{no-load}} \times 100\%$$

Efficiency of linear machine:

$$\eta = \frac{Vi - i^2 R}{Vi} \times 100\%$$

$$= \left[1 - i \frac{R}{V}\right] \times 100\%$$

$$= \left[1 - \frac{F_{load}}{BL} \frac{R}{V}\right] \times 100\%$$

Torque in rotational DC machine:

$$\tau = K\emptyset i$$

Induced voltage in rotational DC machine:

$$e_{ind} = K\emptyset\omega$$

Speed in rotational DC machine:

$$\omega = \frac{V_B - \frac{\tau_{load} R}{K\emptyset}}{K\emptyset}$$

Efficiency in DC rotational Machine with only heat loss:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{P_{in} - P_{loss}}{P_{in}} \times 100\%$$

$$= \frac{V_B i - i^2 R}{V_B i} \times 100\%$$

$$= \left[1 - i \frac{R}{V_B}\right] \times 100\%$$

$$= \left[1 - \frac{\tau_{load} R}{K\emptyset V_B}\right] \times 100\%$$

Speed of the rotating field (P pairs of poles):

$$N_s = \frac{60f}{P} \ (rev/min)$$

$$n_s = \frac{f}{P} \ (rev/s)$$

$$\omega_s = \frac{2\pi \times N_s}{60}$$

Voltage of equivalent synchronous generator:

$$V_\emptyset = E_A - jX_s I_A$$

Voltage of equivalent synchronous Motor:

$$V_{\emptyset} = E_A + jX_s I_A$$

Power in a 3phase synchronous machine:

$$P_{3\emptyset} = \frac{3|E_A||V_{\emptyset}|}{X_s} sin\delta = P_{max} sin\delta$$

Developed torque in synchronous machine:

$$\tau_d = \frac{3|E_A||V_{\emptyset}|}{\omega_s X_s} sin\delta = \tau_{d,max} sin\delta$$

Reactance of synchronous machine:

$$X_s = \frac{E_{A,Opencircuit\ test}}{I_{A,short\ circuit\ test}}$$

Slip in an induction motor:

$$s = \frac{N_s - N_r}{N_s} \times 100\%$$

$$N_r = (1-s)N_s$$

$$\omega_m = \omega_r = (1-s)\omega_s$$

Rotor current frequency in induction motor:

$$f_r = sf_e$$

Airgap Power in induction motor:

$$P_{AG} = I_r^2 \frac{R_r}{s}$$

Rotor losses in induction motor:

$$P_r = sP_{AG} = I_r^2 R_r$$

Converted mechanical power in induction motor:

$$P_{mech} = (1-s)P_{AG} = P_{\text{out}} + P_{mechanical\ loss}$$

Torque on load in induction motor:

$$\tau_{\text{load}} = \frac{P_{\text{out}}}{\omega_m}$$

Induced torque in induction motor:

$$\tau_{\text{mech}} = \frac{P_{AG}}{\omega_s} = \frac{P_{mech}}{\omega_m}$$

At low slip, mechanical torque is proportional to slip.

Parallel to series conversion of core equivalent in induction machine:

$$r_C = \frac{{X_M}^2}{{R_C}^2 + {X_M}^2} R_C$$

$$x_m = \frac{{R_C}^2}{{R_C}^2 + {X_M}^2} X_M$$

Stator resistance in induction machine:

$$R_{s,Yconencted} = \frac{V_{DCetst}}{2I_{DCetst}}$$

$$R_{s,\Delta conencted} = \frac{3V_{DCetst}}{2I_{DCetst}}$$

From no load test on induction machine:

$$r_c = \frac{P_{NL} - P_{F,w}}{|I_{NL}|^2} - R_s$$

$$x_m = I_{NL} - X_s$$

From blocked-rotor test on induction machine:

$$R_r' = \frac{P_{BL}}{|I_{BL}|^2} - R_s$$

$$X_r' = \sqrt{\left(\frac{V_{BL}}{I_{BL}}\right)^2 - \left(\frac{P_{BL}}{|I_{BL}|^2}\right)^2} - X_s$$

Ideal Transformer:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = a \quad \frac{I_1}{I_2} = \frac{N_2}{N_1} = \frac{1}{a}$$

Impedance transfer from secondary to primary:

$$Z_2' = \left(\frac{N_1}{N_2}\right)^2 Z_2 = a^2 Z_2$$

Maximum flux density in core:

$$B_{max} = \frac{V_1}{\sqrt{2}\pi f N_1 A}$$

Open Circuit test:

$$R_C = \frac{V_{oc}^2}{P_{oc}}$$

$$x_m = \frac{1}{\sqrt{\left(\frac{I_{oc}}{V_{oc}}\right)^2 - \frac{1}{R_c^2}}}$$

Or:

$$Y_E = \frac{I_{oc}}{V_{oc}} \angle -cos^{-1}\left(\frac{P_{oc}}{V_{oc}I_{oc}}\right) = \frac{1}{R_C} - j\frac{1}{X_m}$$

Short Circuit test:

$$R_{SE} = \frac{P_{sc}}{I_{sc}^2}$$

$$x_{se} = \sqrt{\left(\frac{V_{sc}}{I_{sc}}\right)^2 - R_{SE}^2}$$

Or

$$Z_{SE} = \frac{V_{sc}}{I_{sc}} \angle cos^{-1}\left(\frac{P_{sc}}{V_{sc}I_{sc}}\right) = R_{SE} + jx_{se}$$

Voltage Regulation:

$$V_R = \frac{V_{2nl} - V_{2fl}}{V_{2fl}} \times 100\%$$

Terminal voltage at separately excited DC motor:

$$V_T = E_A + I_A R_A$$

$$I_A = I_L$$

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

$$E_A = K\emptyset\omega_m = K'\emptyset n_m$$

$$\tau_{ind} = K\emptyset I_A$$

$$n_{m2} = \frac{E_{A2}}{E_{A1}} n_{m1}$$

In shunt DC motor:

$$I_L = I_F + I_A$$

In series DC motor:

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

1-phase Diode Bridge:

$$V_{d0} = \frac{2\sqrt{2}V}{\pi}$$

3-phase Diode Bridge:

$$V_{d0} = \frac{3\sqrt{2}V}{\pi}$$

Mean output voltage of Thyristor Bridge:

$$V_d = V_{d0} cos\alpha$$

Three-Phase

- $I_{base} = \frac{S_{3\phi,base}}{\sqrt{3}V_{LL,base}}$
  - $Z_{base} = \frac{V_{LL,base}}{\sqrt{3}I_{base}}$
  - $Zbase = \frac{(V_{LL,base})^2}{S_{3\phi,base}}$

$$\text{Quantity in per unit} = \frac{\text{actual value}}{\text{base value of quantity}}$$

$$\text{Per-Unit } Z_{new} = \text{Per-Unit } Z_{given} \left(\frac{V_{given}}{V_{new}}\right)^2 \left(\frac{S_{new}}{S_{given}}\right)$$