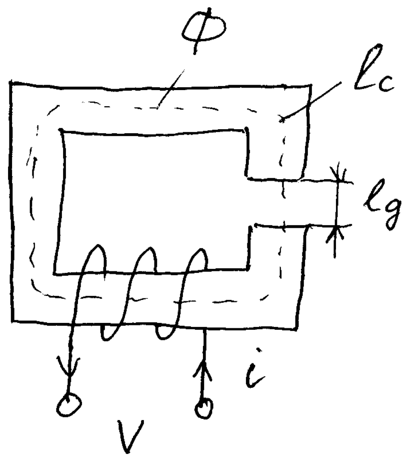
Problem 1 (20pts)

Consider the magnetic system shown below. The core and air-gap have reluctances are $\Re_c = 0.5\times10^6\, A\cdot turn/Wb$ and $\Re_g = 4.5\times10^6\, A\cdot turn/Wb$, respectively. Neglect flux leakage, fringing, and core losses. The coil has 400 turns and the dc resistance of $5\,\Omega$.



(a) (5pts) Draw an equivalent **magnetic** circuit, show the direction of mmf F and the flux Φ

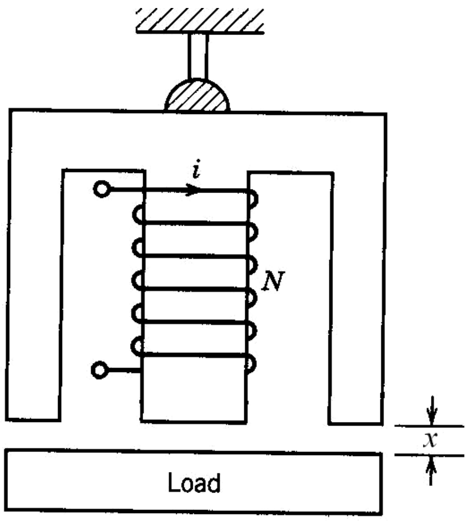
(b) (5pts) Draw an equivalent **electric** circuit and sketch the corresponding qualitative phasor diagram assuming ac source (show all phasors & angles)

(c) (5pts) Calculate the inductance L

(d) (5pts) Calculate the coil impedance Z at 60Hz ac

Problem 2: (20pts)
Consider an electro-mechanical lifting device shown in the figure. You can use common approximations as we did in class and assume magnetically-linear core. The air-gap between the core and the plunger is denoted by x (which has units of meters). Assume that total inductance of this device may be approximated as

$L(x) = 0.2 + \frac{5 \cdot 10^{-3}}{x}$ H, and the dc resistance r is $10\,\Omega$.



(a) (5pts) Sketch the equivalent **magnetic** circuit and label all elements
(b) (5pts) Sketch the equivalent **electric** circuit and label all elements
(c) (10pts) The device is used to lift a 5kg load from a distance of 5 mm. What value of dc voltage V_{dc} and dc current I_{dc} should be applied to the coil?

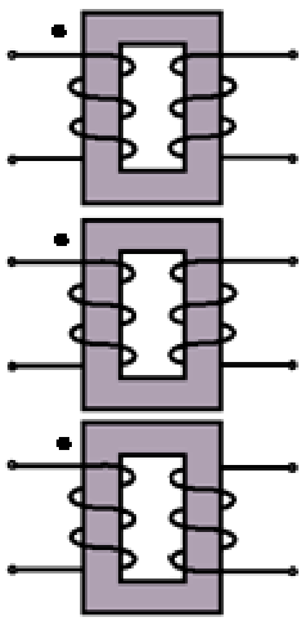
Problem 3 (20pts)
Consider a single-phase 60Hz, 120/24V step-down transformer. The results of the open-circuit and short-circuit tests are: $V_{1,oc} = 120V$, $I_{1,oc} = 1A$, $P_{1,oc} = 20W$, and $V_{1,sc} = 20V$, $I_{1,sc} = 10A$, $P_{1,sc} = 50W$

Assume that winding resistances and leakage reactances are respectively equal when referred to the same side, $R_1 = R_2'$ and $X_1 = X_2'$. You may use common assumption as we did in class. Calculate the equivalent circuit parameters each referred to its side.

Problem 4: (20pts)

Assume that you have three identical step-down transformers shown on the figure below with $N_1 = 300$ and $N_2 = 100$. The transformers may be assumed ideal and connected into Δ/Δ. The load is composed of series *R-L* ($R = 8\,\Omega$ and $X = 6\,\Omega$) per-phase, which are Y-connected and balanced. The primary side is connected to a 3-phase 208V (line-to-line) balanced source. All voltages are **rms** values.

a. (3pts) Label the polarity of each secondary winding with dot "$\bullet$". (Hint: note the direction of each winding!)
b. (5pts) Sketch the connection of the windings and the load resistors and inductors right on this figure below.
c. (2pts) Label the input primary side terminals (on your left) with ***ABC*** and the output terminals (load side on your right) with ***abc***.
d. (5pts) Calculate the **total three-phase real and reactive power** $P_{3\phi}$ and $Q_{3\phi}$ supplied to the load
e. (5pts) Calculate the **primary (input) line** current I_1 and its power factor angle in degrees



Problem 5 (20pts)

Consider a **Permanent-Magnet DC motor** with the following parameters: nominal voltage $V_a = 24$ V; armature resistance $R_a = 2\Omega$; torque constant $K_t = 0.122\left[\frac{N \cdot m}{A} \text{ or } \frac{V \cdot \sec}{rad}\right]$; no-load speed 1800 rpm.

(a) (5pts) Draw an equivalent circuit and appropriately label its elements

(b) (5pts) Calculate the no-load armature current $I_{a,nl}$, friction torque T_{fric}, and the total no-load power loss P_{nl_loss}.

(c) (5pts) Calculate the starting torque T_{start} when the motor is supplied with nominal voltage

(d) (5pts) Assume that the maximum current that can be drawn from the given 24V dc source is 6A. Calculate the smallest value of an additional resistor R_{start} that can be used to safely start this motor. Sketch the circuit

Problem 6 (20pts)

Consider a 115V series-connected DC motor with the following parameters: armature resistance $R_a = 1\Omega$; and field winding resistance $R_f = 2\Omega$. The motor is supplied from a dc source $V_t = 115\,\text{V}$ and is operating under nominal load at speed $n = 3000\,\text{rpm}$ drawing armature current $I_a = 5\,\text{A}$.

(a) (5pts) Draw an equivalent circuit

(b) (5pts) Calculate the induced back emf, E_a

(c) (5pts) Assuming friction torque is 5% of the developed torque, calculate the load torque T_m and efficiency η in %

(d) (5pts) Calculate the torque at zero speed (starting torque), T_{start}

Problem 7 (20pts)

Consider a 60Hz, 36V (line-to-line), Y-connected, NEMA Clsass B (Squirrel-Cage) Induction Motor with the following per-phase parameters: $R_1 = 0.1\,\Omega$, $R_2 = 0.2\,\Omega$, $X_1 = X_2 = 0.3\,\Omega$, and $X_m = 6\,\Omega$ (**all parameters and variables are referred to the stator**). The motor is supplied with the nominal (rated) voltage and is driving a mechanical load. The speed of the motor shaft is n = 864 rpm. You can neglect core and friction losses and use an approximate equivalent circuit. Recall that $T_e = 3\frac{1}{\omega_{syn}} \cdot (I_2)^2 \cdot \frac{R_s}{s}$. Determine the following:

(a) (10pts) Number of poles P and slip s
(b) (5pts) The input power factor PF and the total (3-phase) input real power
(c) (5pts) Total output mechanical power

Problem 8 (20pts)

Consider a 3-phase, 2-pole **Permanent Magnet Round-Rotor Synchronous Generator** with per-phase stator resistance and synchronous reactance $R_a = 0.1\Omega$ and $X_s = 2\ \Omega$, respectively. Assume that this generator operates at 60Hz, 24V (line-to-line), and outputs electric power $S_{3\phi} = 300VA$ to a load with 0.8 lagging power factor.

(a) (6pts) Sketch a phasor diagram and label the q- and d- axes, all relevant angles, and phasors

(b) (7pts) Calculate the induced voltage E_f and the rotor angle δ in degrees

(c) (7pts) Assume mechanical rotational losses $P_{mech\_loss} = 20W$, calculate the efficiency η

Problem 9 (20pts)

Consider a **Salient Pole Synchronous Machine**. The generator delivers rated (nominal) power at unity power factor and rated (nominal) terminal voltage and rotor angle $\delta = 20^\circ$. The generator open circuit voltage is 1.2pu. The stator resistance is negligible.

(d) (10pts) Sketch a phasor diagram and label the q- and d- axes, all relevant angles, and phasors

(e) (10pts) Calculate the reactances X_q and X_d in per unit