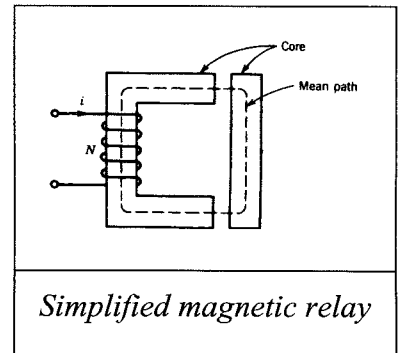


1. Explain the following concepts, use drawings and equations when adequate.
 - a) Describe the stator and rotor constructions and the principle of operation of a **cage induction motor**. (Hint: rotating field, induced current, forces on conductors, etc...) (2p.)
 - b) List the loss components in an asynchronous motor. Explain why and where they occur and how they are represented in the equivalent circuit of the motor. (2 p.)
 - c) Explain the three running modes of operation of an induction machine by drawing the Torque-Speed/Slip curve and give the range of the slip for each mode of operation (2 p.)
 - d) What are the 4 necessary conditions for connecting (synchronizing) a running synchronous generator to the infinite bus? Explain what happens if any of them is not satisfied. (2 p.)
 - e) Draw the complete single-phase equivalent circuit of a transformer and explain what each of its component represents (2p.)
 - f) Explain how the power factor of a synchronous machine can be controlled, while the machine is delivering a constant active power. Draw the phasor diagram of the machine at unity power factor and lagging power factor (hint: use the terminal voltage as reference, 0 deg) (2p.).

2. The magnetic relay in the figure has a coil of 500 turns carrying a current $I_{dc} = 4,19$ A. The mean core path length is $l_c = 360$ mm and each air gap is $l_g = 1,5$ mm. The relative permeability of the core is $\mu_r = 1250$ and its cross-section is $A_c = 100$ mm². Neglect the flux fringing in the air gaps.



- a) Draw the equivalent magnetic circuit of the relay and calculate its parameters (reluctances and mmf) (2 p.)
- b) Calculate the flux density in the air gap by using the magnetic circuit equations (2 p.)
- c) Calculate the total force acting on the moving part of the relay (2 p.)

3. Tests are performed on a 1-phase, 10 kVA, 2200/220 V, 60 Hz transformer and the following results are obtained:

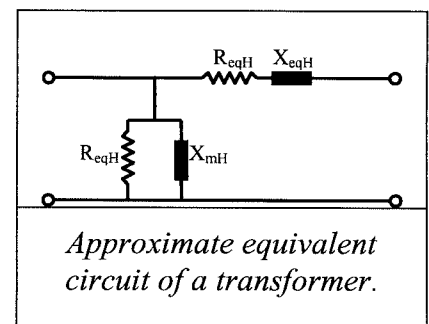
Open-circuit test (high-voltage side open):

Voltmeter 220 V, Ammeter 2.5 A, Wattmeter 100 W.

Short-circuit test (low-voltage side shorted):

Voltmeter 150 V, Ammeter 4.55 A, Wattmeter 215 W.

- a) Derive the parameters for the approximate equivalent circuit shown in the figure, in which the shunt branch is moved to the supply terminal, referred to the high-voltage side (6p.)



4. A three phases, 14 kV, 10 MVA, 60 Hz, two poles, 0,85 PF lagging, star-connected synchronous generator has $X_s = 20 \Omega$ per phase and $R_s = 2 \Omega$ per phase. The generator is connected to an infinite bus and is running at rated condition.
 - a) Determine the excitation voltage E_f (2 p.)
 - b) Determine the load angle δ (2 p.)
 - c) Draw the phasor diagram at this rated operation point (2 p.)

Evaluation:

Grade	Lower limit	Upper limit
0	0	13
1	14	16
2	17	19
3	20	22
4	23	26
5	27	30

Some useful formulas and drawings:

Magnetic reluctance: $\mathfrak{R} = \frac{l}{\mu A}$

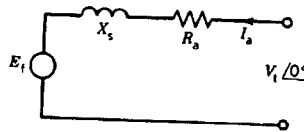
Magnetomotive force: $F = Ni$

Force pressure: $F_m = \frac{B_g^2}{2\mu_0}$

Speed of AC-machine: $n = \frac{120f}{p}$ (p is the number of poles!)

Slip of induction machine: $s = \frac{n_s - n}{n_s}$

Equivalent circuit of a synchronous motor:



Convention: lagging reactive power positive -- > phase angle of current negative

AC active power: $P = 3V_{ph}I_{ph} \cos \phi = \sqrt{3}VI \cos \phi$

Magnetic permeability: $\mu = \mu_r \mu_0$; $\mu_0 = 4\pi 10^{-7} \text{ Hm}^{-1}$