ELEC-C8407 Electromechanics, examination 29.1.2018, 16.30-19.30, AS2.

1. Explain the following concepts, use drawings and equations when adequate.
   a) Describe the construction and operation of a separately exited DC-motor. (hint: stator, rotor, commutator, and operation principles) (2 p.)
   b) Explain the effect of an external resistance connected to the rotor of a wound-rotor induction motor on its speed-torque profile. (hint: slip-torque plot at different resistances) (2 p.)
   c) Explain how the rotating field is produced in the air gape of an AC machine (hint: 3-phases winding in the stator, mmf´s of each phase and their sum) (2 p.)
   d) Explain the static stability limits of a synchronous machine. What are these limits? Why they are important? What happens if any of them exceeds? (hint: use drawing in the PQ plan) (2p.)
   e) Draw the complete single-phase equivalent circuit of a transformer and explain what each of its component represents physically (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, and arbitrary currents with different angles) (2p.)

2. The magnetic circuit of Fig. 1 has a core of relative permeability $\mu_r = 2000$ The depth of the core is 5 cm. The coil has 400 turns and carries a current of 1,5 A. The dashed line shows the average flux path.
   a) Draw the magnetic equivalent circuit and calculate its parameters (mmf and reluctances) (2 p.)
   b) Calculate the flux and the flux density in the core from the equivalent circuit (2 p.)
   c) Determine the inductance of the coil from the results of (b) (2 p.)

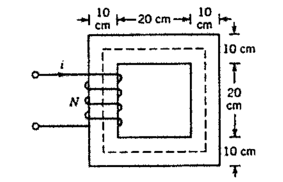

Fig. 1: Magnetic circuit.

3. A three phases, 250 kW, 460 V, 60 Hz, eight-poles, star-connected induction machine is connected to a 460 V infinite bus and is running as a generator at a slip $s = -2,5\,\%$. The IEEE-recommended equivalent circuit of the machine in Fig. 2 has the following parameters:

$$R_1 = 0{,}015\Omega;\ R_2^{'} = 0{,}035\Omega;$$

$$X_1 = 0{,}145\Omega;\ X_2^{'} = 0{,}145\Omega;\ X_m = 6{,}5\Omega$$

   a) Determine the speed of the rotor (2 p.)
   b) Determine the power delivered to the infinite bus and the power factor (2 p.)
   c) Determine the efficiency of the generator. The rotational and core losses are 3 kW (2 p.)

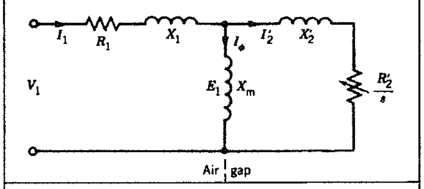

Fig. 2: The IEEE-recommended equivalent circuit of an induction machine.

4. A 1 MVA, 3 phases, 2300 V, 60 Hz, 10 poles, star-connected cylindrical-rotor synchronous motor is connected to an infinite bus. The synchronous reactance is 4,23 Ω. The synchronous motor delivers 746 kW and operates at 0,85 power factor leading. All losses may be neglected.
   a) Determine the armature current I_a (2p)
   b) Determine the excitation voltage E_f and the load angle δ. (2 p.)
   c) Determine the maximum power the motor can deliver for the excitation of part (a). (2 p.)

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

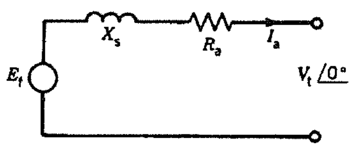
Magnetomotive force: $F = Ni$

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 generator:



Real power of a synchronous machine: $P_{3\phi} = \frac{3|V_t||E_f|}{|X_s|}\sin\delta = P_{max}\sin\delta$

Imaginary/Reactive power of a synchronous machine: $Q_{3\phi} = \frac{3|V_t||E_f|}{|X_s|}\cos\delta - \frac{3|V_t|^2}{|X_s|}$

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

In ac systems, the electrical quantities are complex-valued; they have real and imaginary parts (or amplitude and phase angle)

For an asynchronous machine, we can write the rotor resistance part as: $\frac{R_2'}{s} = R_2' + \frac{(1-s)R_2'}{s}$