S-17.3020 Transient phenomena in electrical machines
Exam 05/05/2008 at 9 – 12 o'clock, Room I 246.

1. Explain briefly
   a) the basic machine with four windings,
   b) small-signal analysis of electrical machines,
   c) state-space presentation of a system of differential equations,
   d) what does a space-vector of a three-phase stator current mean,
   e) the four basic assumptions of space-vector theory.

2. A simple dc-machine with an armature and field winding is running in a steady state. The windings are supplied from voltage sources. The voltage of the field winding drops by 5 %. Derive the differential equations from which the small changes in the currents and speed can be solved.

3. The stator of an electrical machine has a symmetric three-phase winding. The rotor is cylindrical and it has no winding. Due to the sinusoidally distributed air-gap flux density, the mutual inductances of the phase windings are $M = L_h \cos\gamma$, where γ is the electrical angle between the magnetic axes of the windings. The leakage inductance of the winding is $L_{\sigma s}$. Use the definition of a space vector and derive the equation for the stator flux linkage

$$\underline{\psi}_s^s = (L_{\sigma s} + L_m)\underline{i}_s^s$$ n,30

and the equation for the magnetisation inductance L_m. The currents of the stator phase windings are assumed to be arbitrary except that the zero sequence current is zero.

4. A permanent-magnet synchronous machine is connected to a symmetric three-phase grid. It rotates at the speed $\omega = \omega_s/p$. The flux produced by the permanent magnets induces an electromotive force E (rms-value) in the phases of the machine. When the unloaded machine is disconnected from the grid, its speed ω starts to decelerate due to the friction and core losses. The friction loss P_f and core loss P_c are

$$P_f = C_f\omega^3 \ , \quad P_c = C_h\omega + C_e\omega^2$$

Derive an equation for the space vector of the stator voltage after the disconnection. There is no damper winding in this machine. The mass of inertia of the rotor is J.

5. After a three-phase short circuit at the terminals of a synchronous machine, the currents in stator phase a and field winding are

$$i_{sa} = -\hat{u}_{s0}\left\{\left[\frac{1}{X_d} + \left(\frac{1}{X'_d} - \frac{1}{X_d}\right)e^{-t/T'_d} + \left(\frac{1}{X''_d} - \frac{1}{X'_d}\right)e^{-t/T''_d}\right]\cos(\omega t + \vartheta_{r0}) - \frac{1}{2}\left(\frac{1}{X''_d} + \frac{1}{X''_q}\right)e^{-t/T_a}\cos\vartheta_{r0} - \frac{1}{2}\left(\frac{1}{X''_d} - \frac{1}{X''_q}\right)e^{-t/T_a}\cos(2\omega t + \vartheta_{r0})\right\}$$

$$i_f = i_{f0}\left[1 + \left(\frac{X_d}{X'_d} - 1\right)e^{-t/T'_d} - \left(\frac{X_d}{X'_d} - 1\right)e^{-t/T_a}\cos\omega t\right]$$

   a) To which windings are the current components and time constants associated with?
   b) What can you say about the relative magnitude of the time constants?
   c) How do the currents change if we neglect the resistances?