Homework #3: Generator and Load Modeling
(120 Points)

Question 1 (10 points): Prove these two formulas respectively on L'_d and L''_d on Slide #51 (Table 4.1 in Kundur's book)

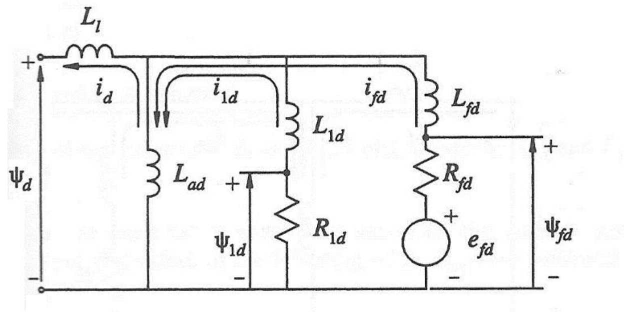
$$L_d\times(T_4/T_1)= L_l+L_{ad}//L_{fd} \qquad\qquad L_d\times(T_4T_6)/(T_1T_3)=L_l+L_{ad}//L_{fd}//L_{1d}$$

Question 2 (10 points): Prove the differential equation on E'_d in the 2-axis (1.1) generator model from the voltage and flux equations. Verify that this equation can be obtained from the 2.2 generator model (Slide #66) with $T''_{d0}=T''_{q0}=0$.

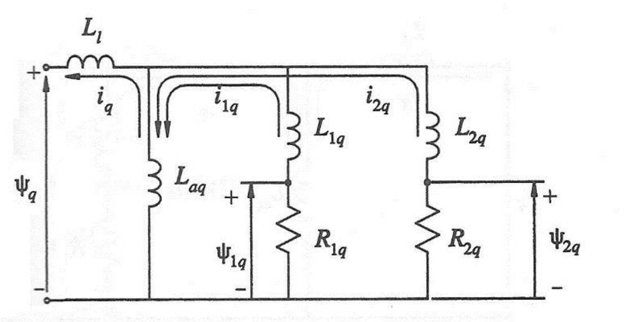
$$T'_{q0}\frac{d}{dt}E'_d=-E'_d+(X_q-X'_q)\cdot i_q \qquad \text{where} \quad E'_d=-\omega_r L_{aq}\psi_{1q}/L_Q$$

Question 3 (30 points): Consider the synchronous generator in Example 8.2. A three-phase short circuit is applied at the instant when the rotor direct axis position is at θ=30°. Use **ode45** to simulate equation (8.36) in Saadat's book (or the equation on Slide #44). Alternatively, you can directly revise the MATLAB code "chp8ex2.m" in POWR_ToolBox. Obtain and plot the transient waveforms for the stator currents i_a, i_b, i_c, i_d, i_q, the field current i_F and damper winding currents i_Q and i_D.

Question 4 (70 points): Consider the following equivalent circuits for a 384 MVA, 24kV, 0.85 power factor, 60Hz, 3 phase, 2 pole synchronous generator.



(a) d-axis equivalent circuit



(b) q-axis equivalent circuit

It has the following parameters:

L_l=	0.183 pu	R_a=	0.0014 pu
L_{ad}=	1.5949 pu	L_{aq}=	1.5749 pu
L_{fd}=	0.7017 pu	R_{fd}=	0.0012 pu

L_{1d}=	0.0845 pu	R_{1d}=	0.0222 pu
L_{1q}=	0.401 pu	R_{1q}=	0.00523 pu
L_{2q}=	0.0641 pu	R_{2q}=	0.01431 pu

Stored energy at rated speed = 1006.5 MW·s
Damping coefficient K_D=0

1. Ignoring saturation, calculate transient and subtransient reactance parameters in per unit values and open-circuit time constants using the formulas in Slide #48

   $X'_d, X''_d, X'_q, X''_q, T'_{d0}, T''_{d0}, T'_{q0}, T''_{q0}$

2. Assuming the following open-circuit saturation curve for both d- and q-axis saturation characteristics, Draw the saturation curve (refer to Kundur's Figure 3.30 or Slide #36)

   A_{sat}= 0.03125 B_{sat}=6.931

   ψ_{T1}= 0.8 pu ψ_{T2}= 1.0 pu L_{ratio}= 1.5

3. With the armature terminal voltage at rated value, consider two operating conditions with the following steady-state generator outputs

   Output 1: P_t= 307 MW Q_t= 115 MVAr
   Output 2: P_t= 345 MW Q_t= -154 MVAr

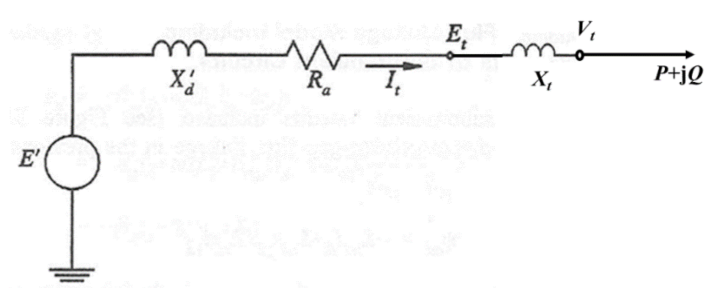
   For each of the two conditions,

   i) Compute factor K_{sd}, (assuming K_{sq}=K_{sd}), internal rotor angle δ_i, and per unit values of ψ_{at}, E_q, e_d, e_q, i_d, i_q, i_{1d}, i_{1q}, i_{2q}, i_{fd}, e_{fd}, ψ_{fd}, ψ_{1d}, ψ_{1q}, ψ_{2q},

   ii) Calculated the phasors of terminal voltage E_t, terminal current I_t, sub-transient voltage E'' and transient voltage E'. Draw the phasor diagram about those phasors and voltages on R_a, X_d, X_q, X'_d, X'_q, X''_d, X''_q. Are the heads of phasors E_q, E' and E'' on the same straight line and why?

   iii) Calculate steady-state air-gap torque T_e in per unit and N·m. How much is T_m in per unit?

   iv) Consider the *classic model* for the generator and assume that it is connected to a load through reactance X_t =j0.1 pu as shown by the figure. Calculate the per unit voltage magnitude V_t, real power P and reactive power Q of the load.



If the load of the bus under the current condition can be described by the following frequency dependent exponential load model, where V_{t0}, P_0 and Q_0 take the values of V_t, P and Q calculated above and f_0=60Hz

$$P=P_0(V_t/V_{t0})^{0.9}\times[1+1.2\times(f-f_0)/f_0]$$
$$Q=Q_0(V_t/V_{t0})^{2.1}\times[1-1.5\times(f-f_0)/f_0]$$

If at two time points t_1 and t_2, actual measurements of f and V_t are

at t_1	f=59.75Hz	V_t=0.99 pu
at t_2	f=60.05Hz	V_t=0.96 pu

Assume T_m to be constant. Calculate $d\Delta\omega_r/dt$ in rad/s^2 at t_1 and t_2.