HOMEWORK # 2   -   Deadline: November 8, 2019

SATURATION IN THE SYNCHRONOUS MACHINE

Consider a synchronous machine in steady state, rotating at nominal speed.
The stator resistance R_a is neglected, for simplicity.
Saturation is taken into account.

Step 1

Derive the following relations from the model in slide # 31 of the lecture
"Dynamics of the synchronous machine" (using per unit EMFL system) :

$$M_d = \frac{M_d^u}{1 + mV_\ell^n} \qquad\qquad M_q = \frac{M_q^u}{1 + mV_\ell^n}$$

$$v_d = -(L_\ell + M_q)i_q \qquad\qquad v_q = (L_\ell + M_d)i_d + M_d i_f$$

where V_ℓ is the magnitude of the voltage "behind leakage reactance" X_ℓ :

$$V_\ell = ||\bar{V}_\ell|| \qquad\qquad \bar{V}_\ell = \bar{V} + jX_\ell\bar{I}$$

with $X_\ell = \omega L_\ell = L_\ell$

Step 2

Consider that the machine is operating with a terminal voltage V, producing an active power P and a reactive power Q (all in per unit).

Starting from (V, P, Q), provide the detailed step-by-step procedure to determine the field current i_f (in per unit EMFL system) taking saturation into account.

Suggestions:

- use Step 1 to determine the saturation, and hence the saturated reactances $X_d = \omega L_{dd} = L_{dd}$ and $X_q = \omega L_{qq} = L_{qq}$
- to determine the rotor position θ_r^o, use the following property: the phasor
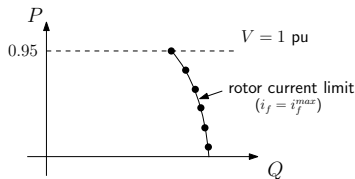
$$\bar{E}_1 = \bar{V} + jX_q\bar{I} \tag{1}$$

  is aligned along the q axis of the machine. X_q is the *saturated* value.
- use slide # 36 of the lecture "The synchronous machine" to compute the Park components of the voltage and the current (in per unit).

Step 3

Develop a MATLAB script to determine (a number of points of) the rotor current limit in the capability diagram :

corresponding to the maximum field current i_f^{max}. Assume $V = 1$ pu.

Suggestion : for P varying from 0 to 0.95 by steps of 0.05 pu, determine the value Q for which $i_f \simeq i_f^{max}$.

	Variant 1	Variant 2	Variant 3	Variant 4	
X_ℓ (pu)	0.15	0.15	0.20	0.17	
X_d^u (pu)	2.2	1.1	1.5	2.3	unsaturated reactance
X_q^u (pu)	2.0	0.7	0.9	2.1	unsaturated reactance
m	0.10	0.08	0.06	0.09	
n	6.0	6.5	7.0	5.9	
i_f^{max} (pu)	1.37	1.88	1.62	1.35	