**EE 5200 - Lecture 14** Wed Oct 3, 2018

**Topics for Today**:

- Announcements
    - Matlab - how was first assignment? Take feedback.
    - Office hrs: 4:05-5:55pm W,F - EERC 123
    - Office: EERC 614. Phone: 906.487.2857
    - Recommended problems from Ch.3, solutions posted
    - Homework SYNCH Part 1 - Due 9am Mon Oct $8^{th}$
    - Next: Transmission Line Parameters, Chapters 4,5,6

Synchronous Machines - Chapter 3.

- Basic internal structure of machines, cylindrical vs. salient
- Field windings
- Calculation with Xd and Xq.
- Calculation Example(s)
- Concepts behind SYNCH exercise set.
- S-S behavior - Xd ; Dynamic behavior - Xd’
- Short-circuit behavior - Xd”; s-s, transient, subtransient

To: ee5200-l@mtu.edu
From: Bruce Mork <bamork@mtu.edu>
Subject: d-q synch machine steady-state loading calcs

First of all, notation-wise, the internal induced voltage of the synch machine is called Ea in some references (voltage induced on armature windings) and in other references it's called Ef (since induced voltage on armature is due to magnitude of field current according to open-circuit characteristic of machine).

In answer to question posed:

Yes, Iq by definition is exactly in phase with Ea.  Referring to Fig. B-5 in Appendix B reference,

1) determine Ia according to load specified, usually assuming Vt = 1.0 pu at 0°.
2,3) calculate Ea' to find torque angle delta (this is based observation that since jXdId is parallel to Ea, then Vt + IaRa + jXqIa lands you somewhere along the phasor Ea and this allows you to determine delta.
4) knowing delta, resolve Ia into its 2 components Ia = Id + Iq
5) then finally, Ea = Vt + IaRa + jXdId +jXqIq.

As a double-check, Ea must end up with the same angle (delta) that you calculated for Ea'. So, the very good thing about this is that there is a double-check built into the calculations, you can immediately see if your answer seems to be correct, i.e. if Ea' and Ea have different angles, then you messed up somewhere along the line...

Dr. Mork

1) [20 pts] A 50-MVA delta-wye transformer is rated 115-13.8-kV. It has standard phase shift of 30° (115-kV side leads 13.8-kV side by 30°). Its self-cooled short-circuit impedance is 0.005 + j0.045 p.u. on the base of the transformer.

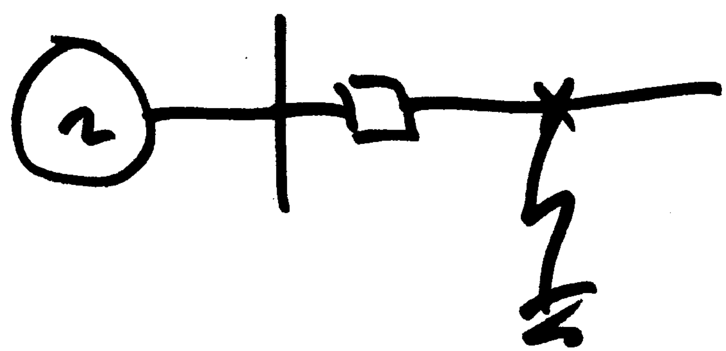
   a) Convert the impedance to 100 MVA base for system calculations.

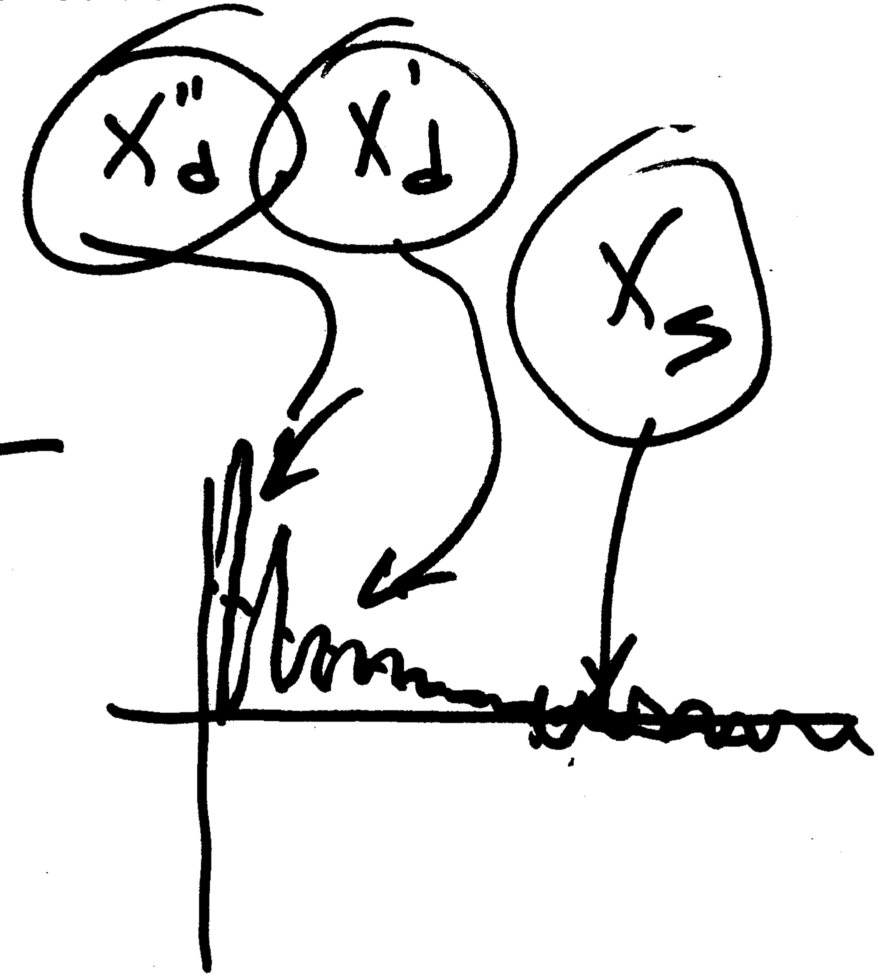
   b) Determine its per unit 2x2 admittance matrix values for i) pos, ii) neg sequence, and iii) zero sequence, being sure to include the effect of phase shift.

   c) Repeat b) for the situation where the transformer is to connect system buses having base voltages of 115 kV and 12.47-kV. Include phase shift and off-nominal turns ratio.

Next: Synchronous Machines - Chapter 3 — Week 5

- Recommended problems & solns for Ch.3 are posted.
- Phasor diagrams - unity, lag, lead
- Salient rotor machines - calculation with <u>Xd</u> and <u>Xq</u>.
- Calculation Example(s)
- P & Q flows thru transmission lines
- More on admittance matrix [Y] construction

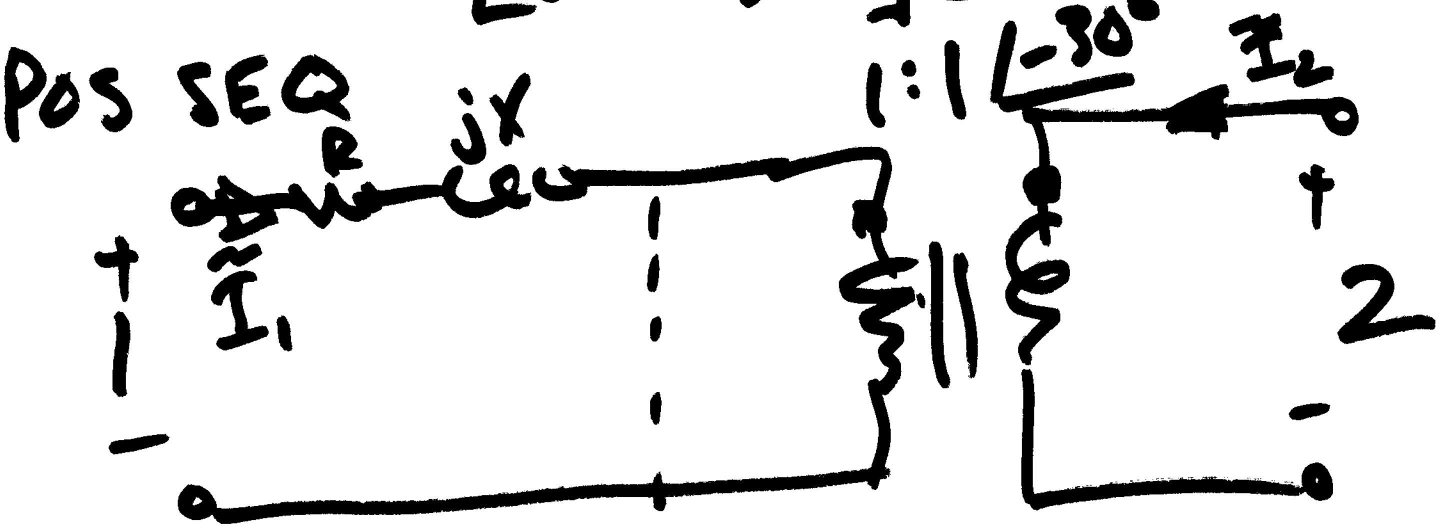


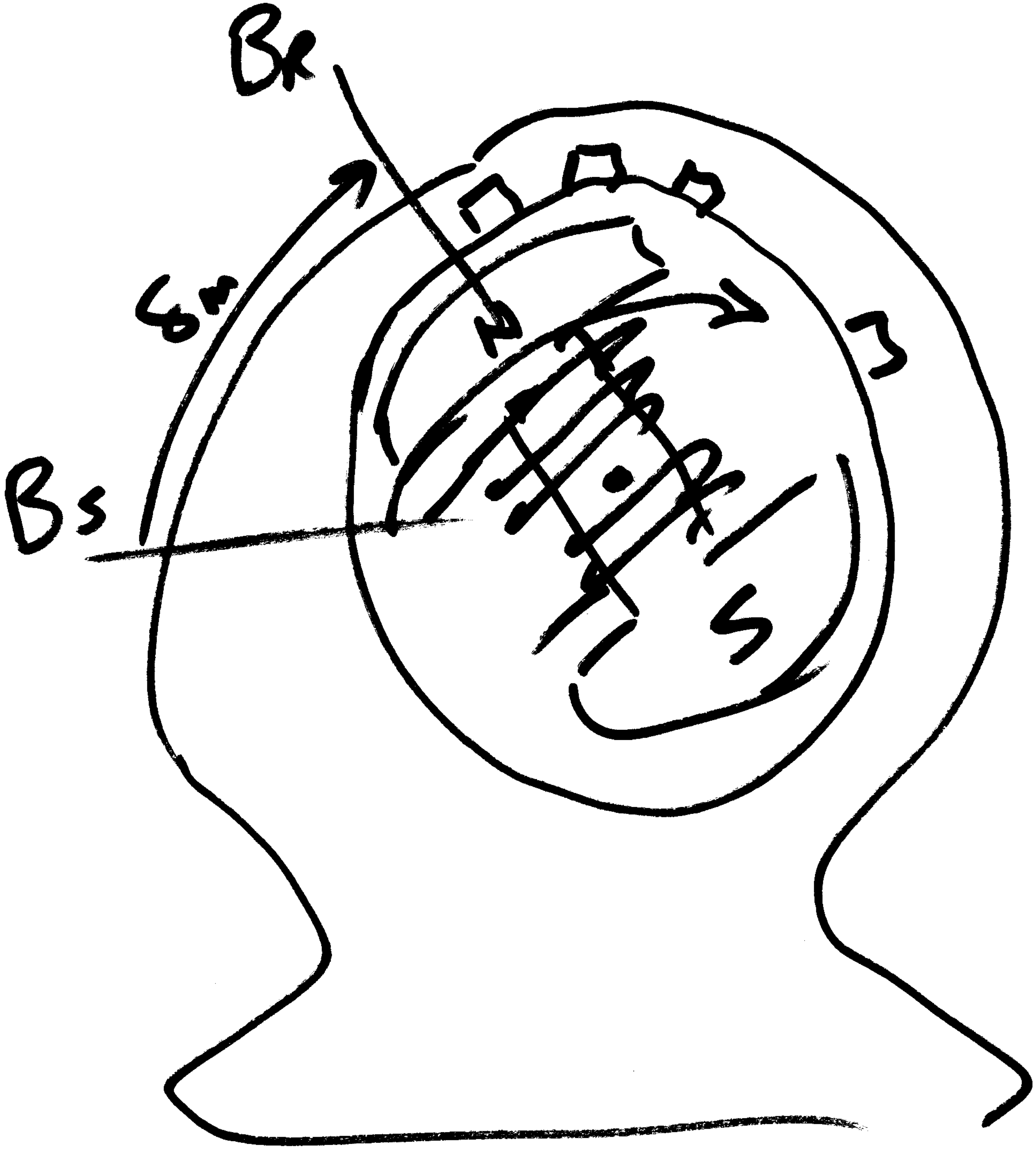


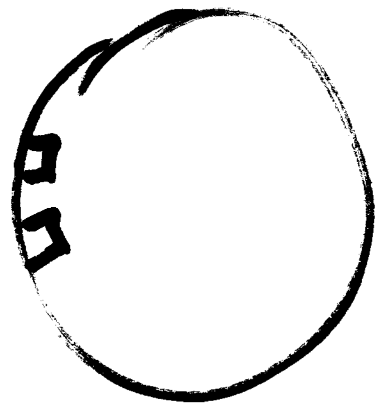
SYNCH Homework - Problem 1 Date Due: Friday Sept 30, 5pm

1) [20 pts] A 50-MVA delta-wye transformer is rated 115-13.8-kV. It has standard phase shift of 30° (115-kV side leads 13.8-kV side by 30°). Its self-cooled short-circuit impedance is 0.005 + j0.045 p.u. on the base of the transformer.
   a) Convert the impedance to 100 MVA base for system calculations.
   b) Determine its per unit 2x2 admittance matrix values for i) pos and ii) neg sequence, being sure to include the effect of phase shift.
   c) Repeat b) for the situation where the transformer is to connect system buses having base voltages of 115 kV and 12.47-kV. Include phase shift and off-nominal turns ratio.

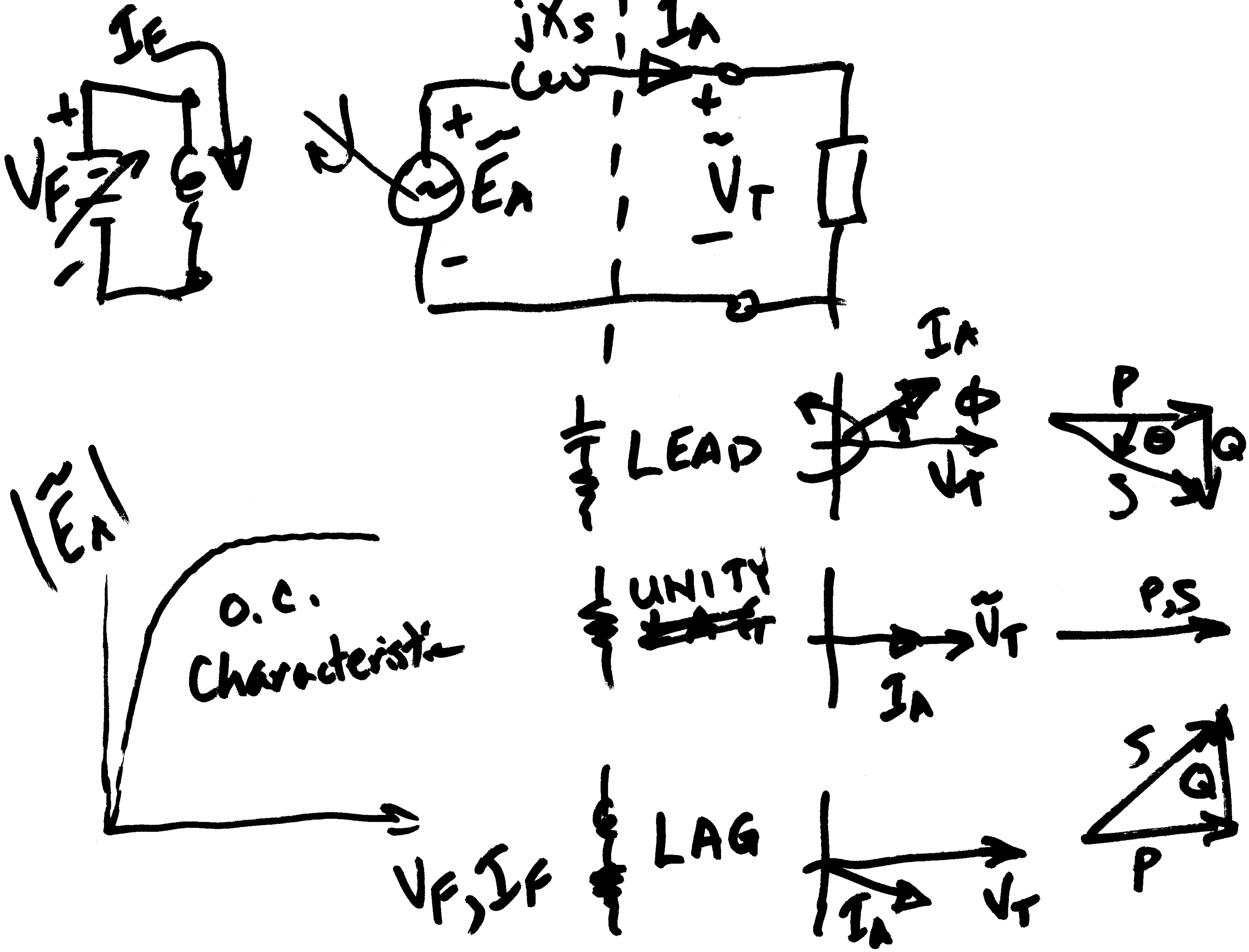
$$\begin{bmatrix} \bar{y}_{11} & \bar{y}_{12} \\ \bar{y}_{21} & \bar{y}_{22} \end{bmatrix} \begin{bmatrix} \tilde{V}_1 \\ \tilde{V}_2 \end{bmatrix} = \begin{bmatrix} \tilde{I}_1 \\ \tilde{I}_2 \end{bmatrix}$$



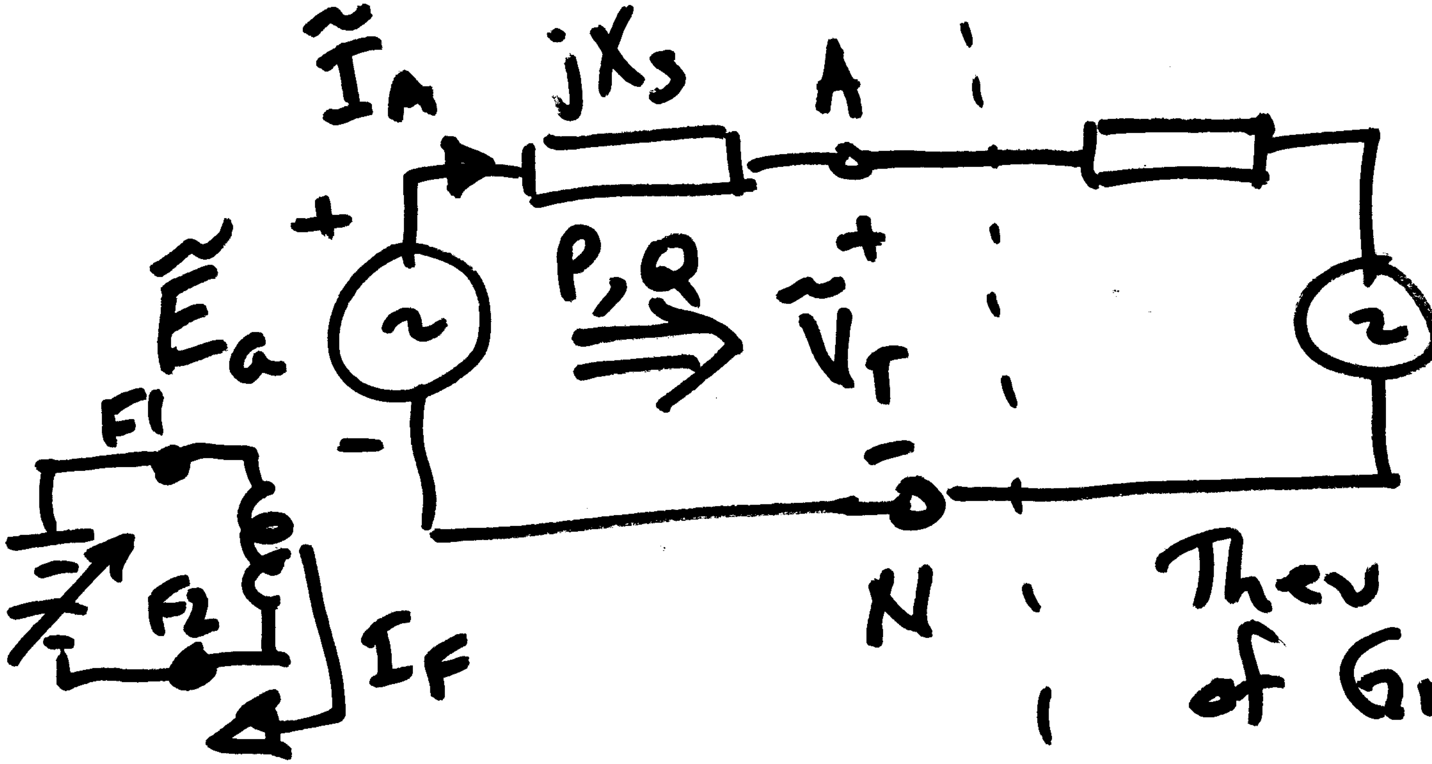


Cylindrical
2-pole
4-pole



$I_E$
$V_F$
$jX_S$
$\tilde{I}_A$
$\tilde{E}_A$
$\tilde{V}_T$
LEAD
$I_A$
$\Phi$
$V_T$
P
Q
S
UNITY
$\tilde{V}_T$
$I_A$
P,S
LAG
$I_A$
$V_T$
S
Q
P
$|\tilde{E}_A|$
O.C. Characteristic
$V_F, I_F$




PF = ?

Typically: $V_T$ ref $\angle 0°$

$\tilde{E}_a = E_a \angle \delta$

$\tilde{E}_a, \tilde{E}_f, \tilde{E}_{af}$

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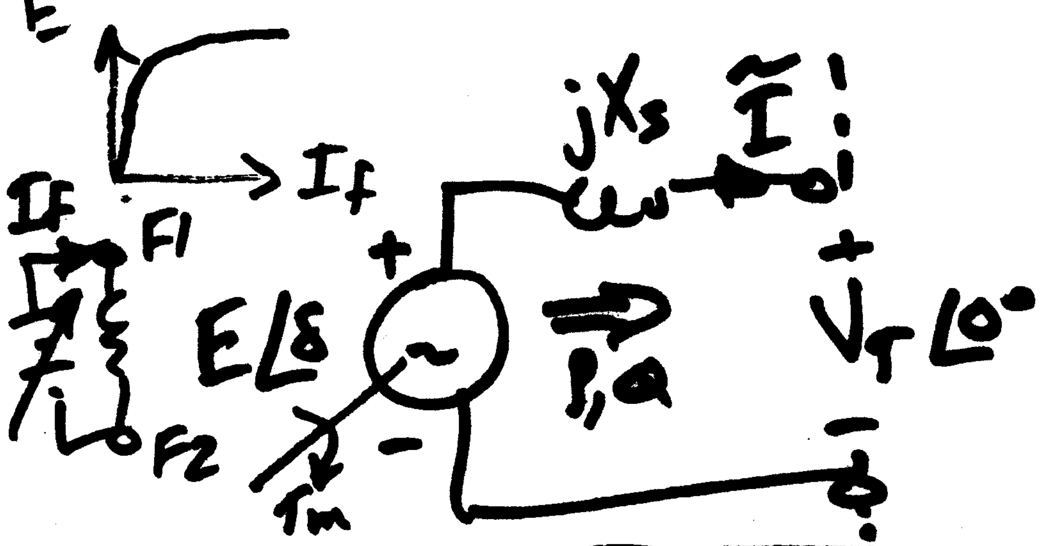
$$P_{OUT} = \frac{E_a V_T}{X_s} \sin \delta_e \qquad \delta_e = \angle \tilde{E}_a - \angle \tilde{V}_T$$

$$Q_{OUT} = \frac{E_a V_T}{X_s} \cos \delta_e - \frac{V_T^2}{X_s}$$

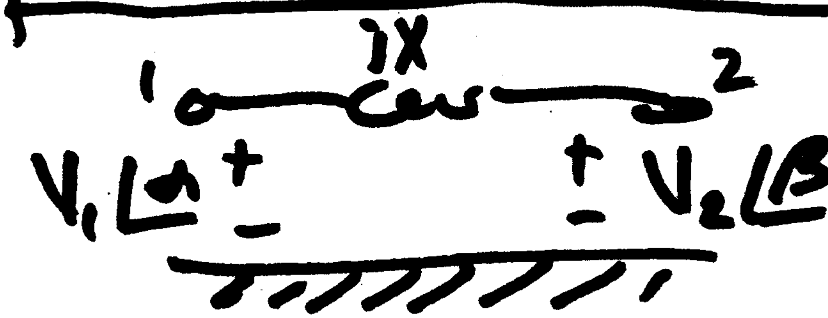



$$\bar{S}_{OUT} = \tilde{V}\tilde{I}^* = P_{OUT} + jQ_{OUT} = \bar{S}_{INTO\ SYSTEM}$$

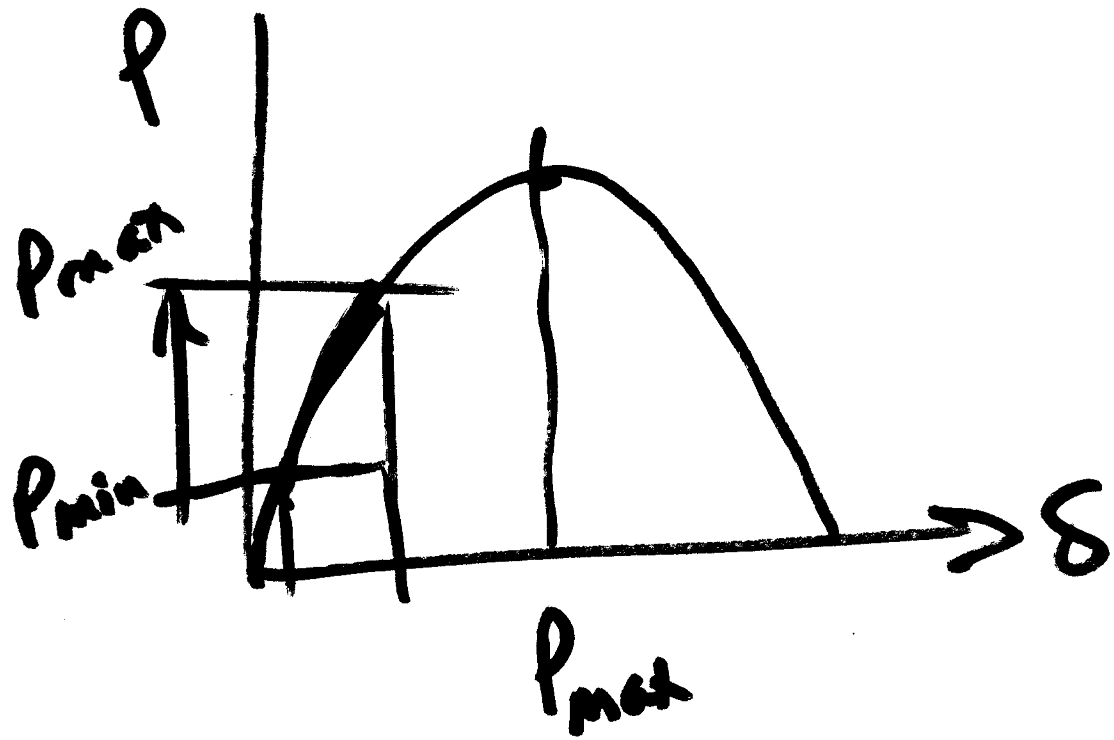
$$P_{OUT} = \frac{EV_T}{X_S}\sin\delta$$

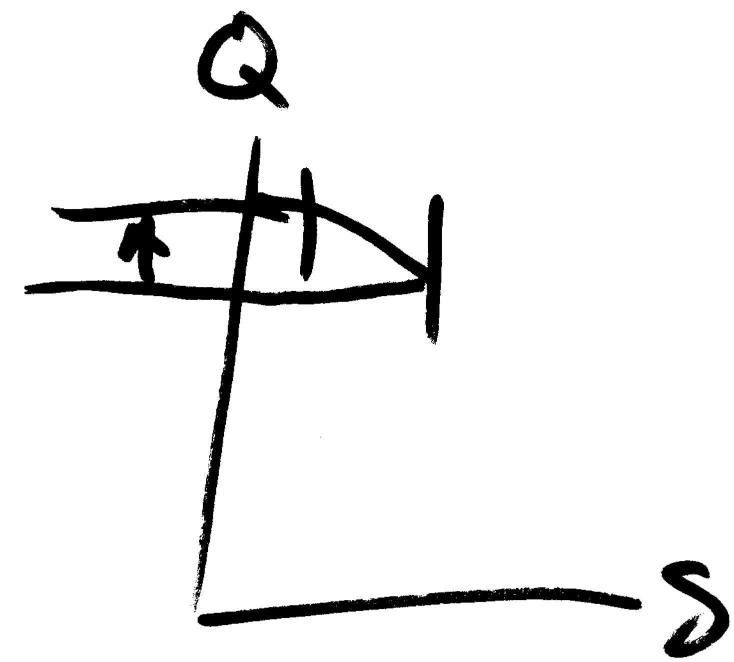
$$Q_{OUT} = \frac{EV_T}{X_S}\cos\delta - \frac{V_T^2}{X_S}$$

$$\delta_m = \angle B_r - \angle B_s$$




$$P_{1\to 2} = \frac{V_1V_2}{X}\sin(\alpha-\beta)$$



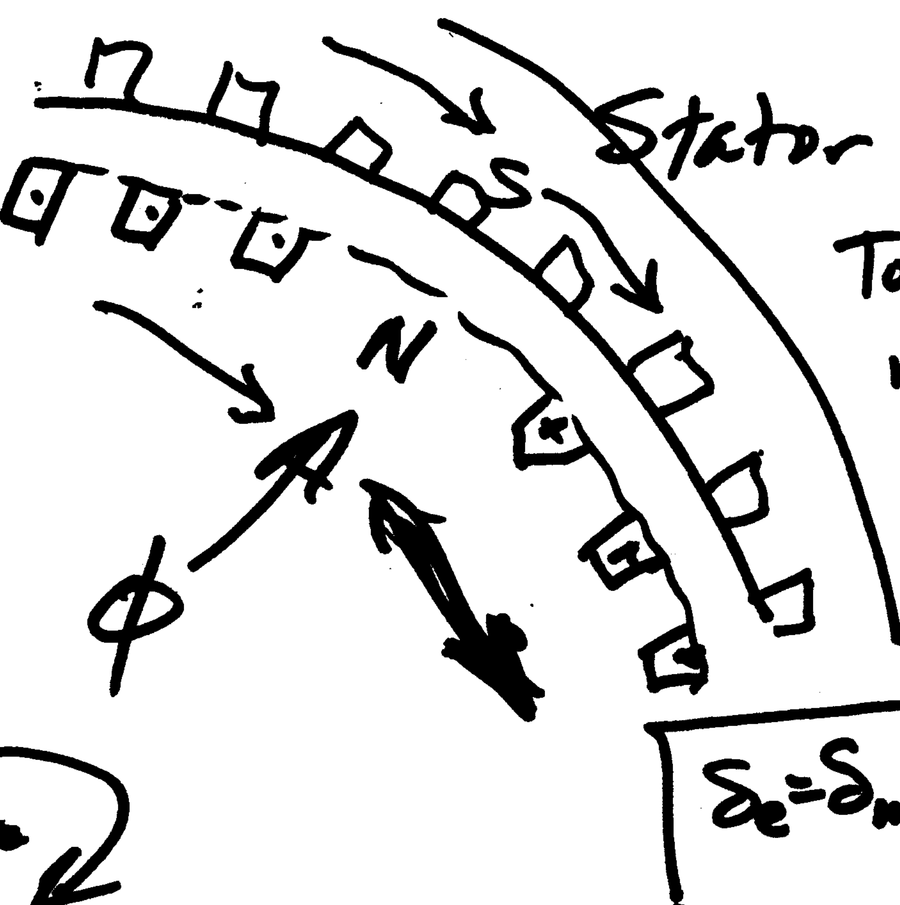

$$\frac{\partial P(\delta)}{\partial \delta} = \ ?$$

Salient  (rotor w/ pole projections)
- Hydro - slower speed.
- more poles.

vs.

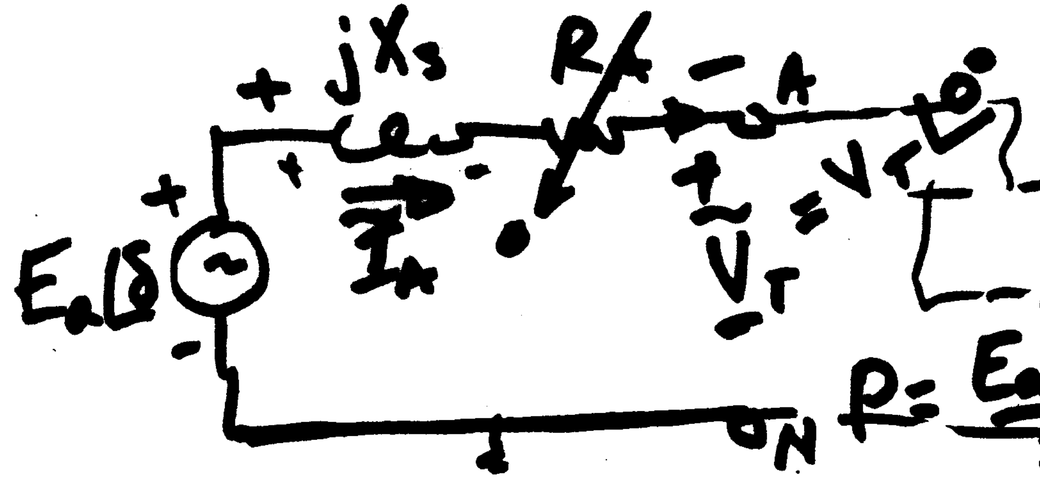
Non-Salient (round rotor)
- steam turbine, high speed.
- 2 or 4 pole.

$P = \frac{E V_T}{X_s} \sin\delta_e$ } electrical dtys!




Torque Angle
mech:
$\delta_m = \angle B_r - \angle B_s$ (mech degrees.)

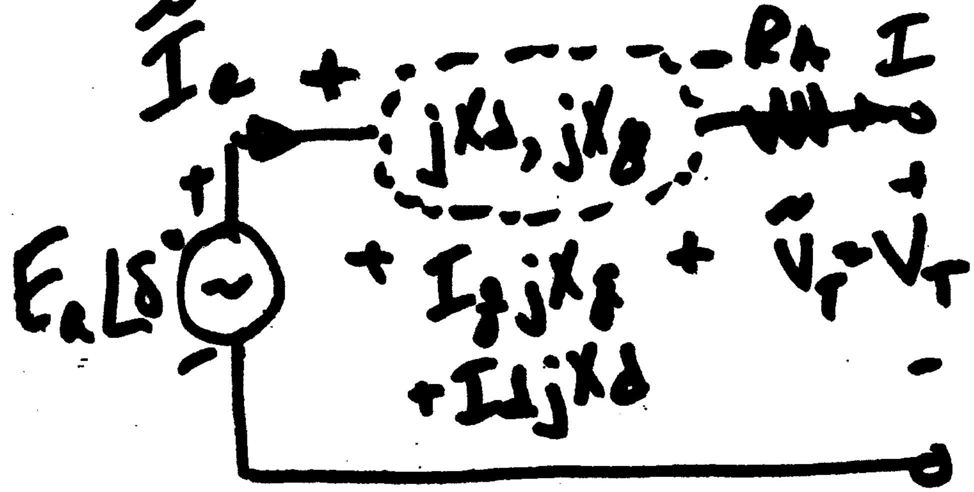
$$\delta_e = \delta_m \frac{N_p}{2}$$




Cylindrical Rotor

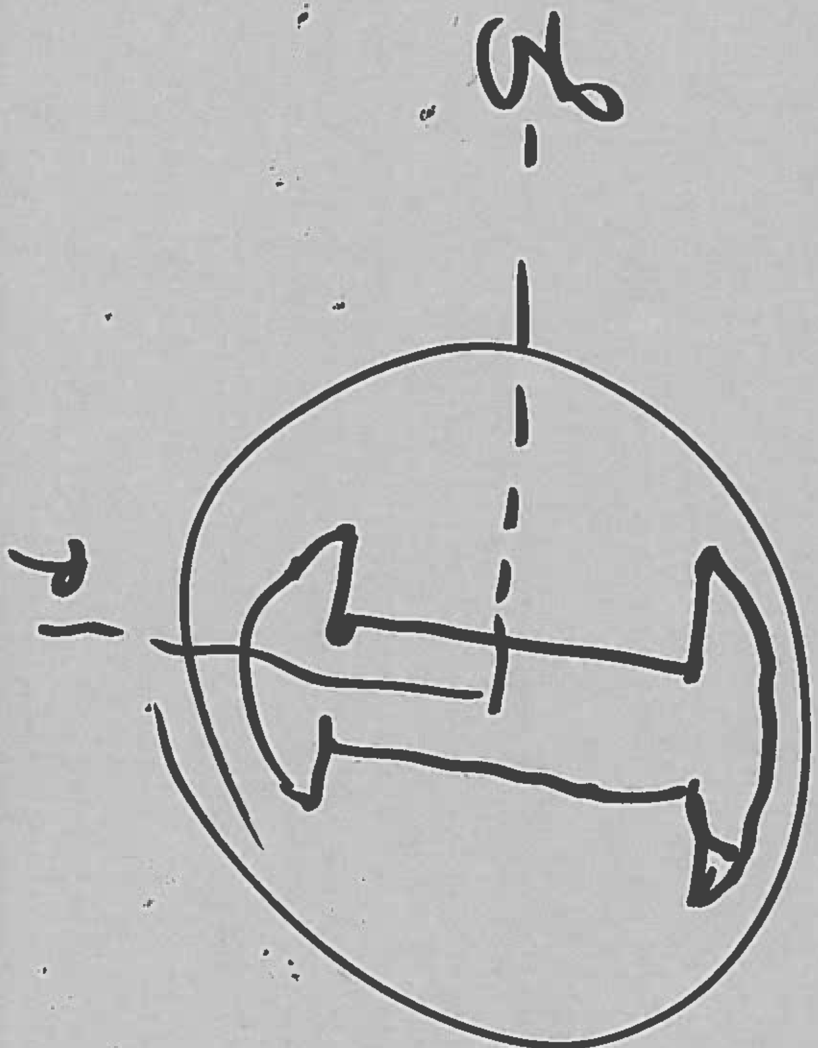
$$P = \frac{E_a V_T}{X_s}\sin\delta \quad \vdots \quad Q = \frac{E_a V_T}{X_s}\cos\delta - \frac{V_T^2}{X_s}$$

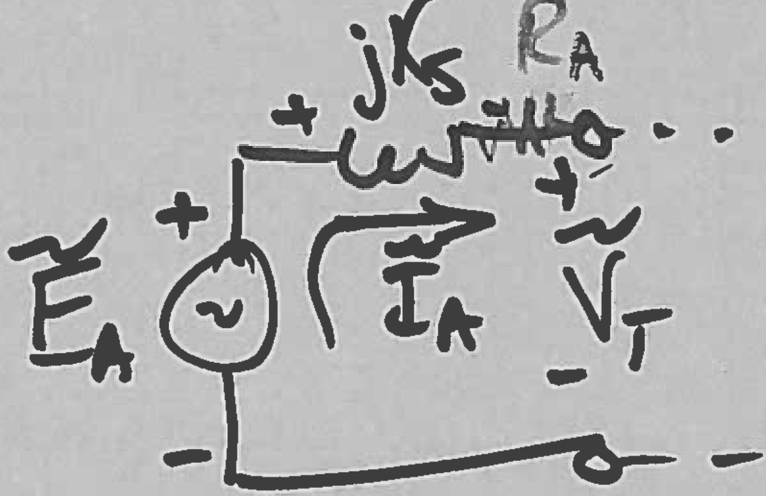
Eqn. (3.38)

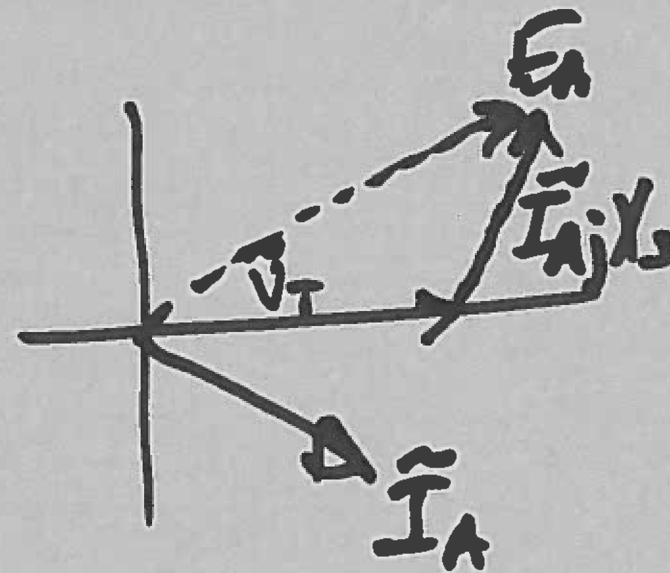


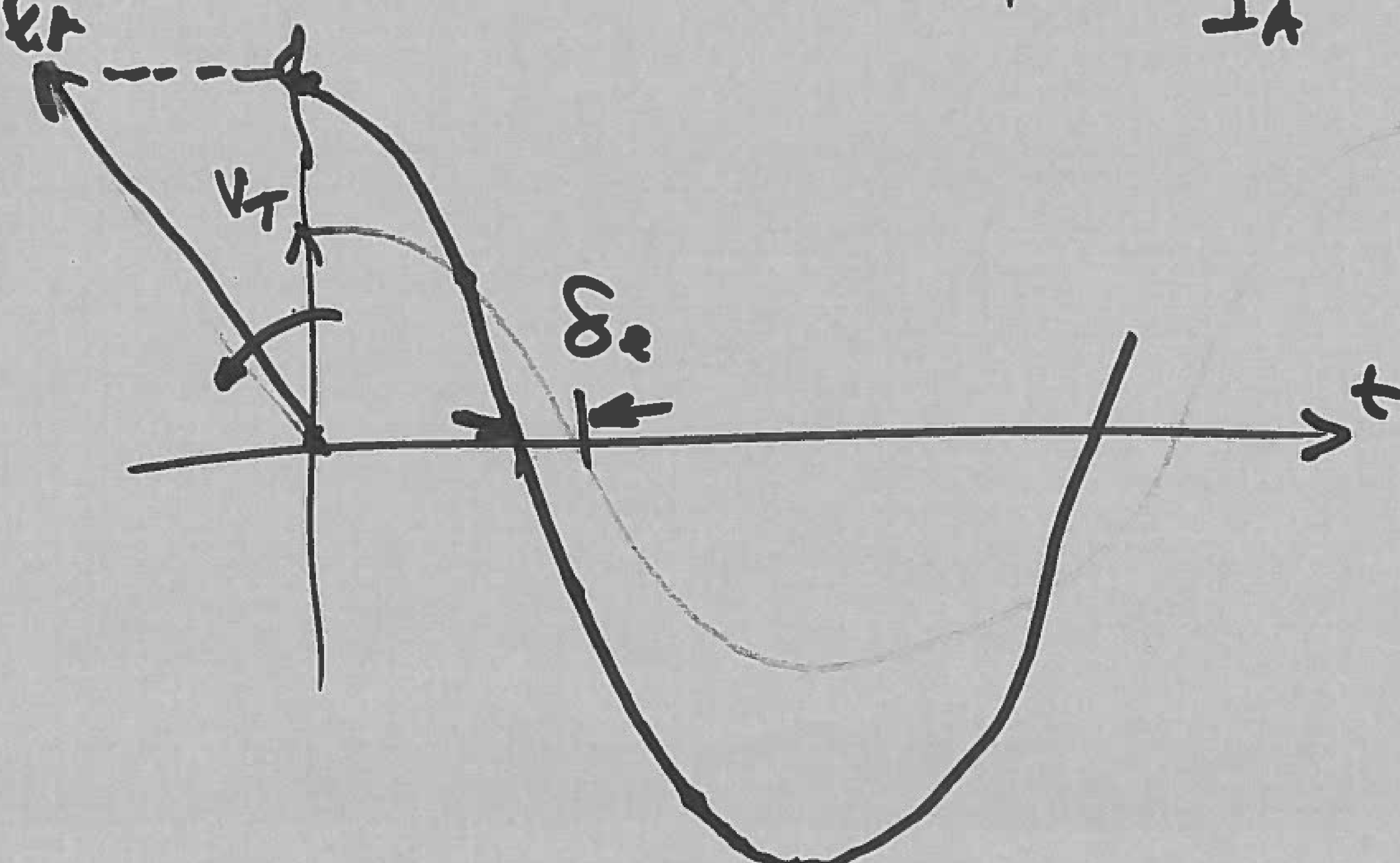

Selient Rotor.

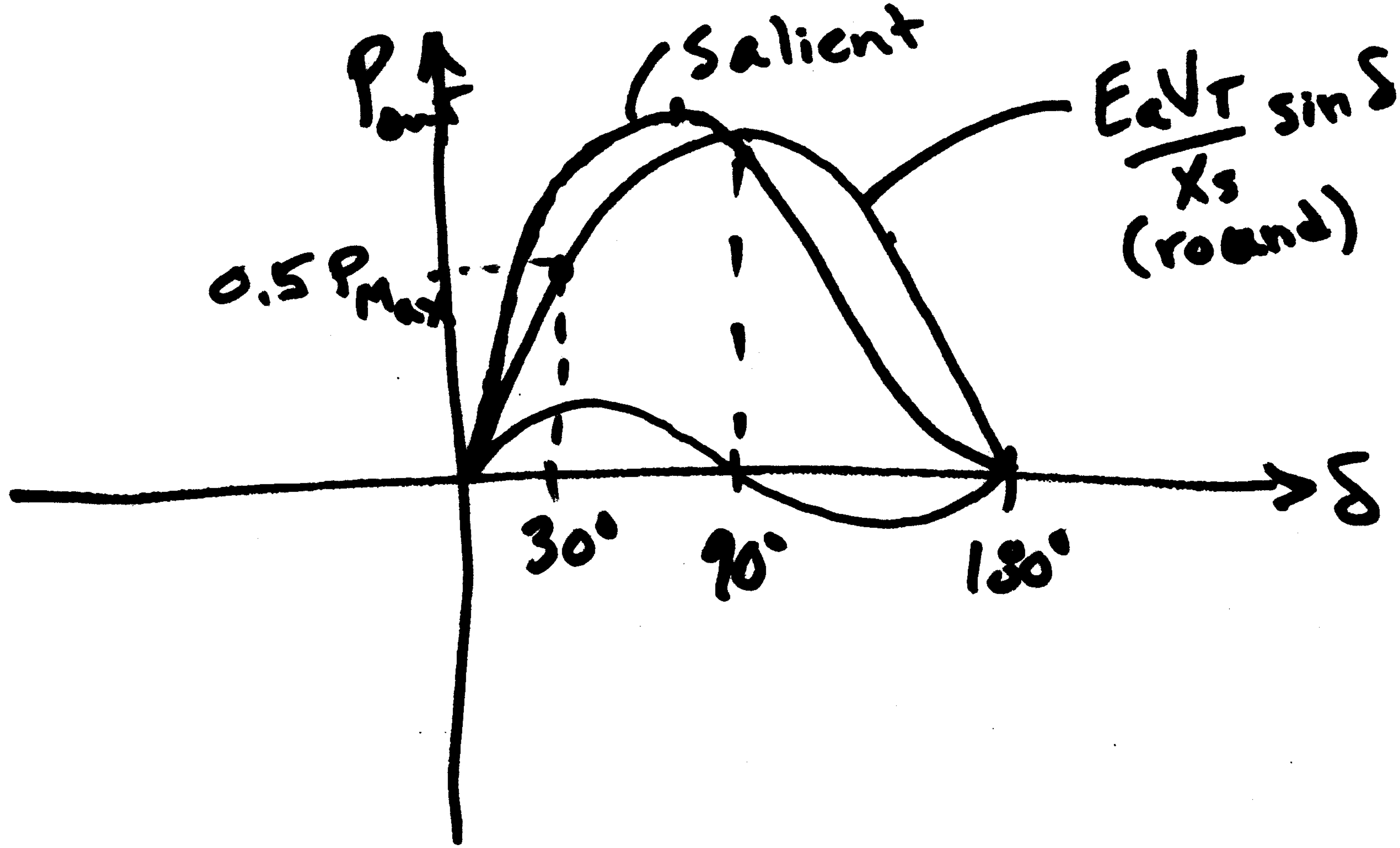
$$P_{out} = \frac{E_a V_T}{X_d}\sin\delta + \frac{V_T^2}{2}\left(\frac{X_d - X_q}{X_d X_q}\right)\sin 2\delta$$




$jX_S$
$R_A$
$\tilde{E}_A$
$\tilde{I}_A$
$\tilde{V}_T$
+
-


$E_A$
$\tilde{I}_A jX_S$
$\tilde{V}_T$
$\tilde{I}_A$


$E_A$
$V_T$
$\delta_e$
t

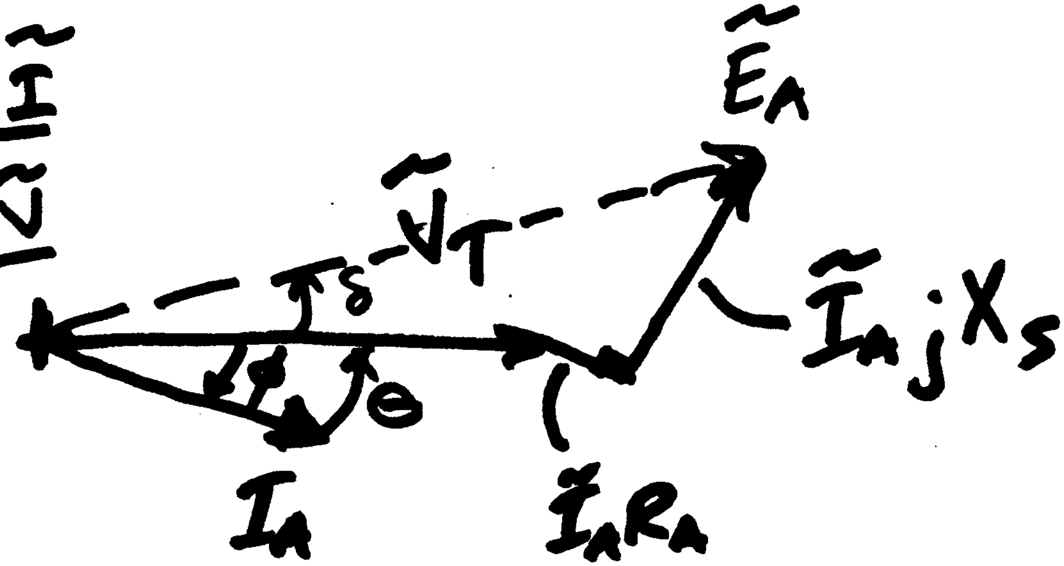


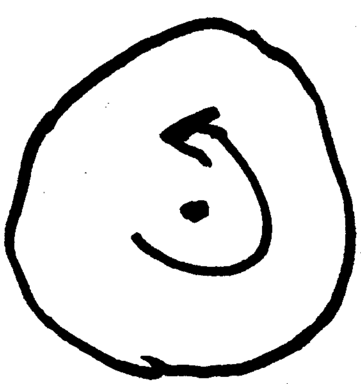
$P_{out}$
Salient
$\frac{E_a V_T}{X_s} \sin\delta$
(round)
$0.5\,P_{max}$
30°
90°
180°
$\delta$

KVL: $\tilde{E}_a = \tilde{I}_A(jX_s + R_A) + \tilde{V}_T$

$\theta = \angle\tilde{V} - \angle\tilde{I}$

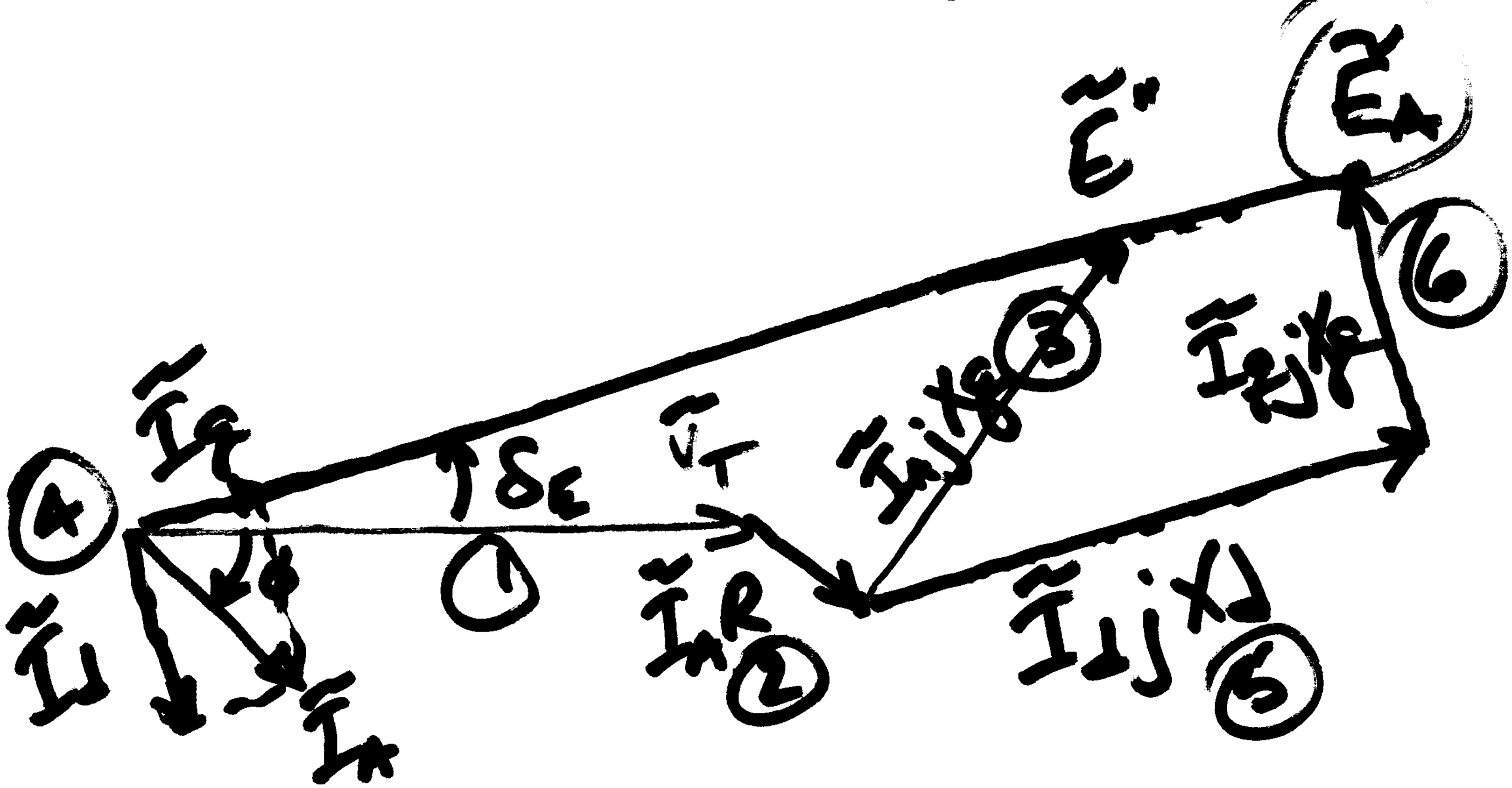
$\phi = \angle\tilde{I} - \angle\tilde{V}$



CYLINDRICAL
ROTOR

**KVL:** $\tilde{E}_A = \tilde{V}_T + \tilde{I}_A R_A + \tilde{I}_q jX_q + \tilde{I}_d jX_d$



To: ee5200-l@mtu.edu
From: Bruce Mork <bamork@mtu.edu>
Subject: d-q synch machine steady-state loading calcs

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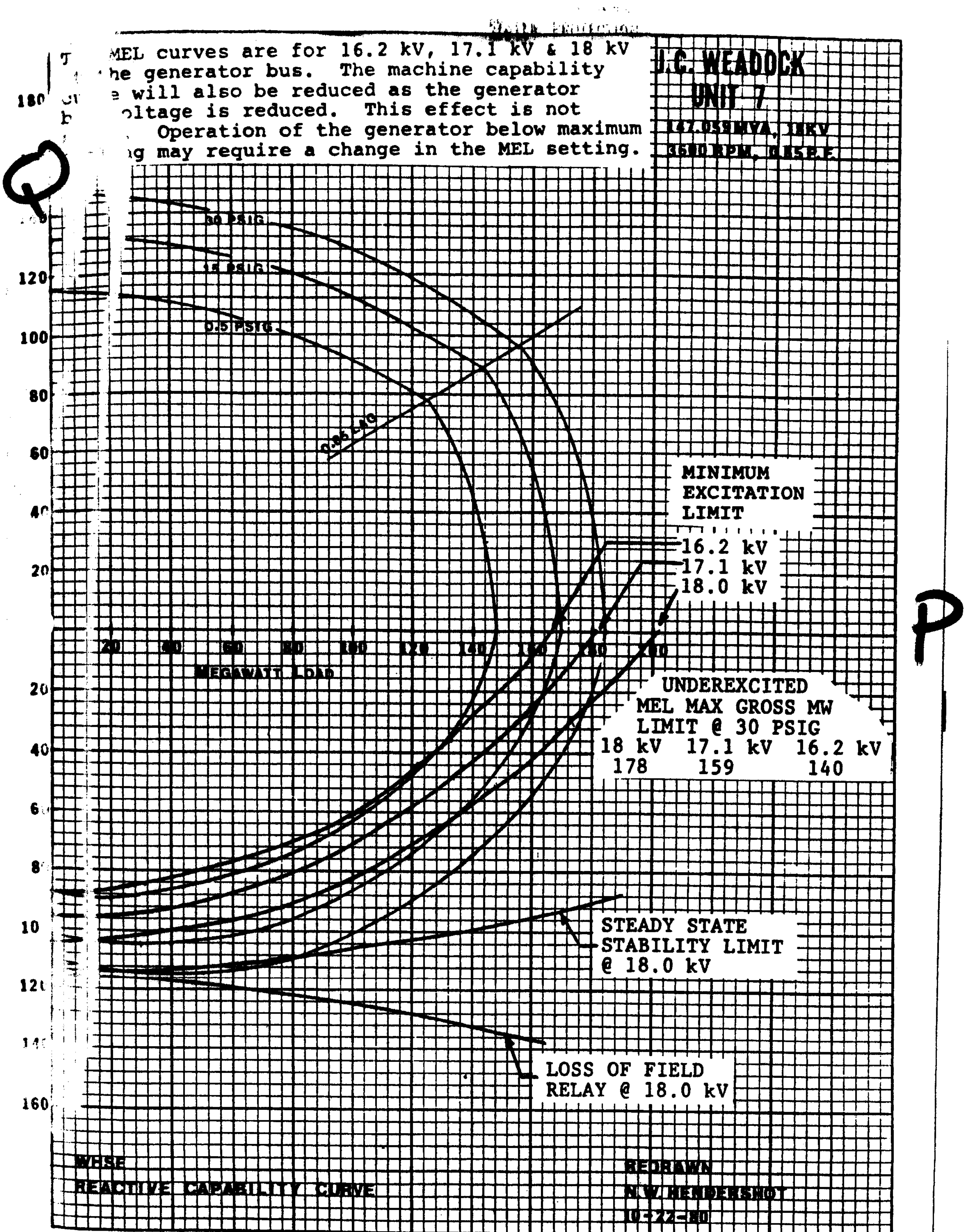


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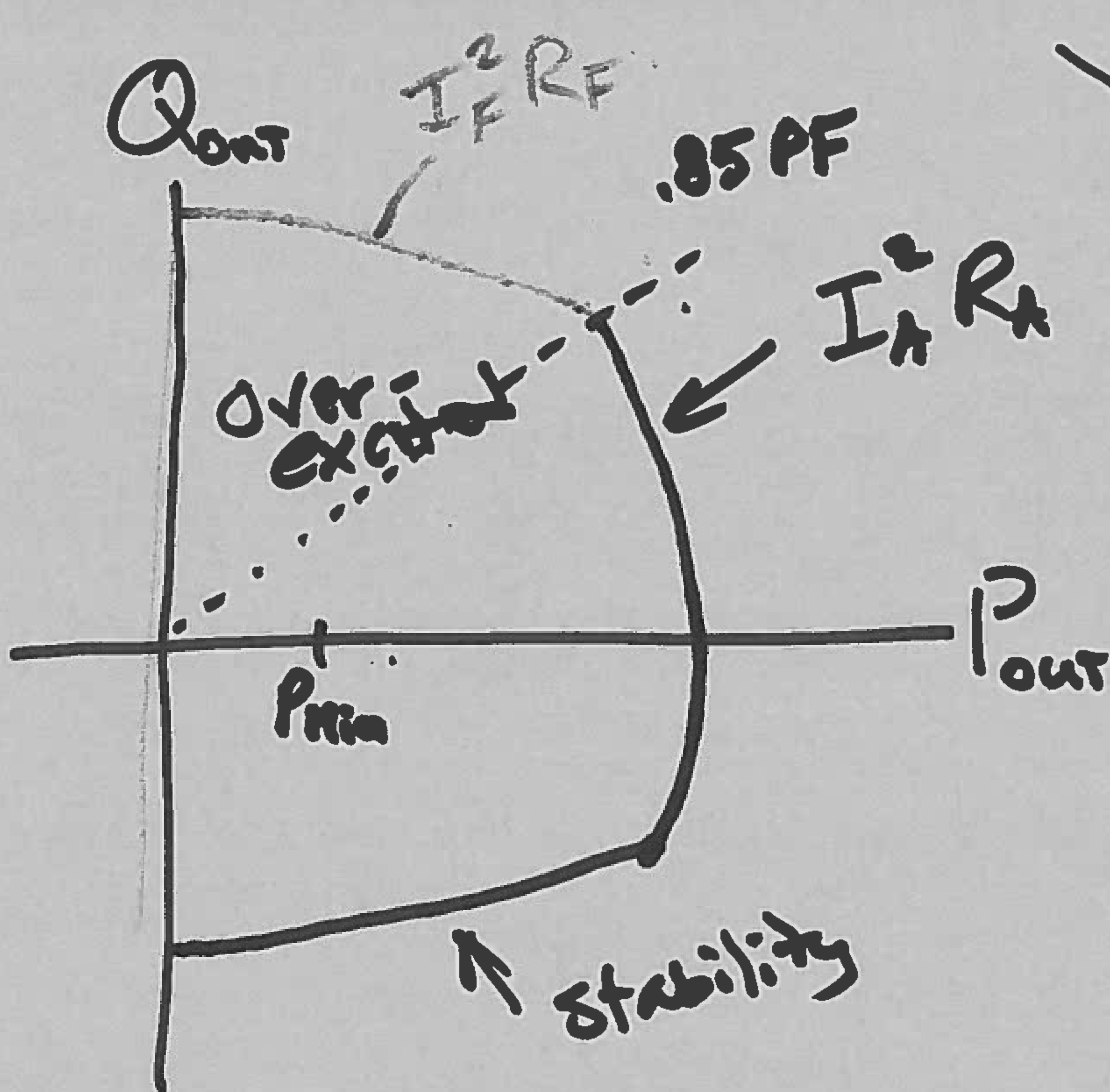
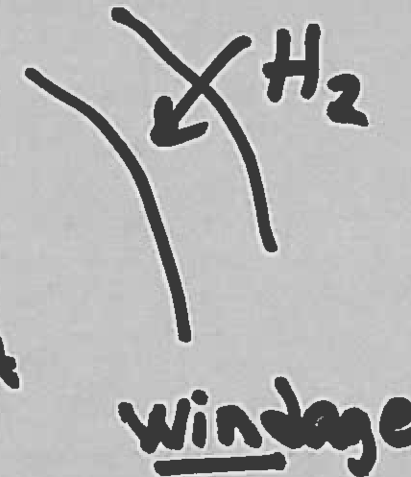
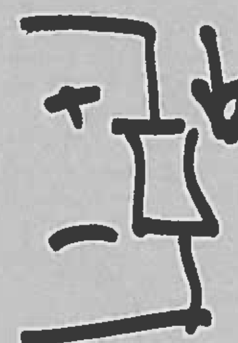

$Q_{OUT}$
$I_F^2 R_F$
.85 PF
$I_A^2 R_A$
Over-
$P_{OUT}$
$P_{min}$
Stability


$H_2$
Windage


+
−

# $H_2$ inside Gen


- Reduce windage losses ($P_{mech\ loss}$)
- Reduce $H_2O$ vapor
- Heat transfer / cooling.