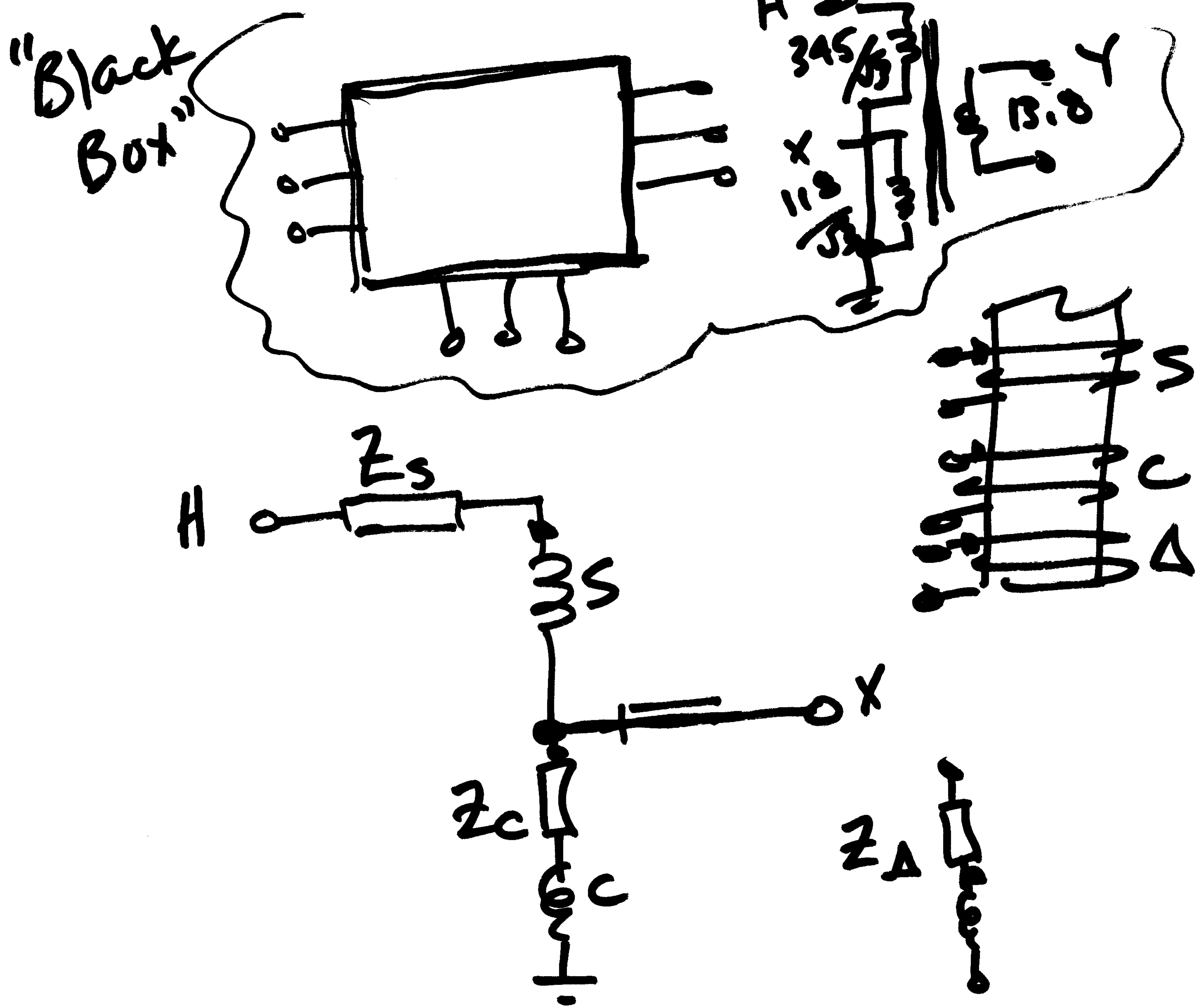
EE 5200 - Lecture 13 Mon Sep 30, 2019

Topics for Today:

- Announcements
  - Matlab - how is it going?
  - Learning Center: TBA
  - Office: EERC 614. Phone: 906.487.2857
  - Recommended problems from Ch.3, solutions posted
  - Next: Transmission Line Parameters, Chapters 4,5,6

Synchronous Machines - Chapter 3. (View the review video !)

- 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


"Black Box"
H
345/√3
X
115/√3
Y
13.8
S
C
Δ
H
Zs
S
X
Zc
C
ZΔ

Three-Winding Y-Y-D AutoTransformer - Interpretation of Factory Test Data Split Rock #10 and #11

Bruce Mork, Jun 25, 2005 C:\RSCH\XFMR\3WIND.xls [ ] = Input Data
(All other cells are locked)

Winding Ratings, OA

	kVL-L	MVA	Current	ZBASE, RATE	ZBASE, 100	ZBASE, TER
H	345	240	401.63	495.94	1190.25	1889.29
X	118	240	1174.27	58.02	139.24	221.02
Y	13.8	63	2635.73	3.02	1.90	3.02

Freq, Hz	Omega
60	376.991

Binary Short Circuit Tests (Using Base of Source Winding):

Source	Shorted	Test MVA	ISOURCE	ISHORT	PMEAS	R, Ohms	QCALC	%ZMEAS	%RCALC	%XCALC	
345	118	240	401.63	1174.27	260,385	0.538	14,013,581	5.84%	0.1085%	5.84%	H-X
345	13.8	63	105.43	2635.73	95,448	2.862	6,860,036	10.89%	0.1515%	10.89%	H-Y
118	13.8	63	308.25	2635.73	96,588	0.339	5,530,557	8.78%	0.1533%	8.78%	X-Y

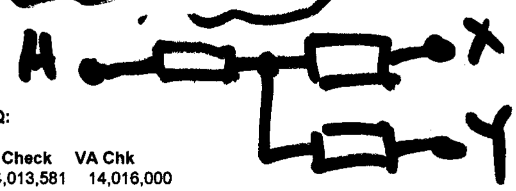
On 100-MVA Base:

	X/R	%Z	%R	%X
ZHX =	53.82	2.43%	0.0452%	2.43%
ZHY =	71.87	17.29%	0.2405%	17.28%
ZXY =	57.26	13.94%	0.2434%	13.93%

Calculate 3-Winding Star-Equivalent Short-Circuit Impedances:

Terminal		R, Ohms	PAC	P Check
H		0.2519	PHX =	260,385
X		0.0335	PHY =	95,448
Y	(Y-Equiv)	0.0042	PXY =	96,588

	% on 100-MVA Base	
	%R	%X
ZH	0.0212%	2.891%
ZX	0.0240%	-0.458%
ZY	0.2193%	14.393%



Ratings of Actual Coils, OA

	kVPH	MVA	Current	ZBASE, RATE	ZBASE, 100	ZBASE, TER
S	131.06	52.64	401.63	326.31	515.29	817.92
C	68.13	52.64	772.64	88.18	139.24	221.02
D	13.80	21.00	1521.74	9.07	5.71	9.07

Calculate Autotransformer Coil Impedances Based on Conservation of Short-Circuit P & Q:

Coil	IRATED	KVRATED	R, Ohms	X, Ohms	PAC	P Check	QAC	Q Check	VA Chk
Series	401.63	131.06	0.3498	32.5475	PHX =	260,385	QHX =	14,013,581	14,016,000
Common	772.64	68.13	0.0509	-0.9700	PHY =	95,448	QHY =	6,860,036	6,860,700
Delta	1521.74	13.80	0.0118	0.8359	PXY =	96,588	QXY =	5,530,557	5,531,400

Short-Circuit Test Conditions in Each Coil:

Test:		H-X			H-Y			X-Y		
Coil	KVRATED	Isc	MVATEST	PCOIL,KW	Isc	MVATEST	PCOIL,KW	Isc	MVATEST	PCOIL,KW
Series	131.06	401.63	157.91	169.28	105.43	41.45	11.66	0.00	0.00	0.00
Common	68.13	772.64	157.91	91.11	105.43	21.55	1.70	308.25	63.00	14.50
Delta	13.80	0.00	0.00	0.00	1521.74	63.00	82.09	1521.74	63.00	82.09
			Total PSC	260.385		Total PSC :	95.448		Total PSC :	96.588

Synthesized Short-Circuit Tests for S-C-D windings:

Test:		S-C			S-D			C-D		
Coil	KVRATED	Isc	MVATEST	PCOIL,KW	Isc	MVATEST	PCOIL,KW	Isc	MVATEST	PCOIL,KW
Series	131.06	401.63	157.91	169.28	160.23	63.00	26.94	0.00	0.00	0.00
Common	68.13	772.64	157.91	91.11	0.00	0.00	0.00	308.25	63.00	14.50
Delta	13.80	0.00	0.00	0.00	1521.74	63.00	82.09	1521.74	63.00	82.09
			Total PSC	260.385		Total PSC :	109.030		Total PSC :	96.588

Details of Synthesized Binary Short Circuit Tests for S-C-D windings (Using Base of Source Winding):

Source	Shorted	Test MVA	ISOURCE	ISHORT	PCALC	QCALC	R, Ohms	X, Ohms	%ZCALC	%RCALC	%XCALC	
131.06	68.13	157.91	401.63	772.64	260,385	14,013,581	0.538	28.958	8.88%	0.1649%	8.87%	S-C
131.06	13.80	63.00	160.23	1521.74	109,030	8,314,013	1.416	107.940	13.20%	0.1731%	13.20%	S-D
68.13	13.80	63.00	308.25	1521.74	96,588	5,530,557	0.339	19.402	8.78%	0.1533%	8.78%	C-D

On 100-MVA Base:

	X/R	%Z	%R	%X
ZSC =	53.82	5.62%	0.1044%	5.62%
ZSD =	76.25	20.95%	0.2747%	20.95%
ZCD =	57.26	13.94%	0.2434%	13.93%

Calculate 3-Winding Star- and Delta-Equivalent Short-Circuit Impedances:

Coil Resitances:

RS, OHMS	0.3498
RC, OHMS	0.0509
RD, OHMS	0.0118

Calculate [A] matrix:

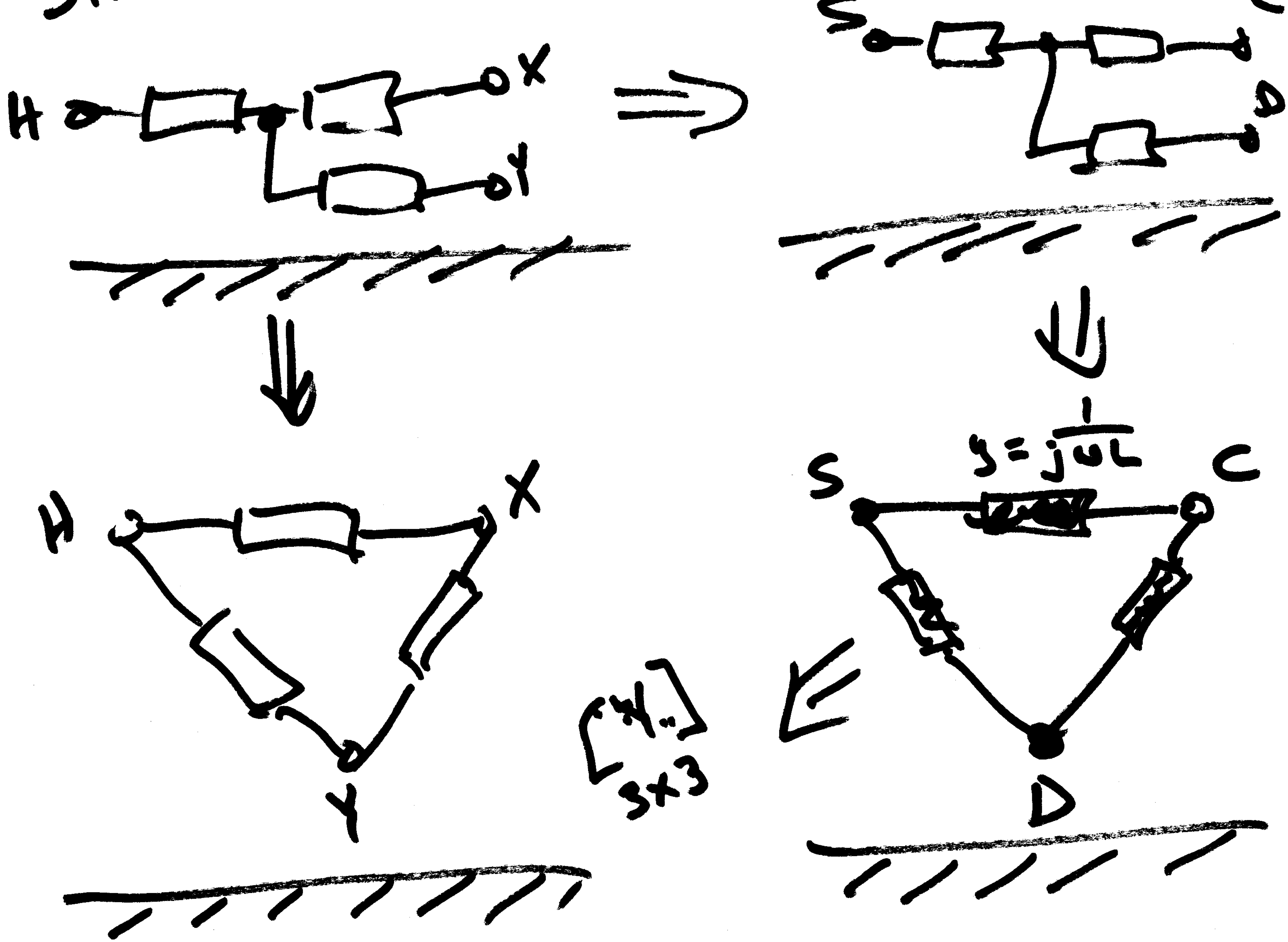
	S	C	D
S	13.100	-26.460	6.220
C	-26.460	72.878	-108.486
D	6.220	-108.486	476.501
VD : VC		0.203	
VD : VS		0.105	
VC : VS		0.520	

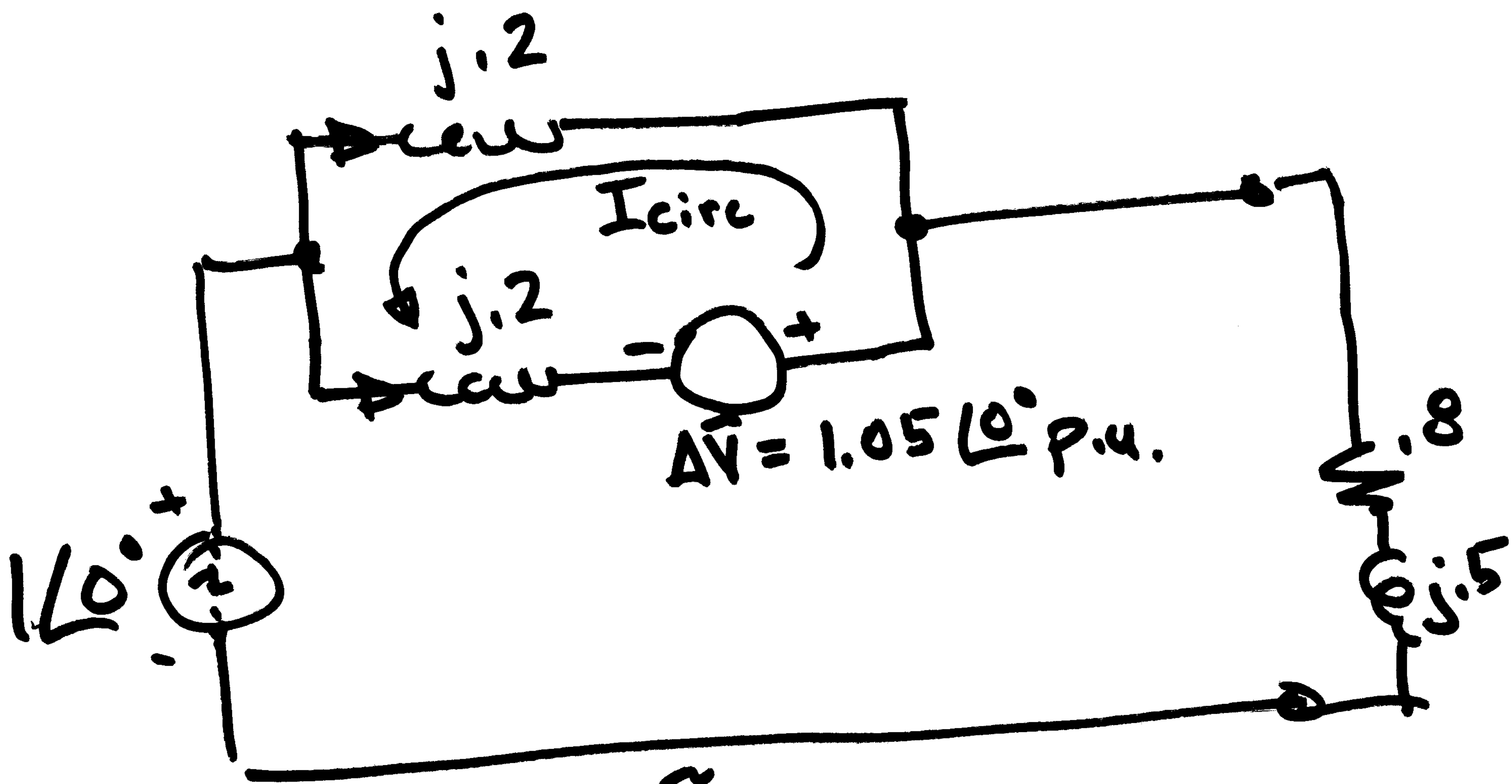
	% on 100-MVA Base		L-1	Referred
	%R	%X		
ZS	0.0679%	6.32%		
ZC	0.0365%	-0.70%		
ZD	0.2068%	14.63%		
ZS-C	0.1164%	5.32%	50.903	C
ZS-D	0.6590%	-111.71%	-59.069	D
ZC-D	0.3547%	12.32%	535.570	D

XS-C // (XS-D + XC-D) 5.62% \
XS-D // (XS-C + XC-D) 20.95% | == Check
XC-D // (XS-C + XS-D) 13.93% /

$[L]^{-1} \Rightarrow [Y]$

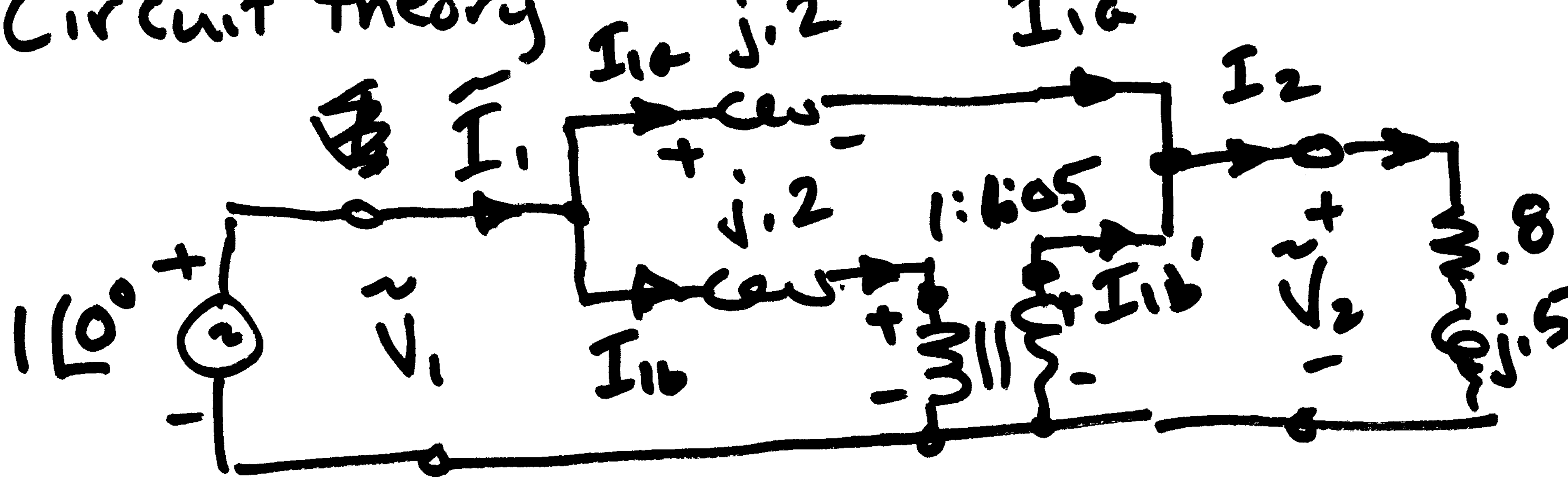
STAR





$$\tilde{I}_{cir} = \frac{\Delta \tilde{V}}{j.4} = -j.125 \text{ p.u.}$$

Circuit theory



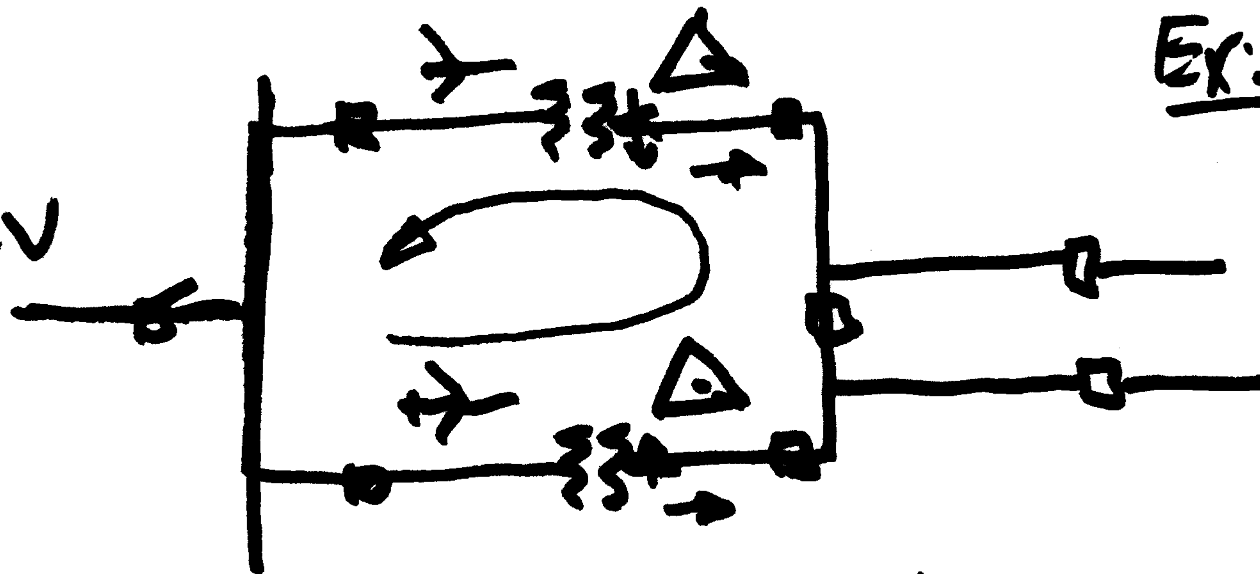
$I_1 = I_{1a} + I_{1b}$

$$I_2 = I_{1a} + I_{1b}' = \frac{1\angle 0° - \tilde{V}_2}{j.2} + \frac{\left(1\angle 0° - \frac{V_2}{1.05}\right)\frac{1}{1.05}}{j.2} = \frac{\tilde{V}_2}{.8 + j.5}$$

KCL:

$\Rightarrow \tilde{V}_2 = .963\angle -5.1$ p.u.

Ex:

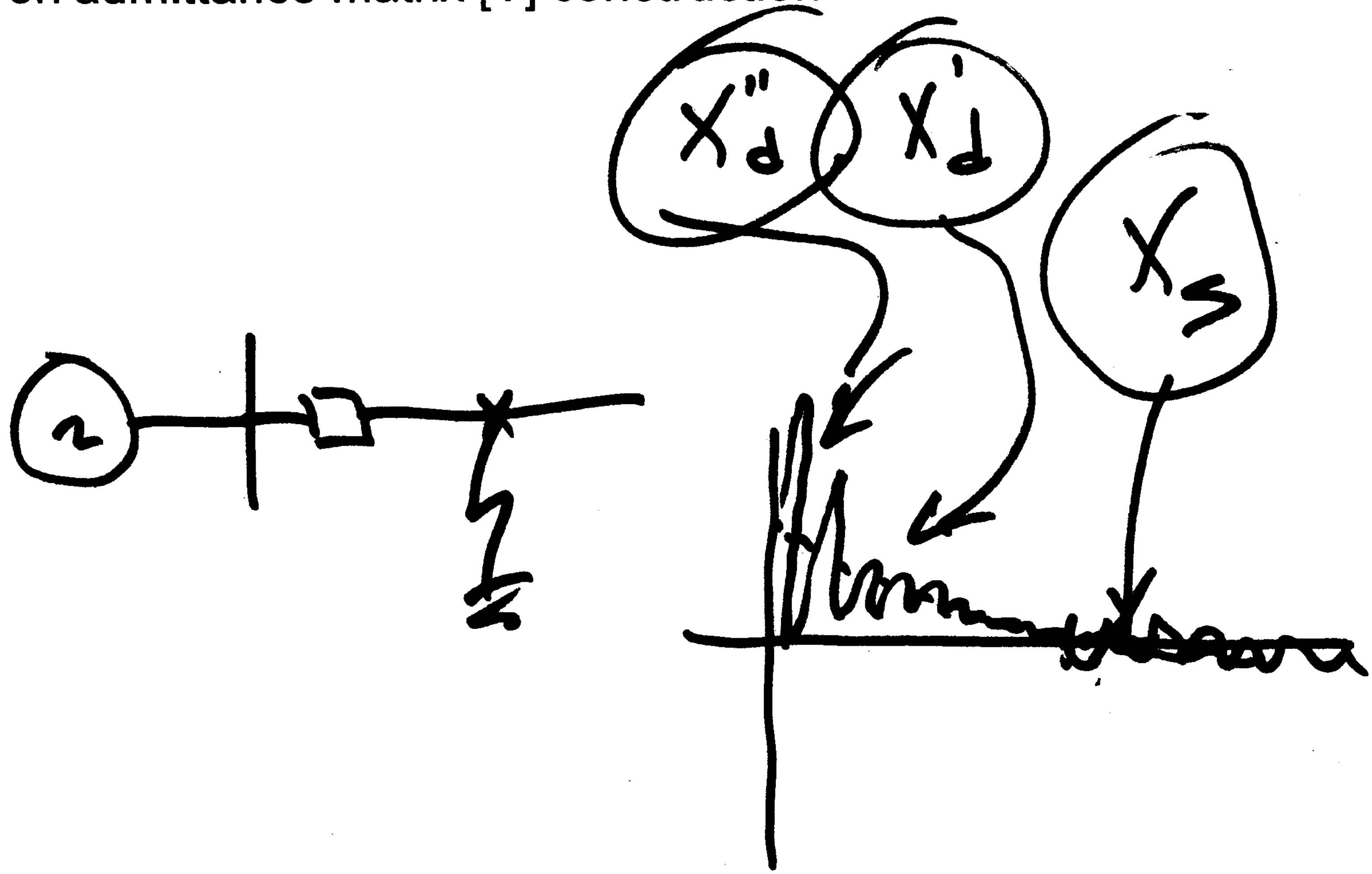


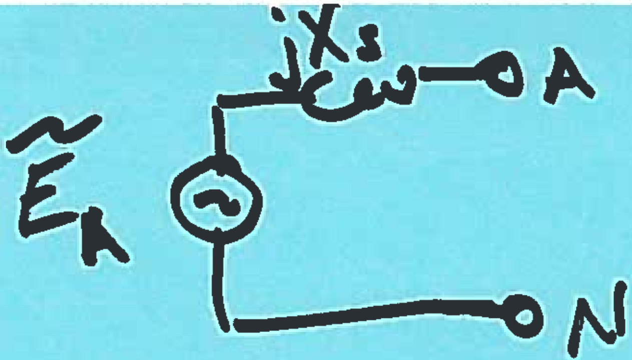
Circulating Vars

Energization Testing of Var Meters

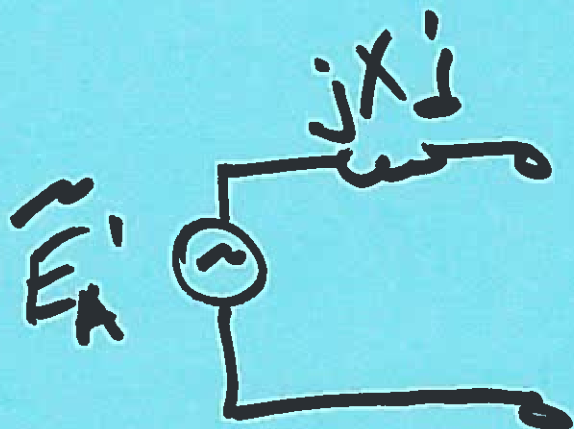
Next: Synchronous Machines - Chapter 3 — Week 5

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

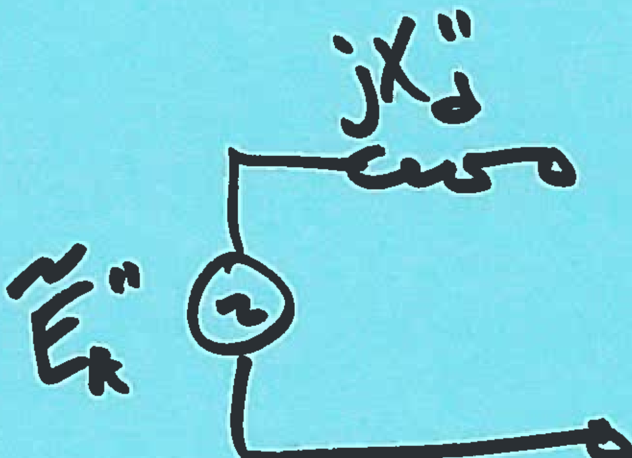




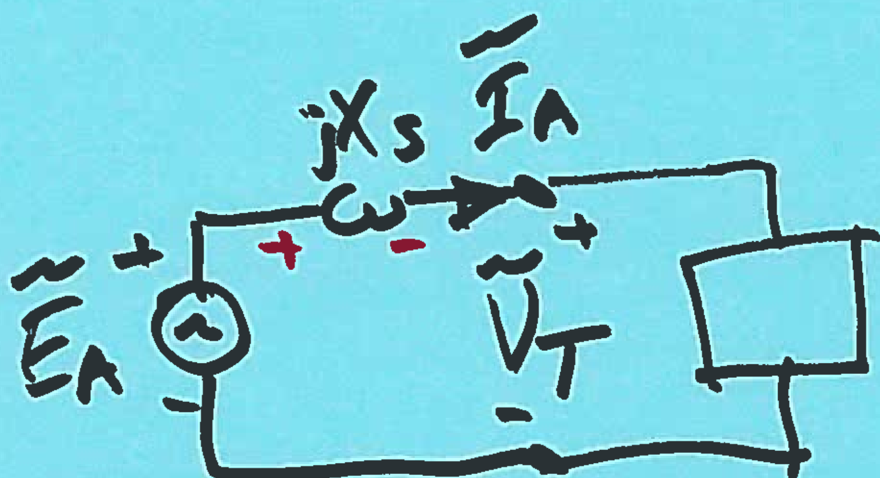
S.S
- Power Flow



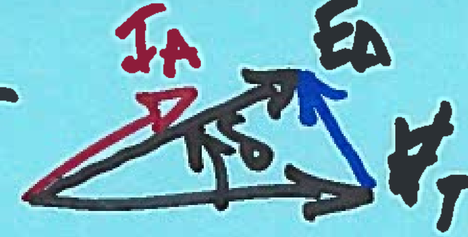
Trans
- Stab



Subtrans
- S.C.
- Switching



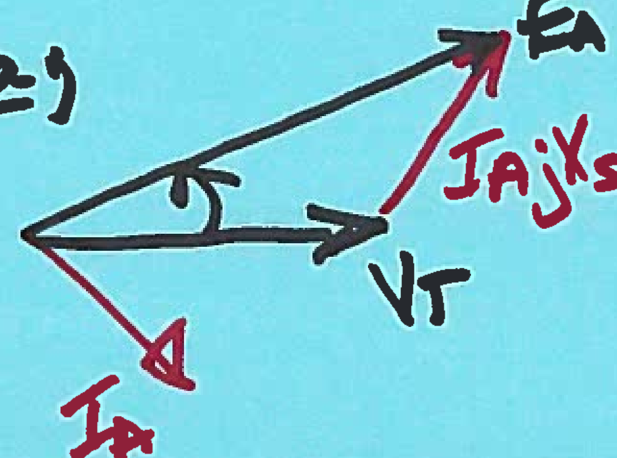
Lead



Unity

$$\left(P_{out} = \frac{E_A V_T}{X_s} \sin\delta\right)$$

Lag



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