EE 5200 - Lecture 10

Mon Sep 23, 2019

Topics for Today:

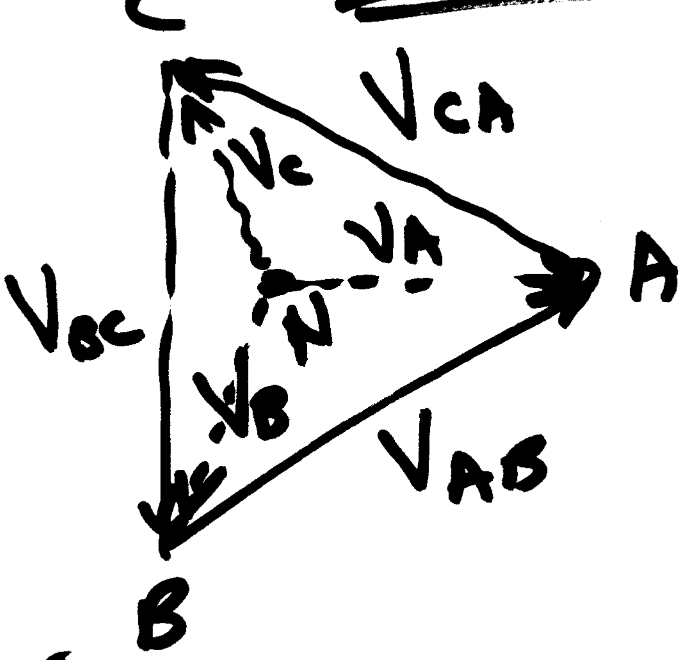
- Announcements
  - Matlab - use remote.mtu.edu remote desktop server...
    - See IEEE Std IEEE Std. 605-2008, Section 11.3.1, for short circuit forces.
  - Office hrs: 11:05-11:55pm W,F in EERC 214
  - Office: EERC 614.   Phone: 906.487.2857
  - Recommended problems from Ch.3

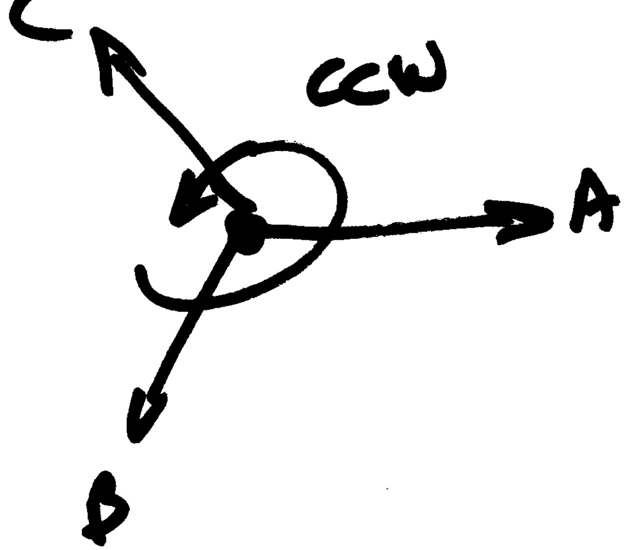
- Transformers and circuits w/transformers
  - An example of phase shift, using VTs system protection
  - Paralleling of transformers
    - Proportioning of MVA flow for unequal MVA size, unlike impedances
    - Circuit calculations for above cases
    - Design and operations issues
  - Phase shifting transformers
  - Remaining topics will be covered in context of system operation & analysis, i.e. Chapters 7 and 8.
    - Per phase Pi-equivalent for off-nominal turns ratio, phase shifts, etc.
    - Incorporation in system admittance matrix for short-circuit and load flow

Next: Synchronous Machines - Chapter 3 (starting with Section 3.9)

- 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

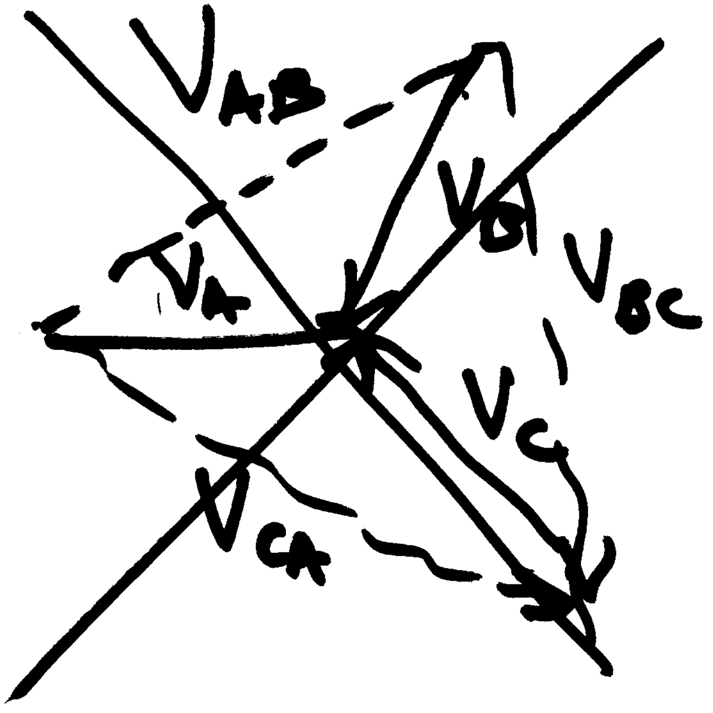
USE THIS

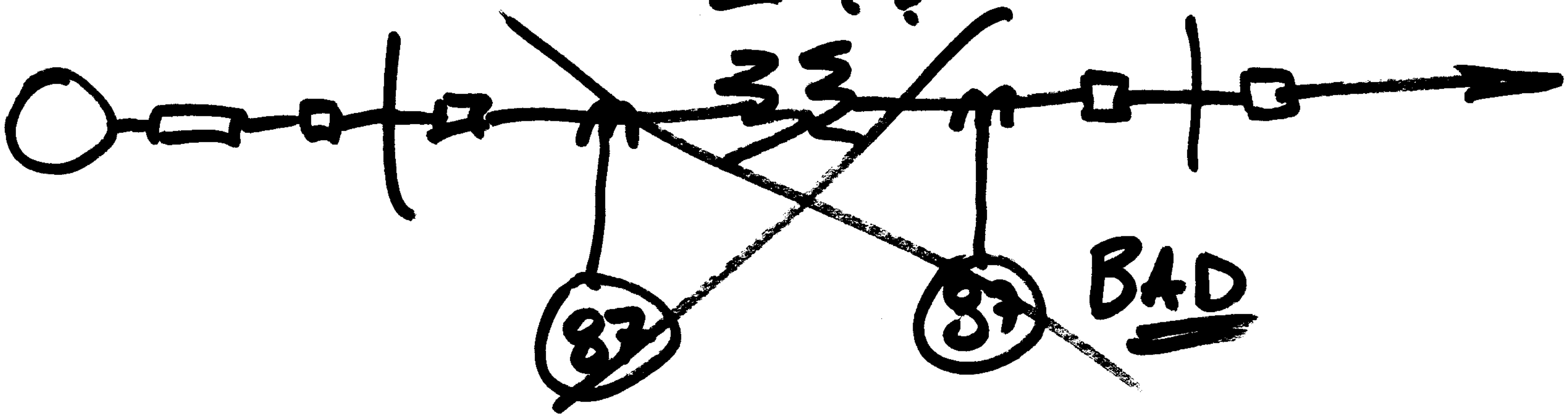


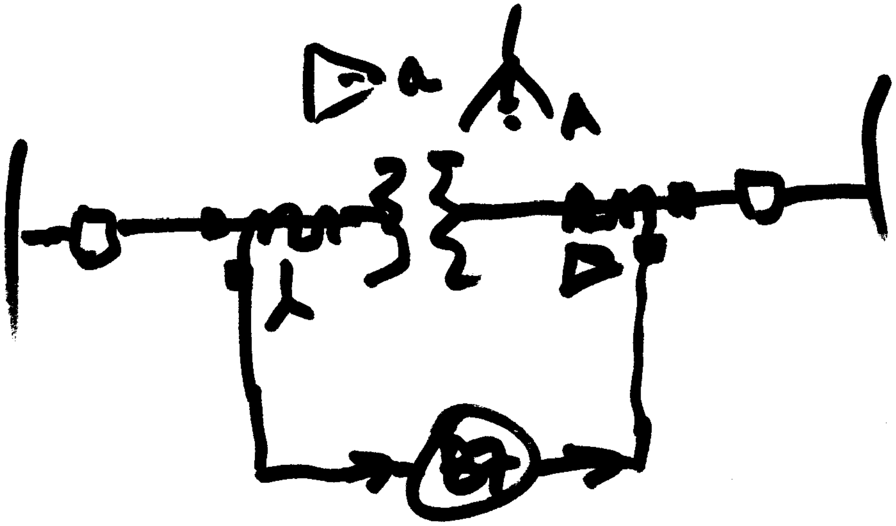


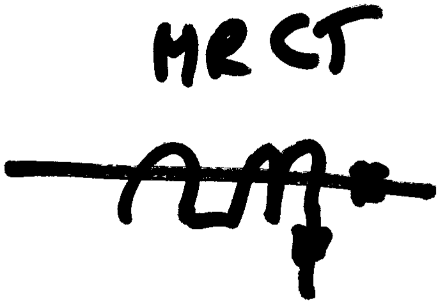
NOT THIS!

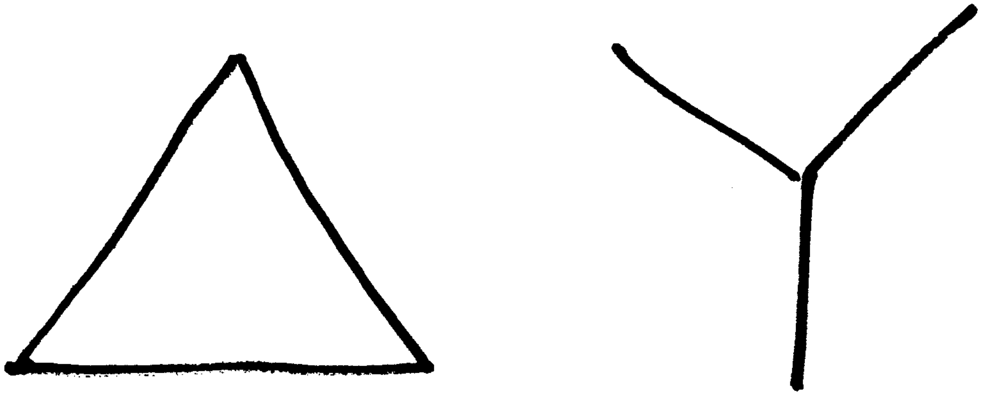
See pp. 19, 20
Fig 1.16, 1.17



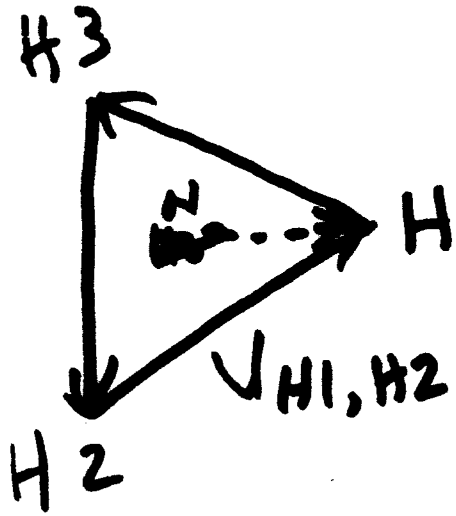

Δ Y
87
87
BAD

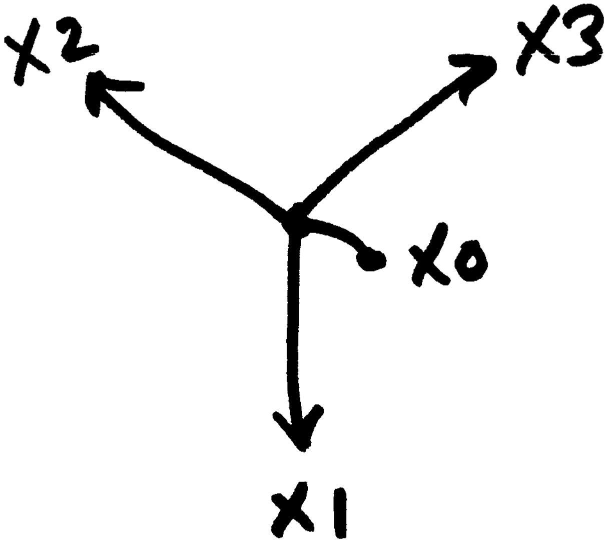

Δ
Y
Y
Δ
87

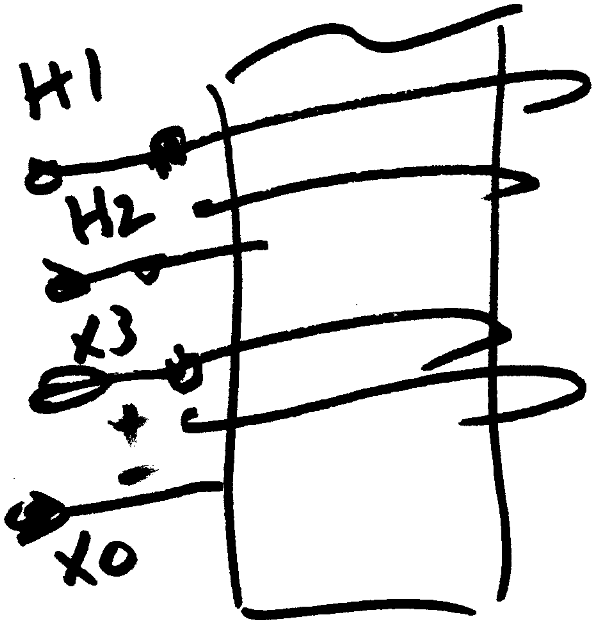

MRCT



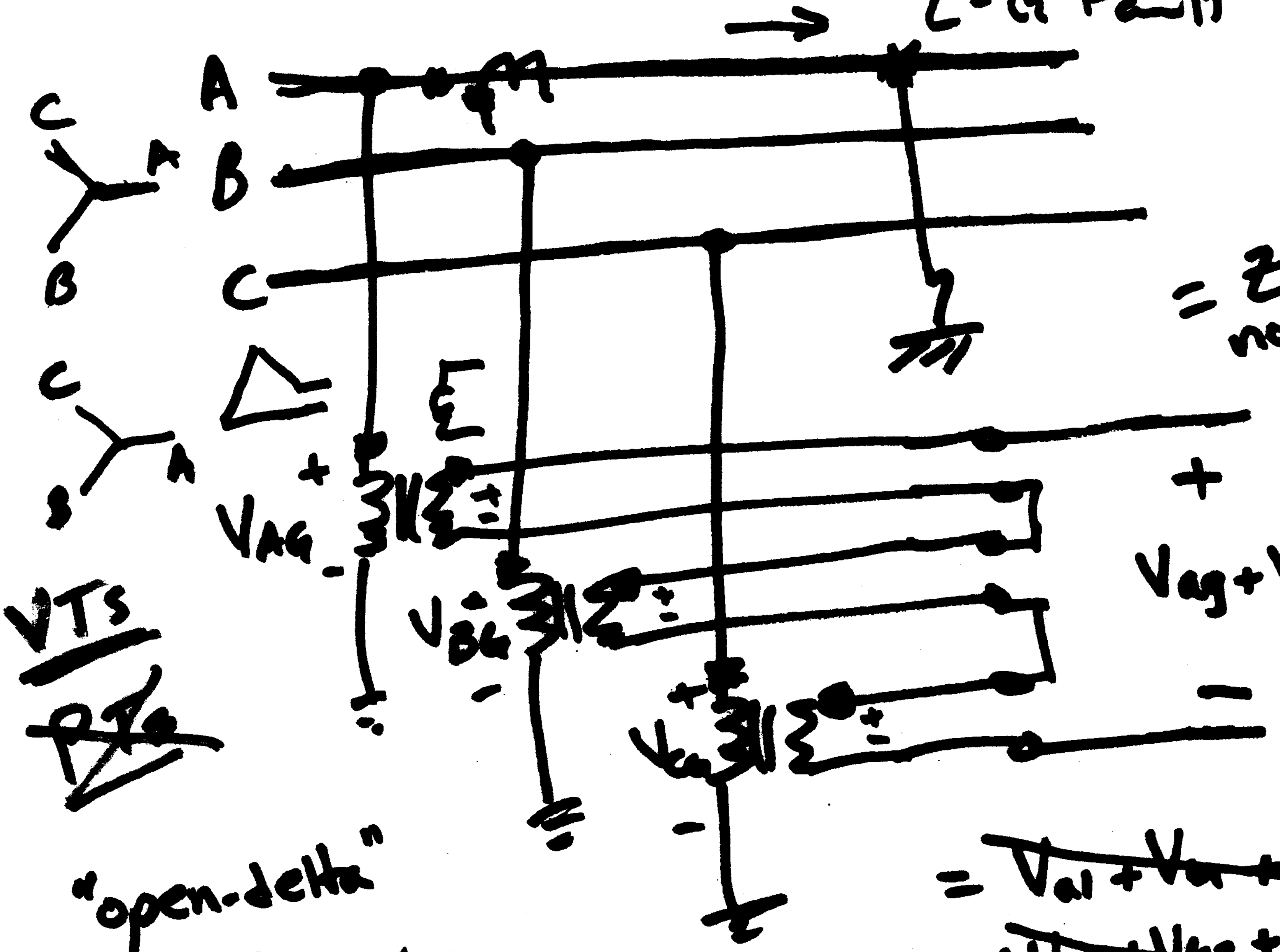
- H1 & X1 "Corners" not labelled!
- Dashed line missing (H1)
- Applied & induced voltages not aligned!


H3
N
H1
$V_{H1,H2}$
H2


X2
X3
X0
X1


H1
H2
X3
+
-
X0

L-G Fault



VTS

~~PTs~~

= zero normally.

$V_{ag} + V_{bg} + V_{cg}$
$= 3V_{a0}$

"open-delta"
or
"**broken delta**"

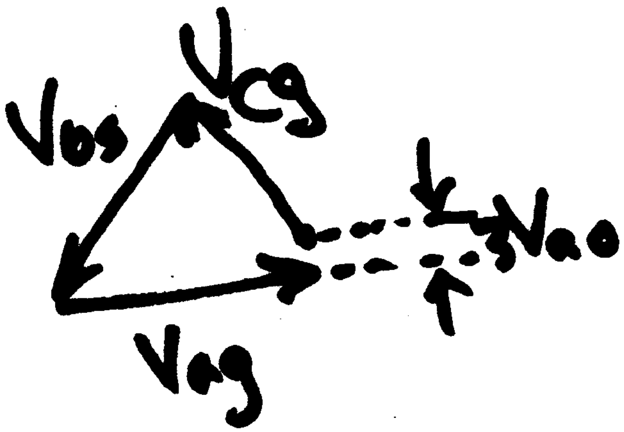
$= \cancel{V_{a1} + V_{b1} + V_{c1}} \rightarrow 0$

$+ \cancel{V_{a2} + V_{b2} + V_{c2}} \rightarrow 0$

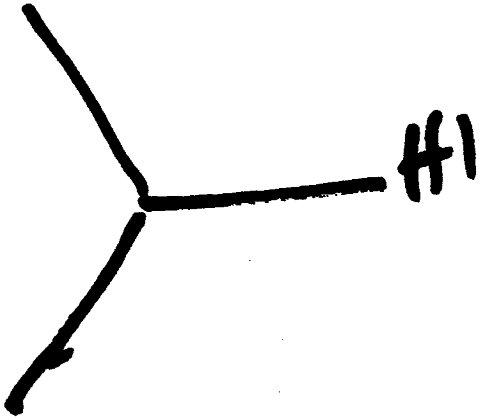
$+ V_{a0} + V_{b0} + V_{c0}$
$= 3V_{a0}$

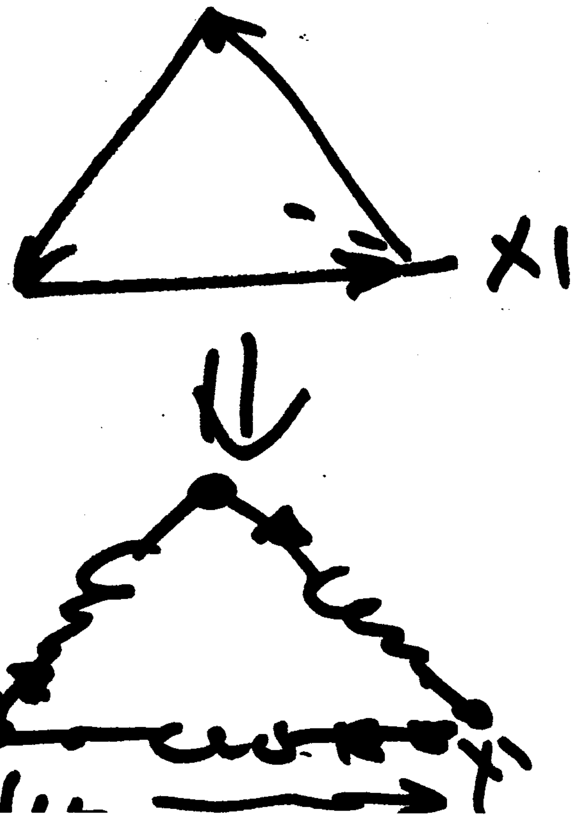
3a

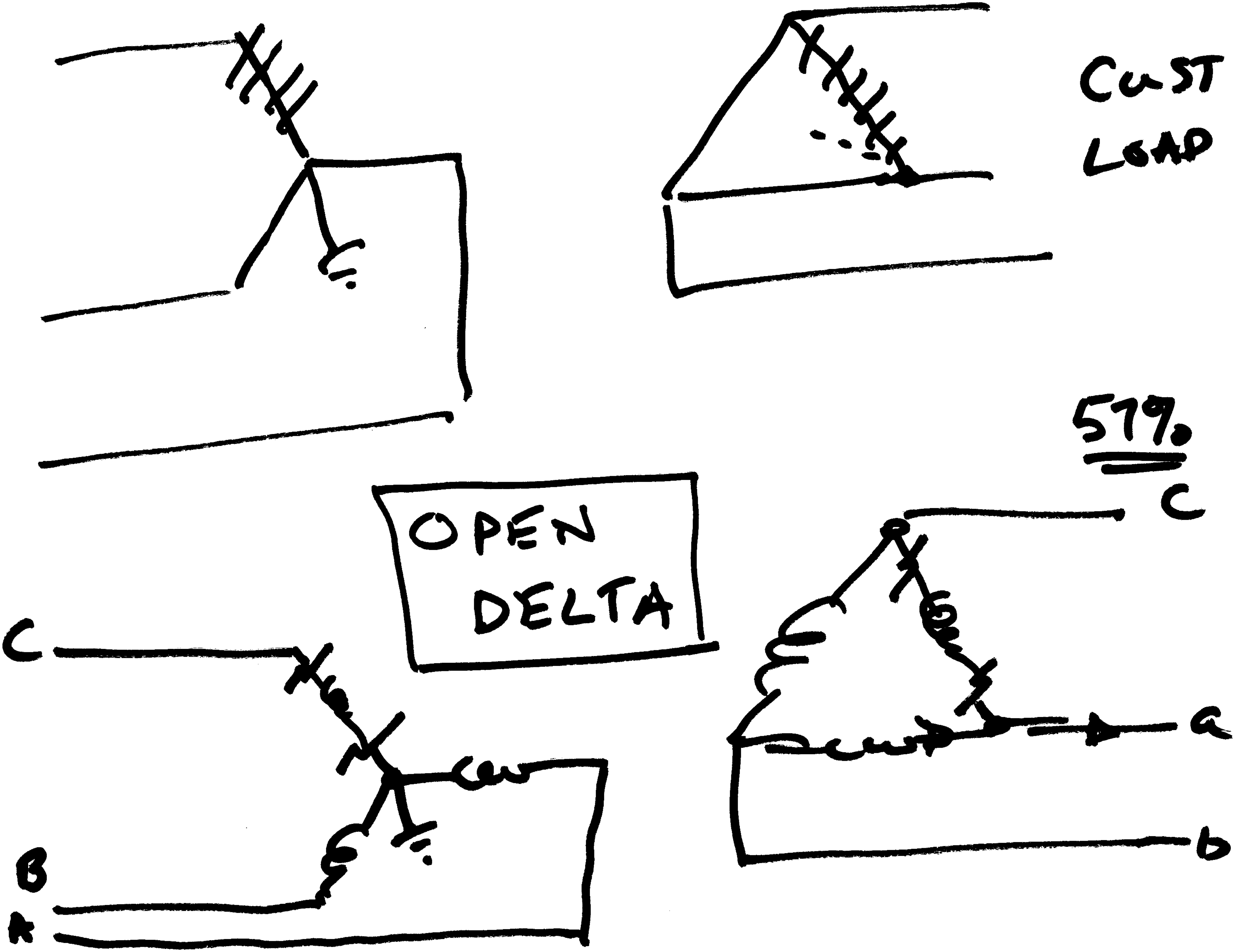
normal

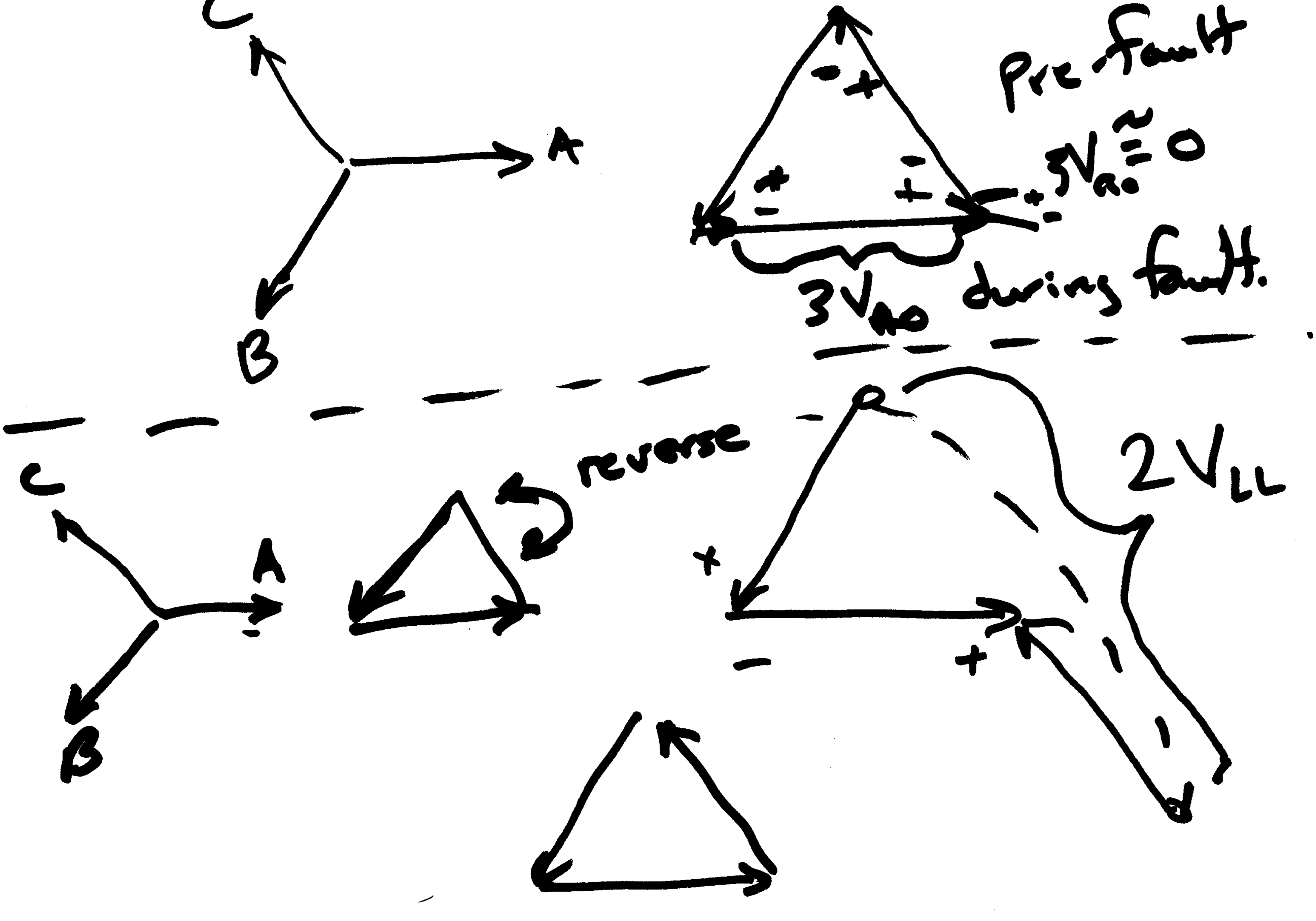


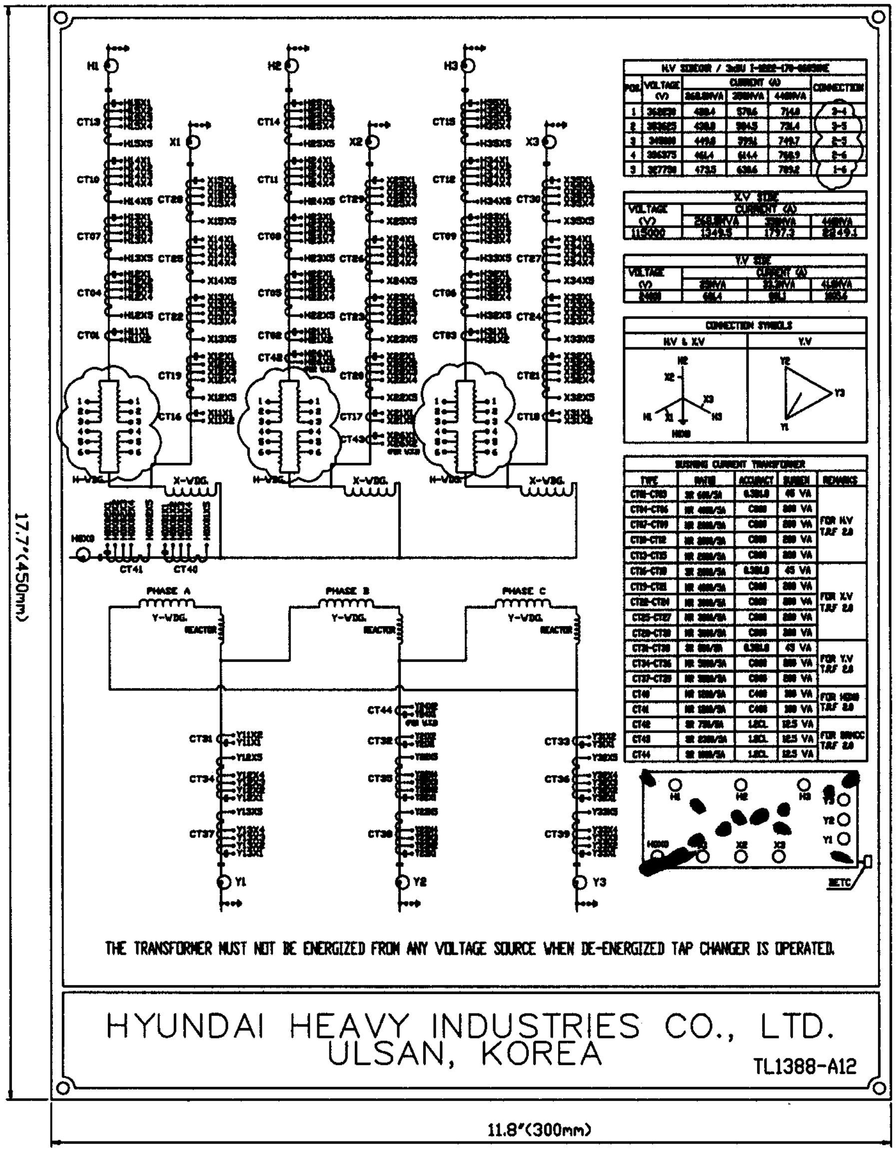
A-G Fault






CUST LOAD
57%
C
a
b
OPEN DELTA
C
B
A


C
A
B
Pre-fault
3V_a0 ≅ 0
3V_a0 during fault.
+
−
C
A
B
reverse
2V_LL
+
−
+



H.V SIDE(OR / 3x[illegible])					
POS	VOLTAGE (V)	CURRENT (A)			CONNECTION
		268.8MVA	358MVA	448MVA	
1	362250	428.4	570.6	714.0	2-4
2	353625	438.9	584.5	731.4	3-5
3	345000	449.8	599.1	749.7	2-5
4	336375	461.4	614.4	768.9	2-6
5	327750	473.5	630.6	789.2	1-6

X.V SIDE			
VOLTAGE (V)	CURRENT (A)		
	268.8MVA	358MVA	448MVA
115000	1349.5	1797.3	2249.1

Y.V SIDE			
VOLTAGE (V)	CURRENT (A)		
	25MVA	33.3MVA	[illegible]
24000	601.4	801.1	[illegible]

CONNECTION SYMBOLS

H.V & X.V | Y.V

BUSHING CURRENT TRANSFORMER				
TYPE	RATIO	ACCURACY	BURDEN	REMARKS
CT01-CT03	[illegible]	0.3B1.8	45 VA	FOR H.V T.R.F 2.0
CT04-CT06	[illegible]	C800	200 VA	
CT07-CT09	[illegible]	C800	200 VA	
CT10-CT12	[illegible]	C800	200 VA	
CT13-CT15	[illegible]	C800	200 VA	
CT16-CT18	[illegible]	0.3B1.8	45 VA	FOR X.V T.R.F 2.0
CT19-CT21	[illegible]	C800	200 VA	
CT22-CT24	[illegible]	C800	200 VA	
CT25-CT27	[illegible]	C800	200 VA	
CT28-CT30	[illegible]	C800	200 VA	
CT31-CT33	[illegible]	0.3B1.8	45 VA	FOR Y.V T.R.F 2.0
CT34-CT36	[illegible]	C800	200 VA	
CT37-CT39	[illegible]	C800	200 VA	
CT40	[illegible]	C400	100 VA	FOR H0X0 T.R.F 2.0
CT41	[illegible]	C400	100 VA	
CT42	[illegible]	1.2CL	12.5 VA	FOR [illegible] T.R.F 2.0
CT43	[illegible]	1.2CL	12.5 VA	
CT44	[illegible]	1.2CL	12.5 VA	

THE TRANSFORMER MUST NOT BE ENERGIZED FROM ANY VOLTAGE SOURCE WHEN DE-ENERGIZED TAP CHANGER IS OPERATED.

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ULSAN, KOREA

TL1388-A12

※ NOTE

1. MATERIAL : STAINLESS STEEL
2. DIMENSION : T0.04(1.0) x 11.8(300) x 17.7(450) Inch(mm)
3. NATURAL FACE, DARK LETTER AND LINE

Rev. No.	DATE	DSN	CHE	APP	DESCRIPTION
1	JULY 16, '07	M.S.LEE	H.D.SONG	J.S.LEE	ADDED SERIES REACTOR
2	Aug. 18, '07	M.S.LEE	H.D.SONG	J.S.LEE	REVISED CT RATIO CT31 TO CT33
3	Sep. 15, '07	M.S.LEE	H.D.SONG	J.S.LEE	REVISED SINGLE RATIO CT CLASS AND BURDEN
4	Sep. 18, '07	M.S.LEE	H.D.SONG	J.S.LEE	REVISED YV BUSHING POSITION AND CONNECTION DIAGRAM
5	Nov.14, '07	M.S.LEE	H.D.SONG	J.S.LEE	REVISED YV CONNECTION
6	Nov.21, '07	M.S.LEE	H.D.SONG	J.S.LEE	ADDED THERMAL RATING FACTOR
7	Feb.12, '08	M.S.LEE	H.D.SONG	J.S.LEE	REVISED YV BUSHING POSITION AND CT RATIO(CT43)
8	Feb.16, '08	M.S.LEE	H.D.SONG	J.S.LEE	ADDED NEW CONTRACT(EQUIP.NO.024469 & 024470)

448MVA 345/115/24KV

DSN	CHK	APP	PROJ.	3RD	TITLE : 3PH 60HZ 268.8/358/448MVA 345/115/24KV
M.S.LEE '070614	H.D.SONG '070614	J.S.LEE '070614	UNIT	Inch	CONNECTING PLATE
			SCALE	1/1	PROJECT NO. 20070921NE003-007, 20073672TNF009 & 010
			SIZE	A3	CAD NO. LM/I1388a12 — SHEET
					REF. NO. TL1388-A11 — 1 OF 1
					DWG. NO. TL1388-A12 — REV. 8

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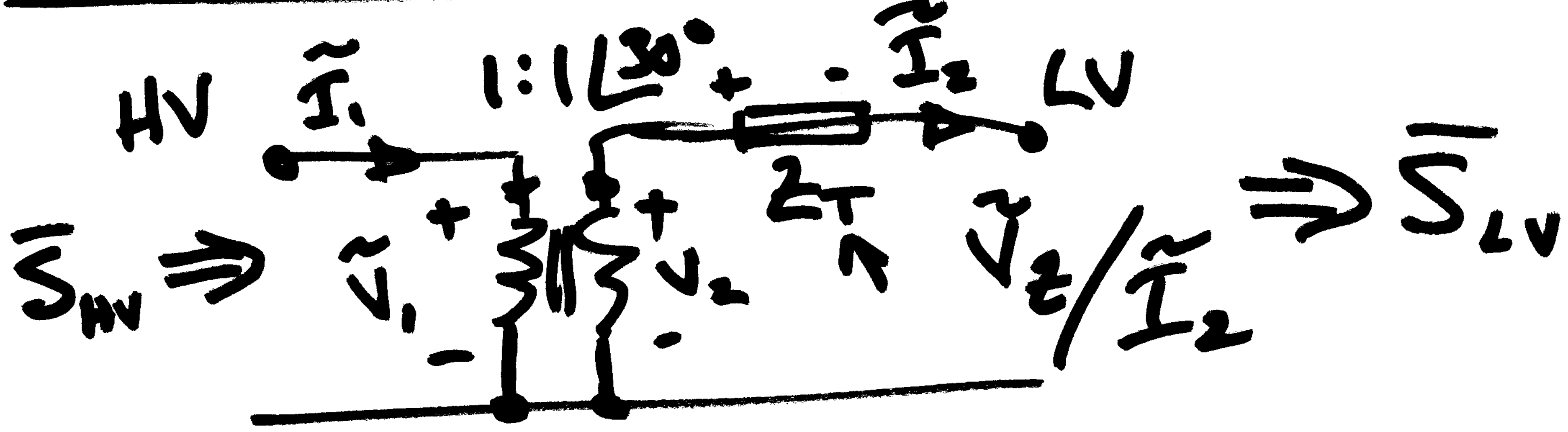
PHASE SHIFTING:

Mathematically: Sequence networks

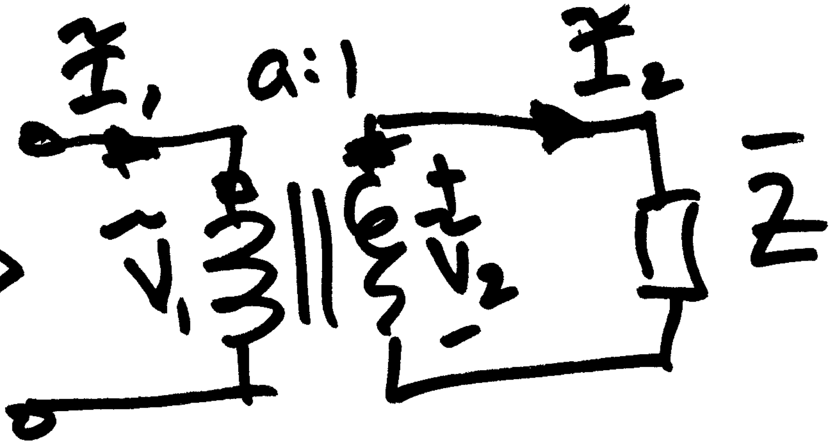


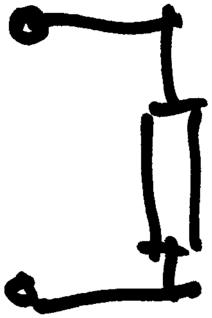
$$\bar{S}_{HV} = \bar{S}_{LV}$$

$$\tilde{V}_1 \tilde{I}_1^* = \tilde{V}_2 \tilde{I}_2^*$$

Can prove that if $\left|\frac{\tilde{V}_1}{\tilde{V}_2}\right| = 1$, then Z_T is same on HV side.

$\bar{Z}_{IN} = ?$ $\Longrightarrow$





$$\bar{Z}_{IN} = \frac{\tilde{V}_1}{\tilde{I}_1} = \frac{\tilde{V}_2 \times a}{\tilde{I}_2 / a^*} = \bar{Z} a a^* = \bar{Z} |a|^2$$

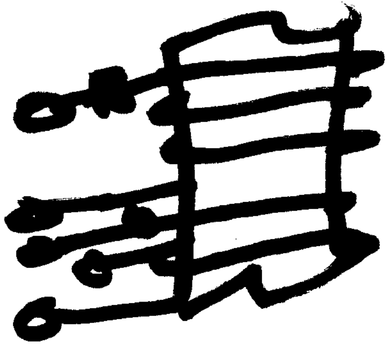
$$\boxed{\bar{Z}_{IN} = Z}$$

$$\boxed{\tilde{V}_1 \tilde{I}_1^* = \tilde{V}_2 \tilde{I}_2^*}$$

$$\Rightarrow \frac{\tilde{I}_1^*}{\tilde{I}_2^*} = \frac{\tilde{V}_2}{\tilde{V}_1} = \frac{1}{a} \Rightarrow \boxed{\tilde{I}_1 = \frac{\tilde{I}_2}{a^*}}$$

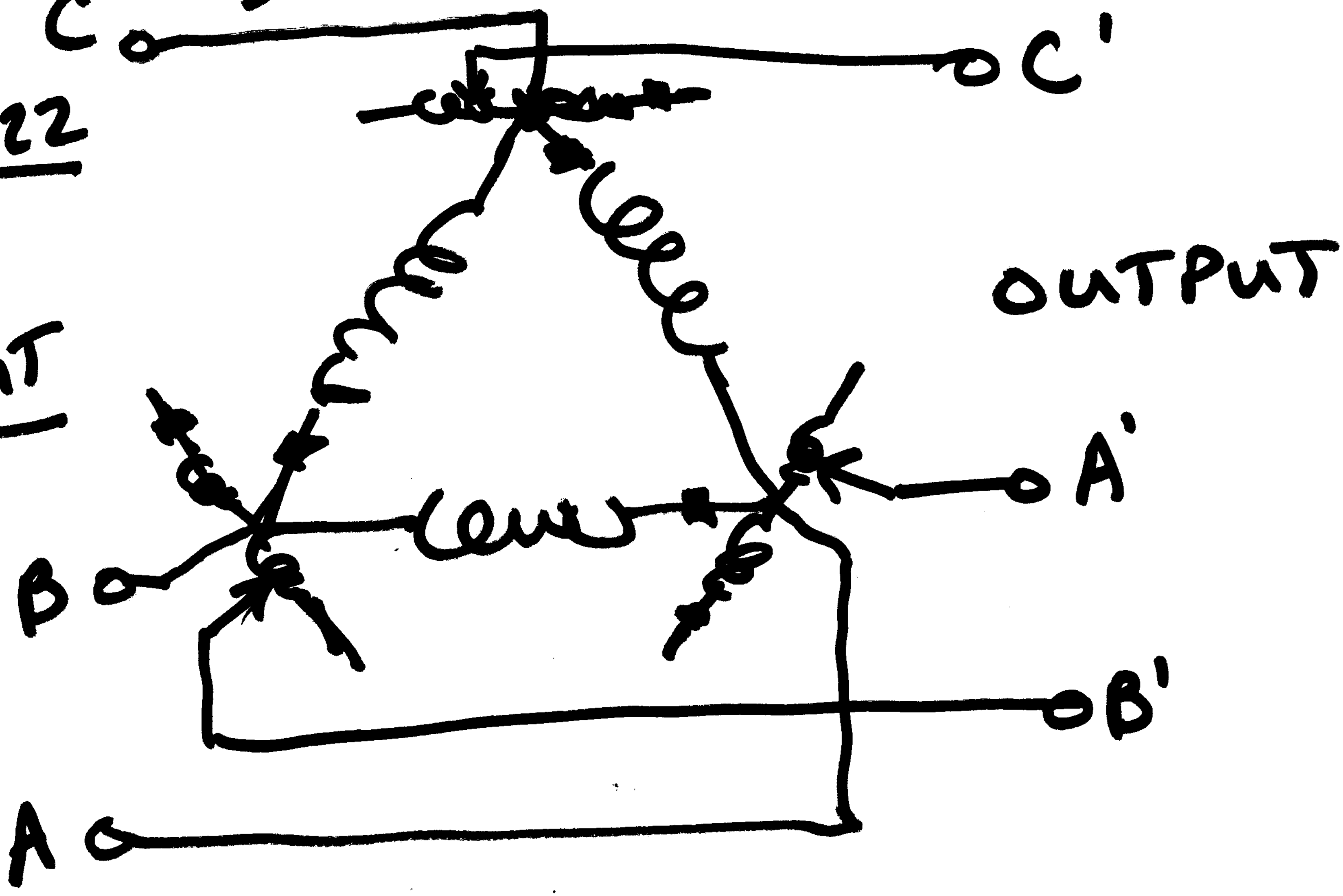
POWER TRANSFORMERS (W/ PHASE SHIFT)

§ 2.9 of text



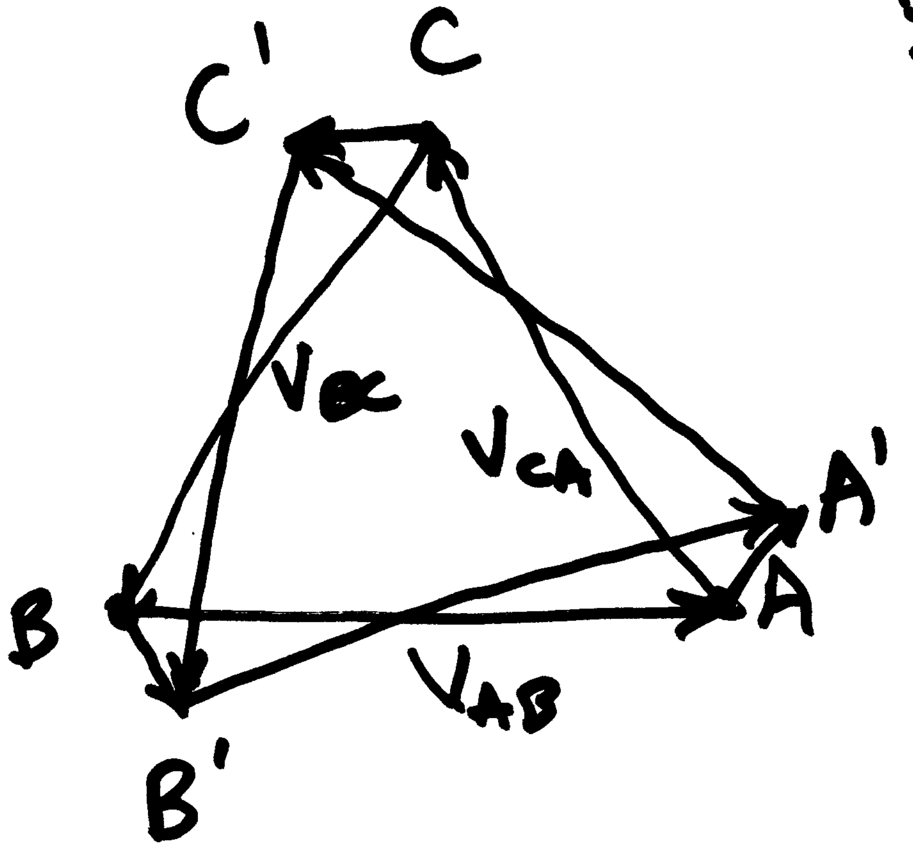
"PS"

Fig 2.22



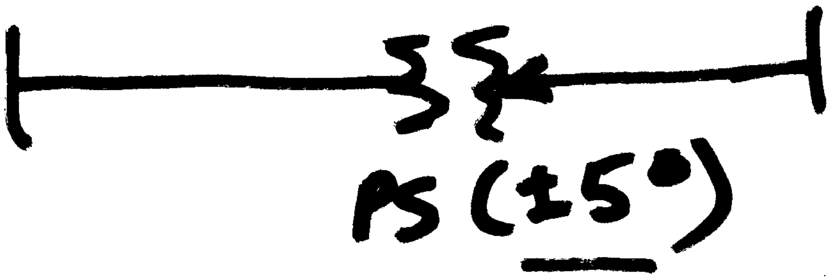
Errata

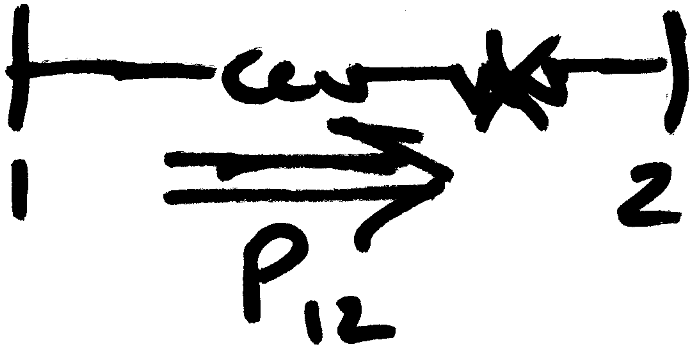
Fig. 2.23

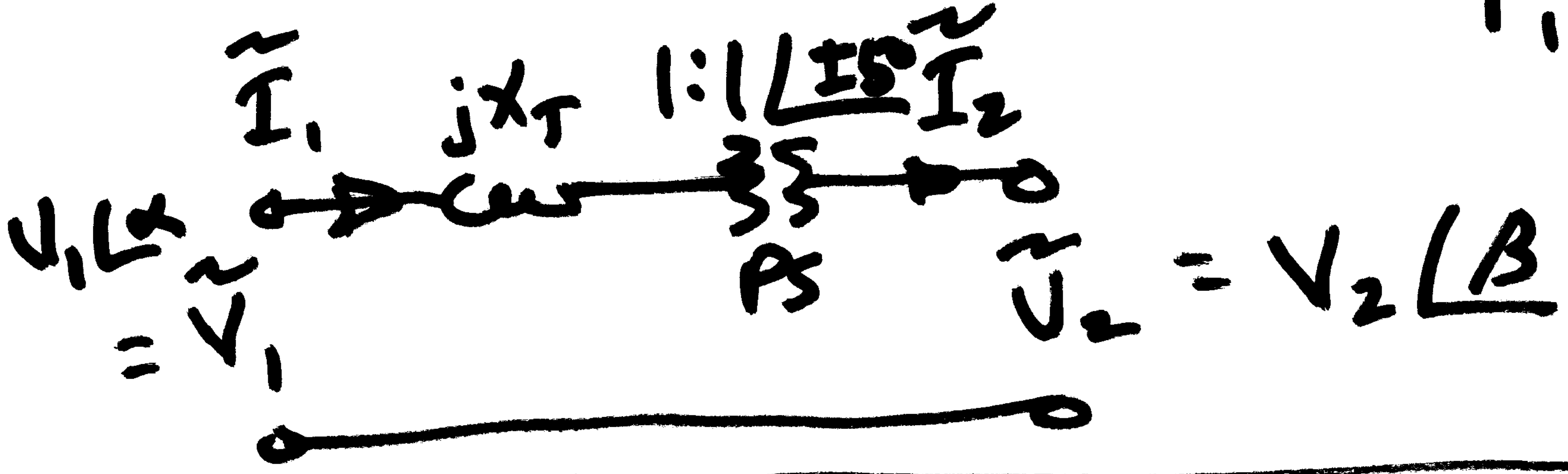


Typically:
±5°

(See also Fig. 2.21)





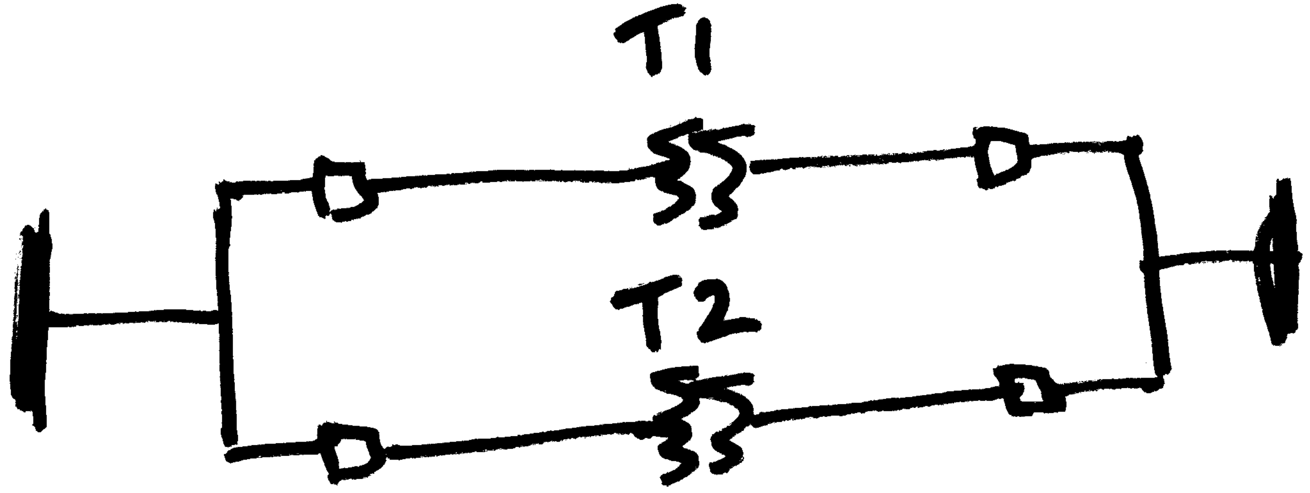


$$\boxed{P_{1\to 2} = \frac{V_1 V_2}{X_T}\sin\underbrace{(\alpha - \underline{\underline{\beta}})}}$$

Increase $P_{1\to 2}$: decrease β (increase $\alpha-\beta$)

Decrease $P_{1\to 2}$: increase β (decrease $\alpha-\beta$)

Next: Paralleling Transformers

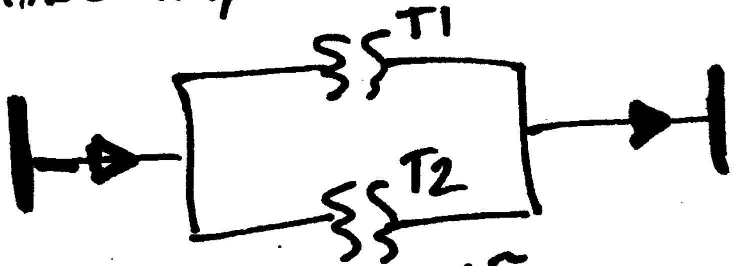


Works well if T1 & T2 are "matched"

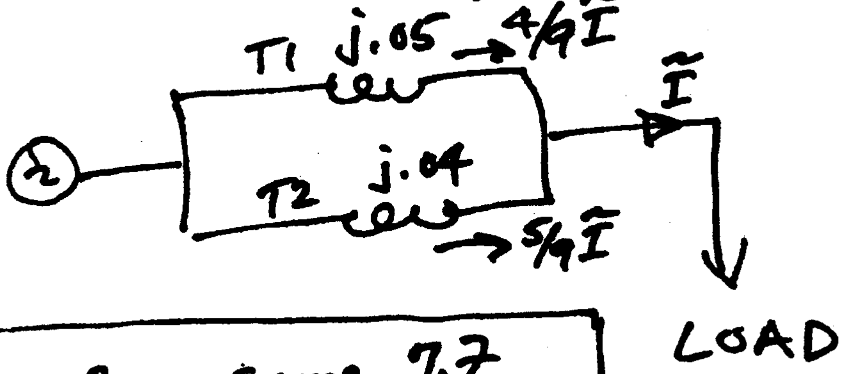
- ISSUES:
    - Impedances
    - Exact voltage ratios

Paralleling XFMRS:

- Unlike impedances, same voltage ratio



		Base: on 100MVA
T1:	90 MVA	j.05 p.u.
T2:	100 MVA	j.04 p.u.



Constraints

$$\frac{I_{T_1}}{I_{T_2}} = \frac{4}{5}$$

Ratings

$$\frac{(90\ \text{MVA})}{(100\ \text{MVA})}$$

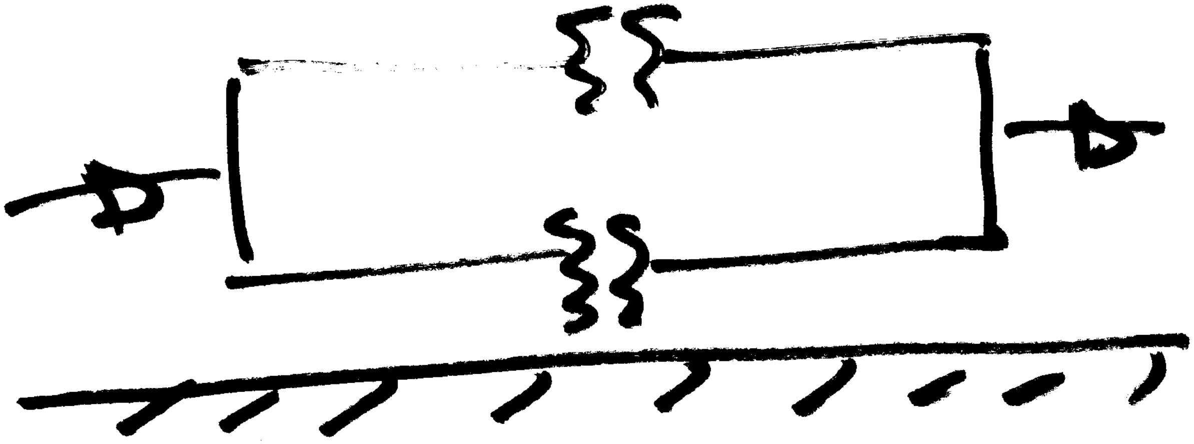
If T_1 @ 90 MVA, T_2 @ ~~$90\frac{5}{4} = 112.5$ MVA~~ BAD

If T_2 @ 100 MVA, T_1 @ 80 MVA GOOD/OK

Key: Spec same %Z on Base of indiv XFMRS!

i.e. T2: j.04 @ 100 MVA BASE
T1: j.04 @ 90 MVA BASE

However, can't use 10MVA of T1 capacity.

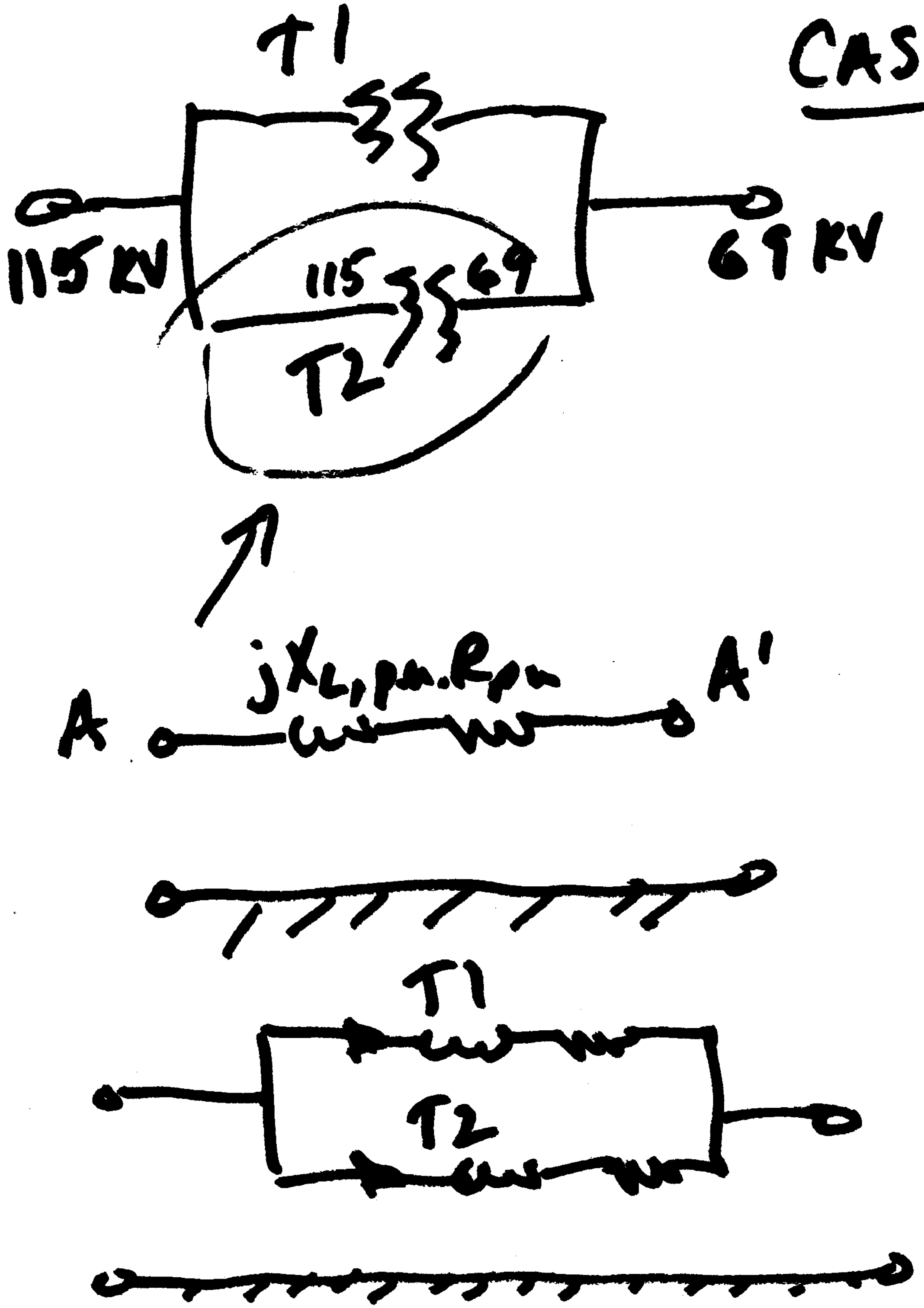


In general, voltage ratios & impedances may not be matched.

Then what?

- Circuit analysis ✓
- Network $[Y]$ - Ch. 7, 8

CASE 1

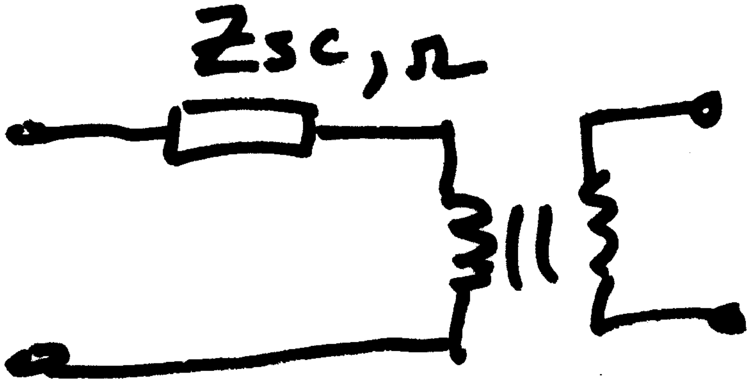


Paralleling

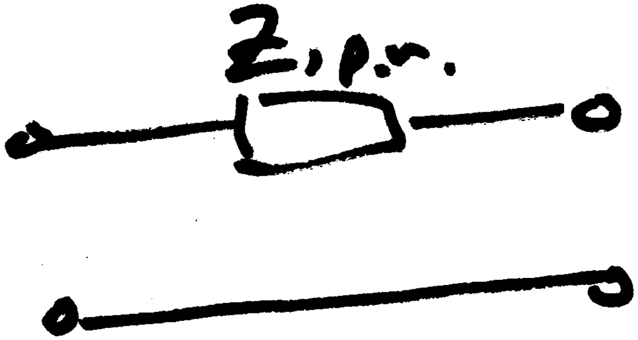
- "Unlike" impedances.
- Equal turns ratios which match V_{BASE} of system.

KEY: Z_{sc} of T1 & T2 equal on base of respective xfmrs.

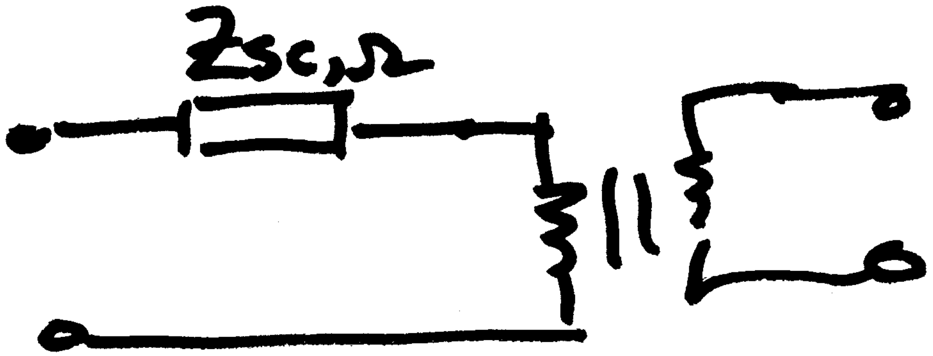
CASE 1



p.u. ⇒



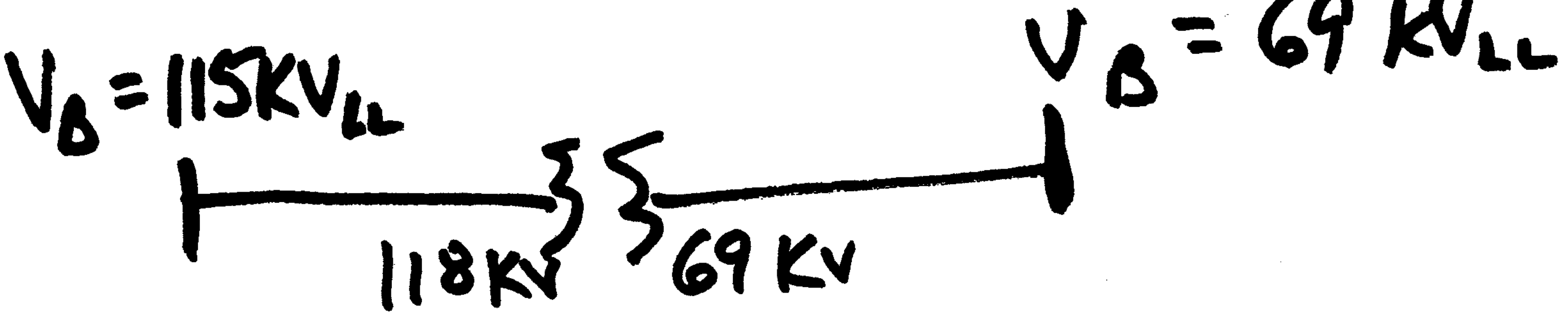
CASE 2

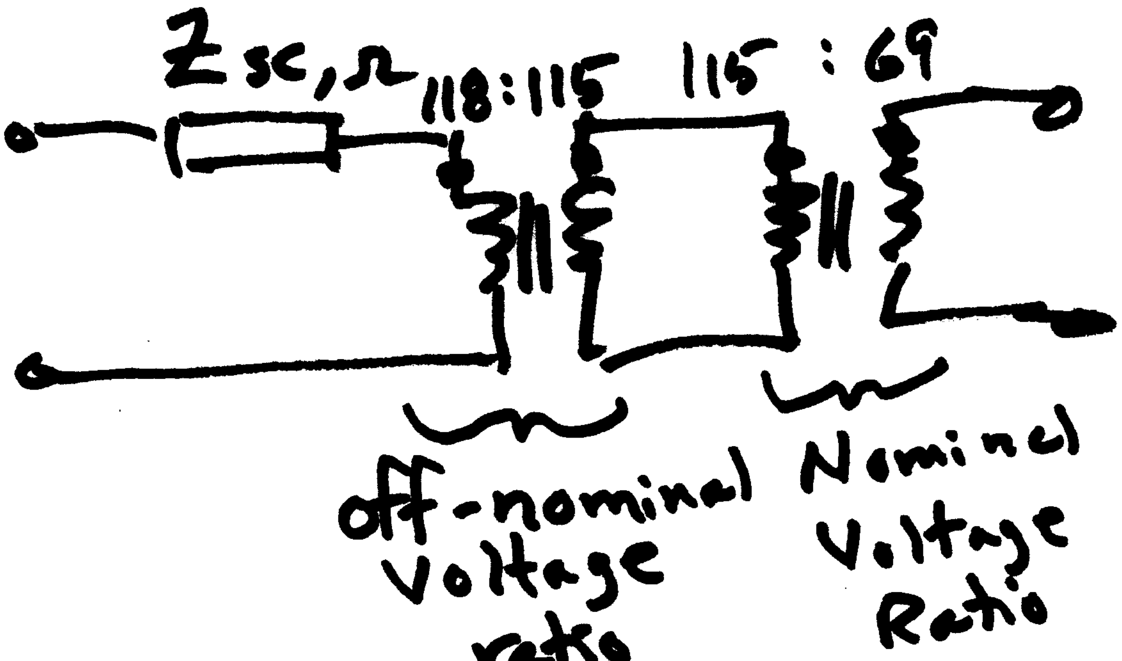


p.u. ⇒ ?

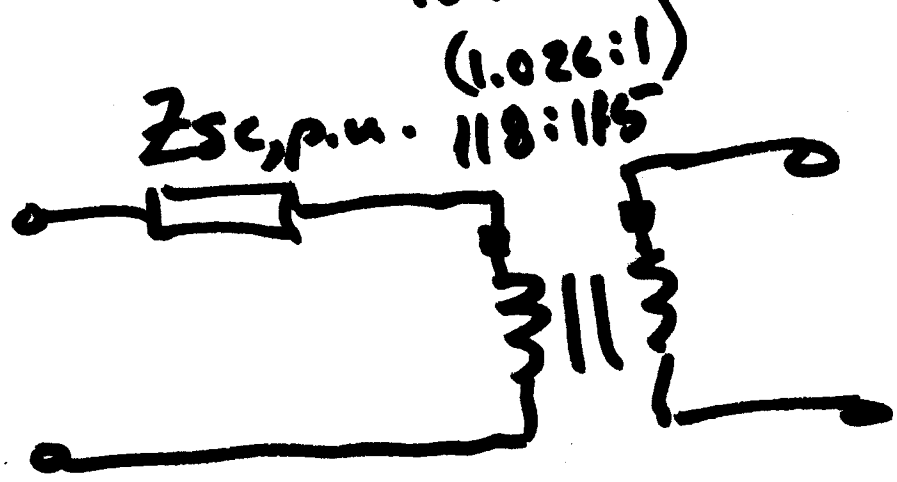
CASE 2

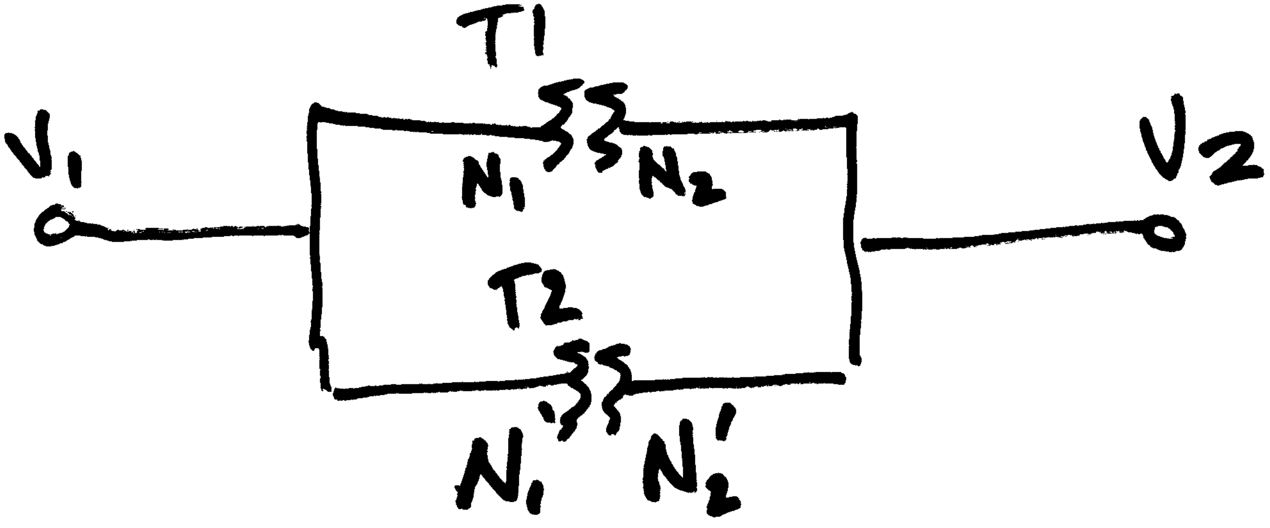
- Turns ratio (voltage ratio) of xfmr is not equal to ratio of V_{BASE} of system.




Zsc,Ω
118:115
115 : 69
off-nominal Voltage ratio
Nominal Voltage Ratio

per unit ⇒

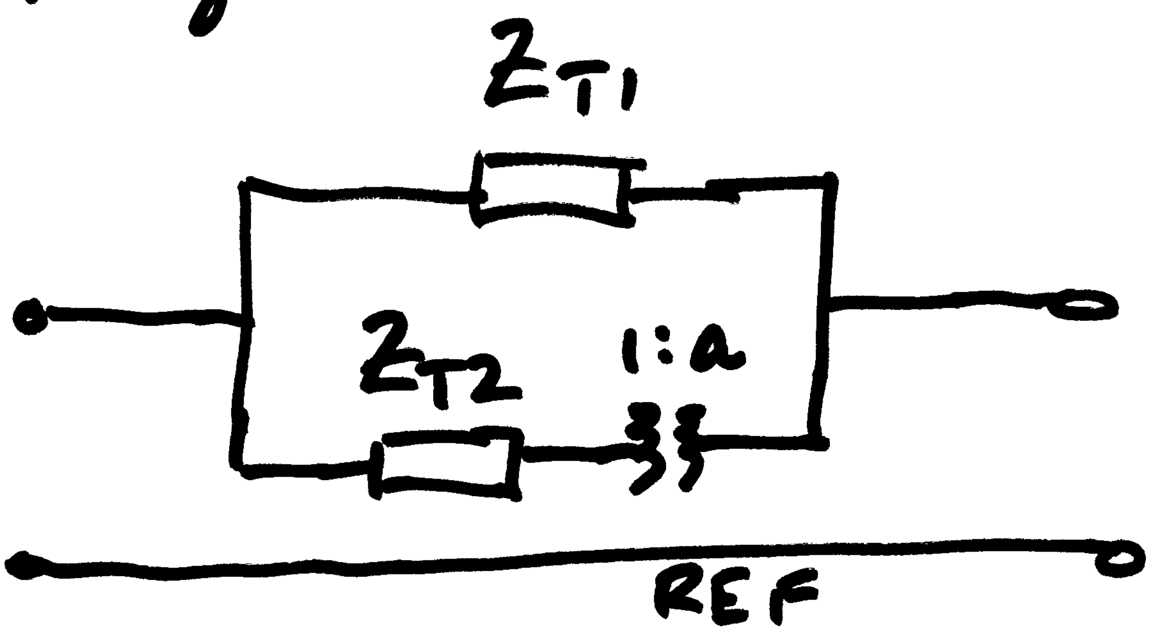

(1.026:1)
Zsc,p.u.
118:115



$$\frac{N_1}{N_2} = \frac{V_1}{V_2}$$

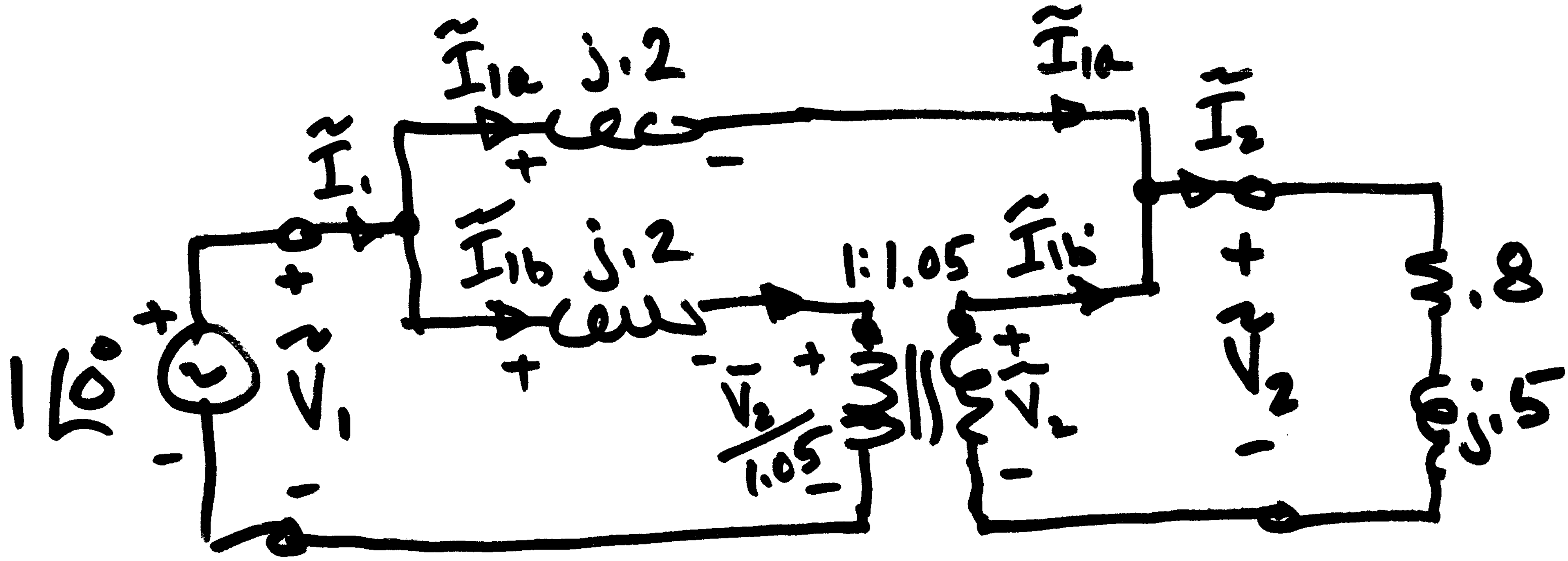
What happens if $\frac{N_1'}{N_2'} \neq \frac{N_1}{N_2}$?

Per Unit Equiv is thus:



3 Methods:

1) Ckt Theory
2) [Y] method
3) Circulating Current method.

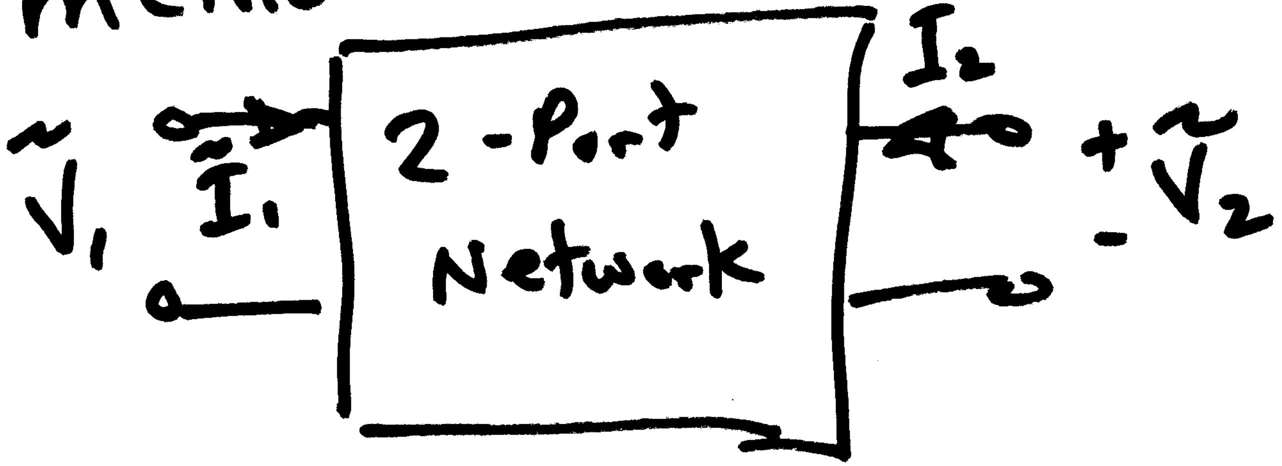


$$\tilde{I}_1 = \tilde{I}_{1a} + \tilde{I}_{1b}$$

$$\tilde{I}_2 = \tilde{I}_{1a} + \tilde{I}_{1b'} = \frac{\tilde{V}_1 - \tilde{V}_2}{j.2} + \frac{\left(\tilde{V}_1 - \tilde{V}_2/1.05\right)\left(\frac{1}{1.05}\right)}{j.2} = \frac{\tilde{V}_2}{.8 + j.5}$$

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

[Y] method:



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

$$[Y_{Bus}][V] = [I_{inj}]$$

Prob 2
(Hmwk#3)

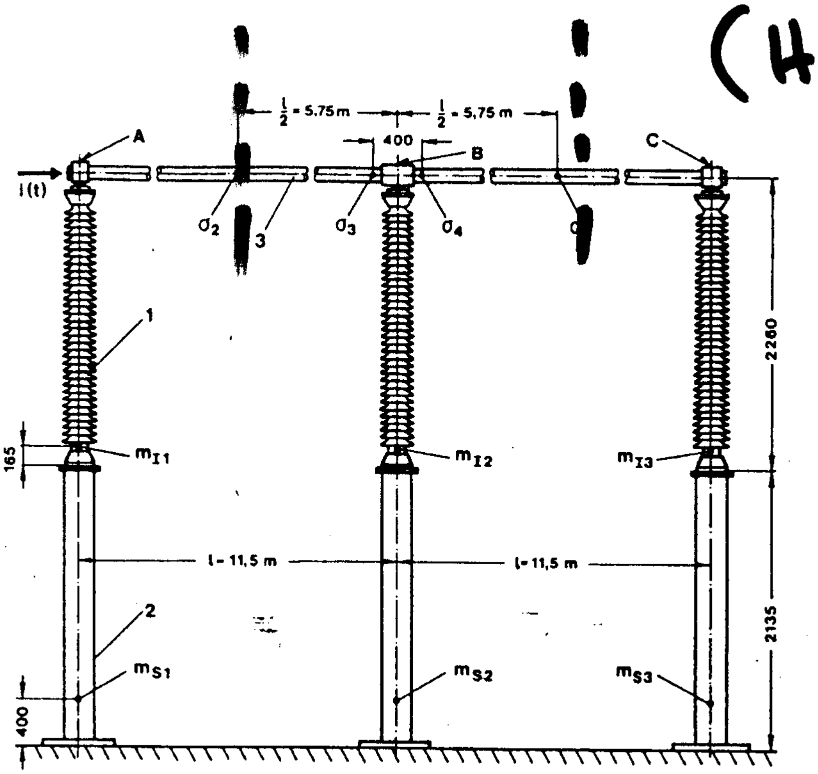


Figure F.1—CIGRE structure D (from Hosemann and Tsanakas [B14])

The structural data used in calculations is presented in Table F.1. The fault parameters are presented in Table F.2.

Table F.1—Structural data

Characteristic	Conductor	Insulator	Support
Length *L*	span of 11.5 m (including portion in conductor clamps)	2.10 m	2.135 m
Material	Aluminum	Porcelain	Steel
Young's modulus *E*	70 GPa	30.6 GPa	206 GPa
Area *A*	2.238E-3 m^2	36.14E-3 m^2	4.714E-3 m^2
Moment of inertia *I*	3.704E-6 m^4	76.08E-6 m^4	26.83E-6 m^4
Mass	6.04 kg/m	180 kg	36.8 kg/m

NOTE 1—In the finite-element model, the insulator length was extended to 2.26 m in order to reach the midconductor position.

NOTE 2—For the insulator and support, the moment of inertia used was obtained from measurements on equivalent spring stiffness (3EI/L3) as provided in Hosemann and Tsanakas [B14]; this is why in Table F.1 the values given do not necessarily correspond to the actual dimensions.

NOTE 3—The bending stiffness for the insulator is assumed constant along its length to correspond to an equivalent beam of constant section although its shape is conical.

NOTE 4—In the finite-element model, lumped masses of 13.8 kg, 18.2 kg, and 13.8 kg have been added at the top of columns 1, 2, and 3, respectively, to account for actual clamp masses. Lumped masses of 36.8 kg have been added to the top of each steel support to account for mass of top plate.

NOTE 5—Conductor is assumed to be pinned at top of columns 1 and 3 and fixed a top of column 2.

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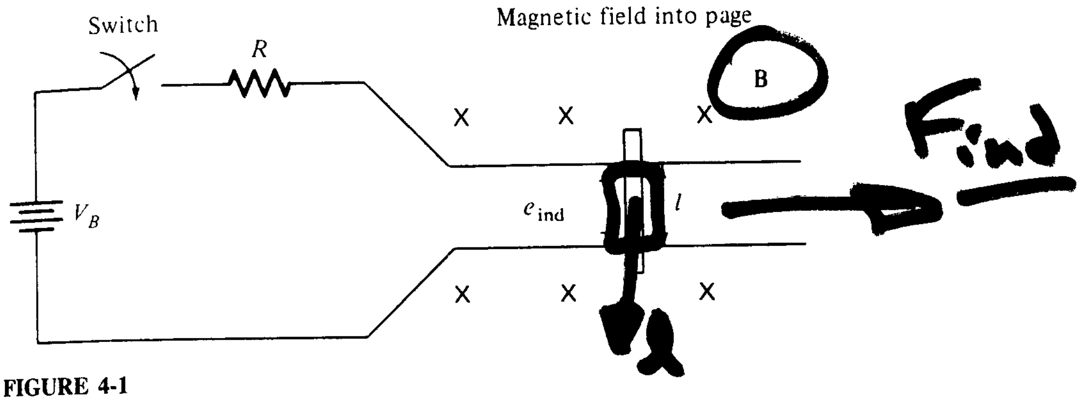


FIGURE 4-1
A linear dc machine. The magnetic field points into the page.

1. The equation for the force on a wire in the presence of a magnetic field:

$$\boxed{\mathbf{F} = i(\mathbf{l} \times \mathbf{B})} \tag{1-43}$$

where $\mathbf{F}$ = force on wire
i = current flowing in wire
$\mathbf{l}$ = length of wire, with direction of $\mathbf{l}$ in the direction of current flow
$\mathbf{B}$ = magnetic flux density vector

2. The equation for the voltage induced in a wire moving in a magnetic field:

$$\boxed{e_{\text{ind}} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l}} \tag{1-45}$$

where e_{ind} = voltage induced in wire
$\mathbf{v}$ = velocity of wire
$\mathbf{B}$ = magnetic flux density vector
$\mathbf{l}$ = length of conductor in magnetic field

3. Kirchhoff's voltage law for this machine. From Fig. 4-1 this law gives

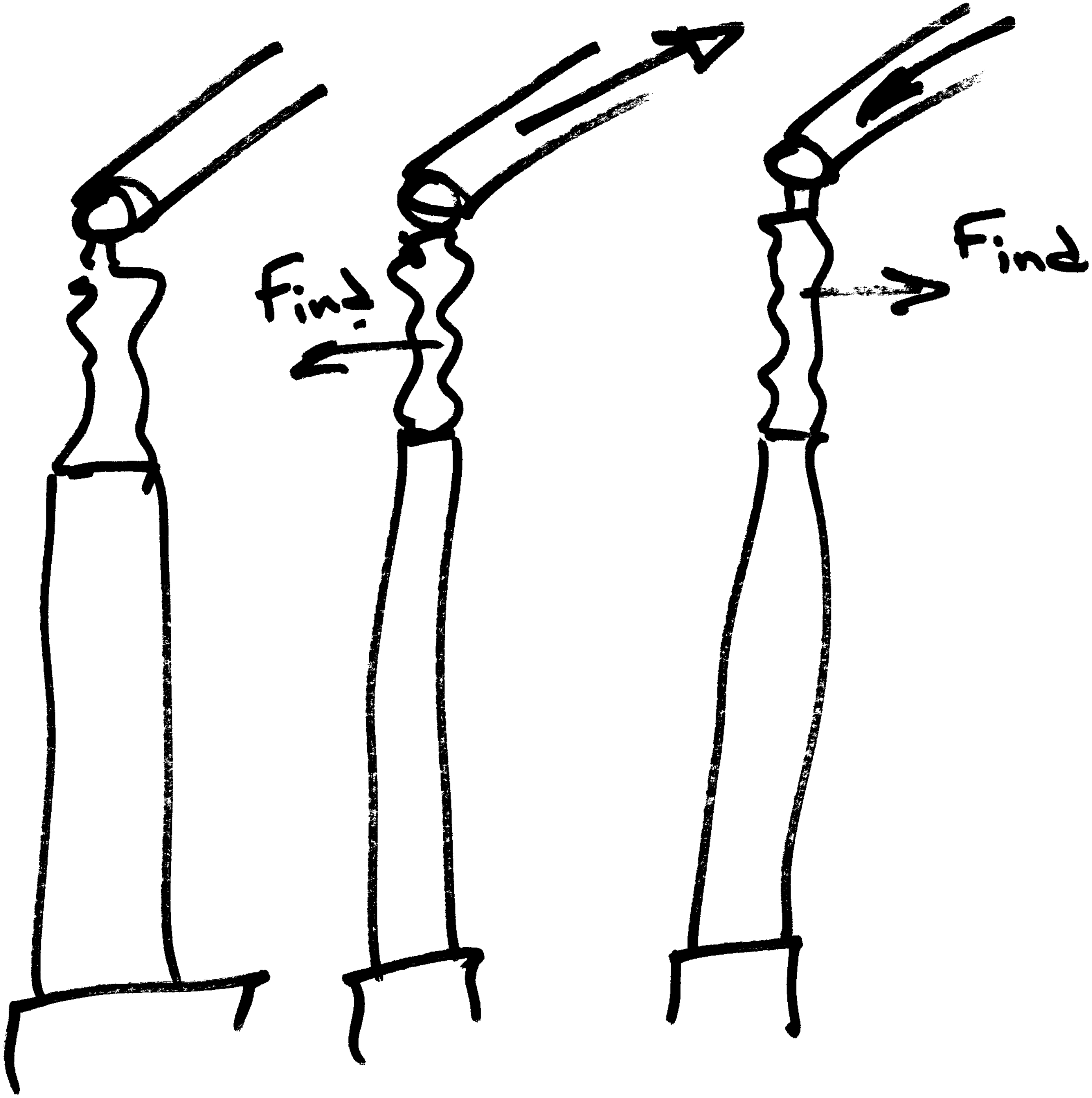
$$V_B - iR - e_{\text{ind}} = 0$$

$$\boxed{V_B = e_{\text{ind}} + iR} \tag{4-1}$$

4. Newton's law for the bar across the tracks:

$$\boxed{F_{\text{net}} = ma} \tag{1-7}$$

The fundamental behavior of this simple dc machine will now be explored by using these four equations as tools.


F_{ind}
F_{ind}

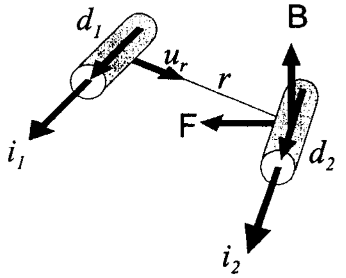
The flow of high levels of current generates forces on the current carrying conductors. The basic physical law is expressed with the *Biot-Savart* equation as below, which is explained with the aid of Figure 19. The figure shows two segments of conductors of lengths d_1 and d_2, respectively and carrying electric current i_1 and i_2, respectively. The force that will act on each one of these two segments is as follows:

$$F(t)=\frac{\mu}{4\pi r^2} i_1(t) i_2(t)\left[d_1 \otimes (u_r \otimes d_2)\right] \tag{13}$$

where

μ	is the magnetic permeability equal to $4\pi \times 10^{-7}$ V-s/(A-m)
r	is the distance between the two conductor segments
u_r	is the unit directional vector in the direction r
d_1	is a vector of length d_1 in the direction of the current flow in conductor segment 1
d_2	is a vector of length d_2 in the direction of the current flow in conductor segment 2

NOTE—The symbol ⊗ is the vectorial cross product.



$$\vec{F} = i(\vec{\ell} \times \vec{B})$$

$$\vec{H} = \frac{i}{2\pi r} ; \vec{B} = \mu_0 \vec{H}$$

Figure 19—Illustration of two conductor segments carrying electric current

In the case of two parallel conductor segments, the cross products simply become the product of the conductor segment lengths and the force is along the line between the two segment centers, either attracting the two conductor segments or repelling them depending on the direction of the current.

This physical law is applicable to rigid bus structures as well as flexible bus structures. In the case of a rigid bus, the geometry of the bus remains practically invariant as the displacements tend to be very small. In the case of a flexible bus, the geometry of the bus varies as the forces from the fault current move the conductors around. As the distances between conductors change, so do the forces from the currents.

11.3.2 Maximum fault condition parameters

In the design process, one must consider the worst possible scenario. In terms of forces from fault currents, the fault initiation instance with respect to the source waveform is very important. Depending on the type of fault considered (phase to phase or three phased), appropriate electrical parameters need to be fixed in numerical calculations as to generate maximum fault conditions for design. The voltage angle at the initiation of fault is random in nature and should thus be fixed to:

a) 0 for phase-to-phase fault for any conductor geometry