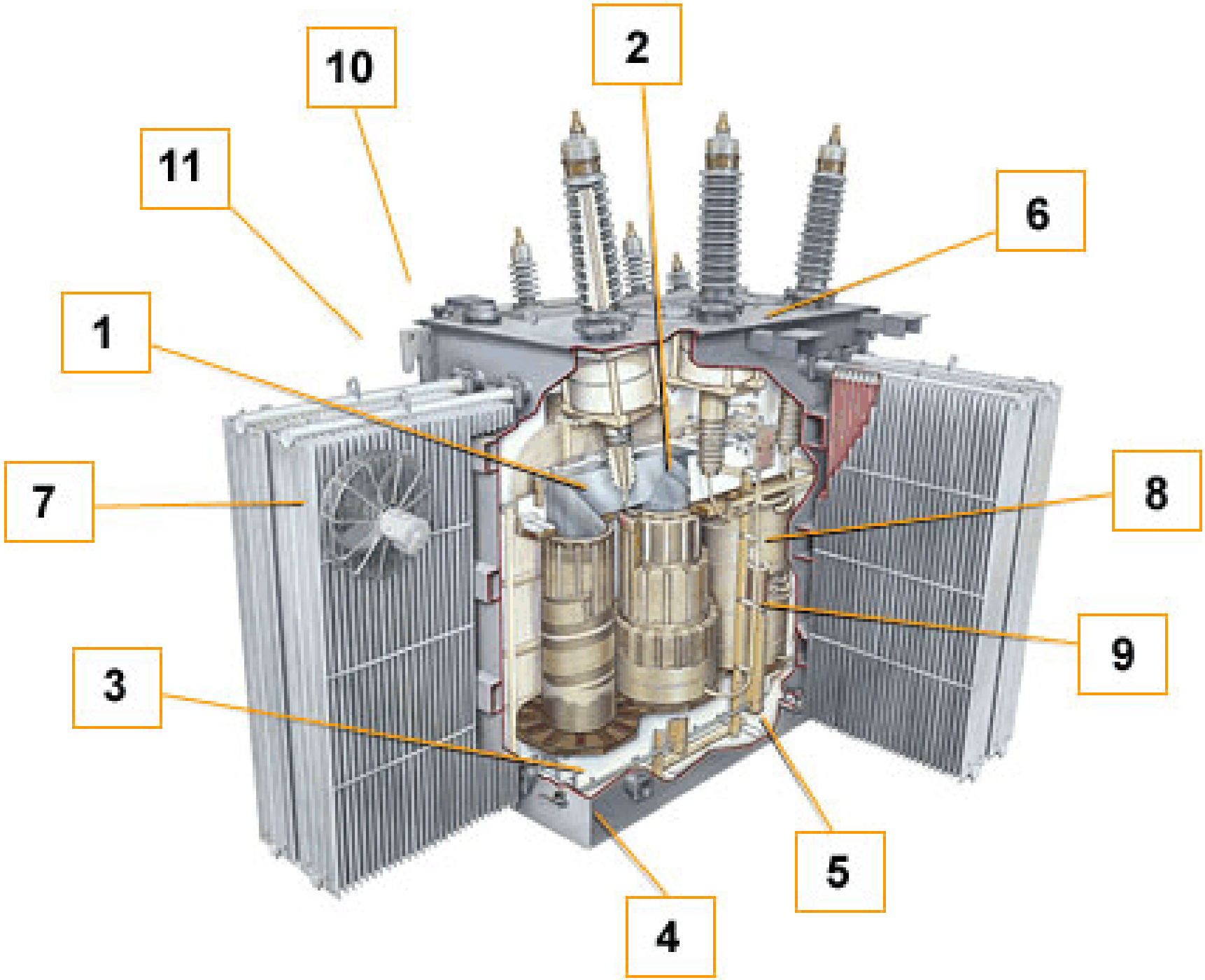
EE 5200 - Lecture 5 Wednesday Sep 11, 2019

Topics for Today:

- Announcements
  - Software: Matlab? Off-campus students have access via Remote Desktop, can optionally buy student edition.
  - Office hrs: 11-12am M,W, 10-11am Fri
  - Office: EERC 614. Phone: 906.487.2857
  - XFMR exercises to be posted on web page
  - Recommended problems from Ch.2, solutions posted

- XFMR, Chapter 2 - Transformers and circuits w/transformers
  - Single phase transformers, basic structure
  - Winding R and Leakage, Core losses and saturation
  - 3-ph transformer banks and phase shifts (ANSI/IEEE vs. IEC)
  - Standard 30°shift transformers, non-standard connections
  - Pos/neg sequence phase shifts, sequence networks
  - Autotransformers
  - Load Tap Changing (LTC) transformers


10
2
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Test your knowledge: How many of the key features on the previous page could you identify? Source: Waukesha Electric, http://www.waukeshaelectric.com/peg-T1.shtml

1. Core (no-load) losses minimized by utilizing laser-scribed, super-grain-oriented steel.
2. Lamination width customized to achieve a near perfect-circle core cross section, resulting in the efficient use of materials plus a lighter, more compact, high performance transformer.
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6. Transformer exterior coated to a minimum thickness of 3 mils; this coating has superior endurance characteristics and meets the ANSI C57.12.28 standard.
7. Galvanized radiators provide excellent corrosion resistance and require minimal maintenance (fan guards and blades also galvanized).
8. Material-stabilized coils are pressure-fit within the core frame.
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Loadflow – Phasor

S.C. – "

Stability – Both Phasor (Grid Calcs)
and time (machine dynamics)

0, Δt, 2Δt, ...

Lightning – time (impulse)

Switching – time (step)

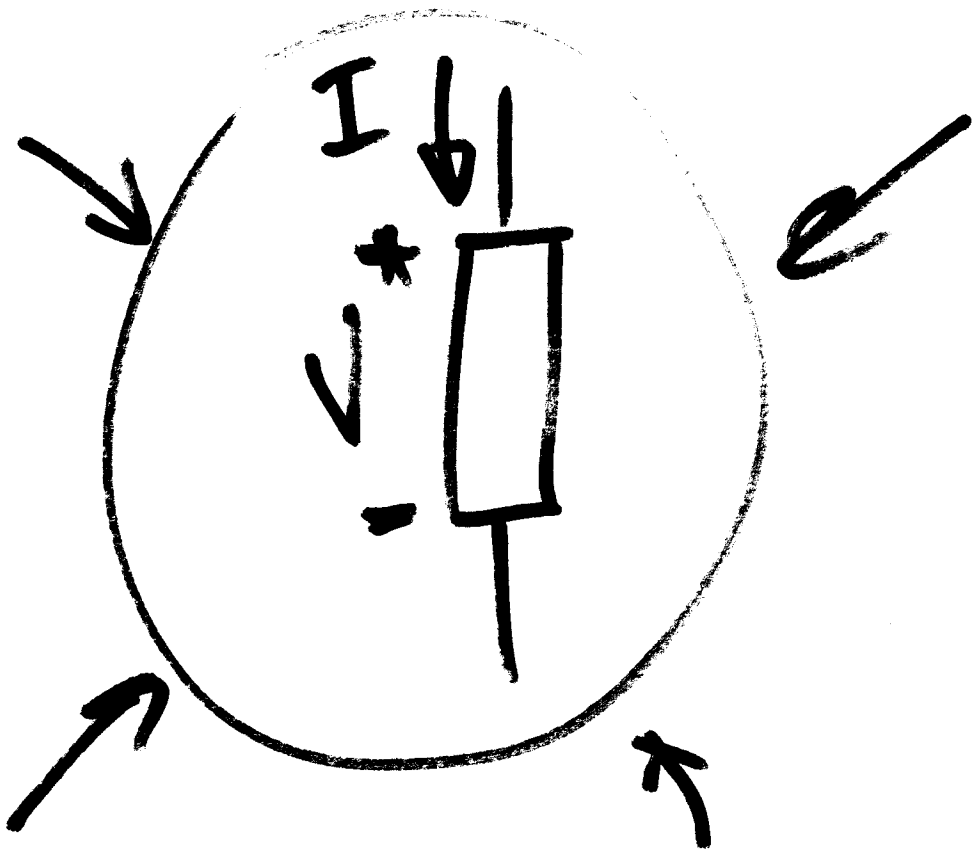
Insulation Design –

CONTENTS

EE 5200 TEXT

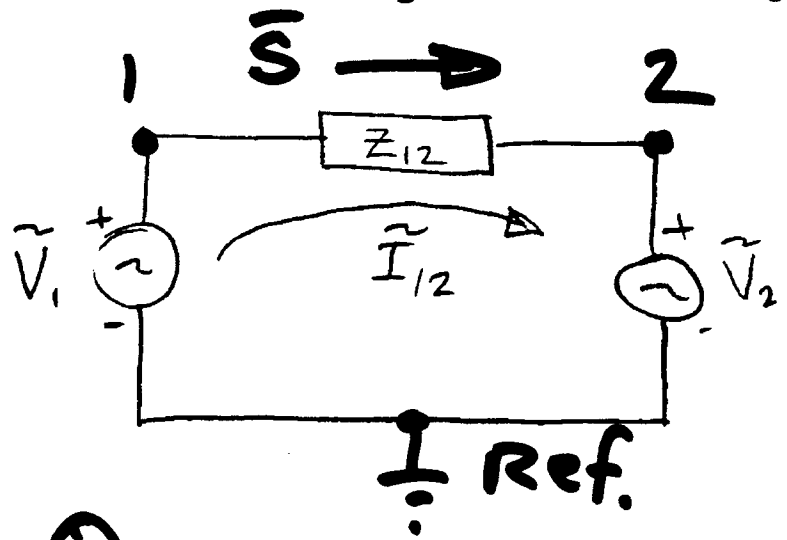
"closed" vs. "open" V phasors.

6 review videos

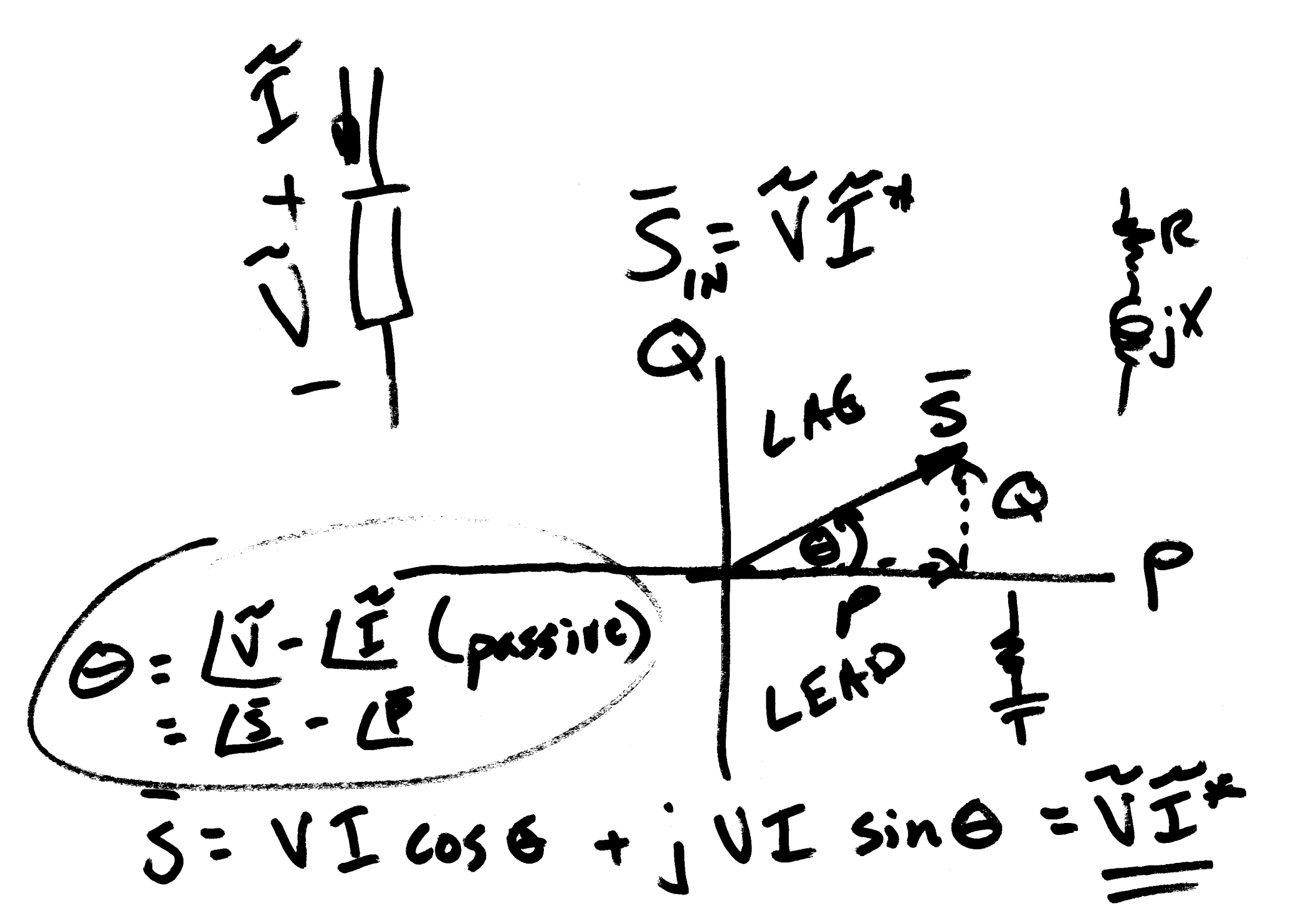

I
+
V
-

1) [15pts] For the following circuit, $v_1(t) = 100\cos(\omega t + 0°)$, $v_2(t) = 120\sin(\omega t - 30°)$ and $\mathbf{Z}_{12} = 0.5 - j0.5\Omega$.

a) Convert $v_1(t)$ and $v_2(t)$ to their phasor equivalents $\mathbf{V}_1$ and $\mathbf{V}_2$.
b) Calculate $\mathbf{I}_{12}$.
c) Calculate the complex power S consumed by "source 2".
d) In terms of generator or load, what are sources 1 & 2? Was the correct guess made in labeling current direction?
e) What is the power factor of "source 1"?

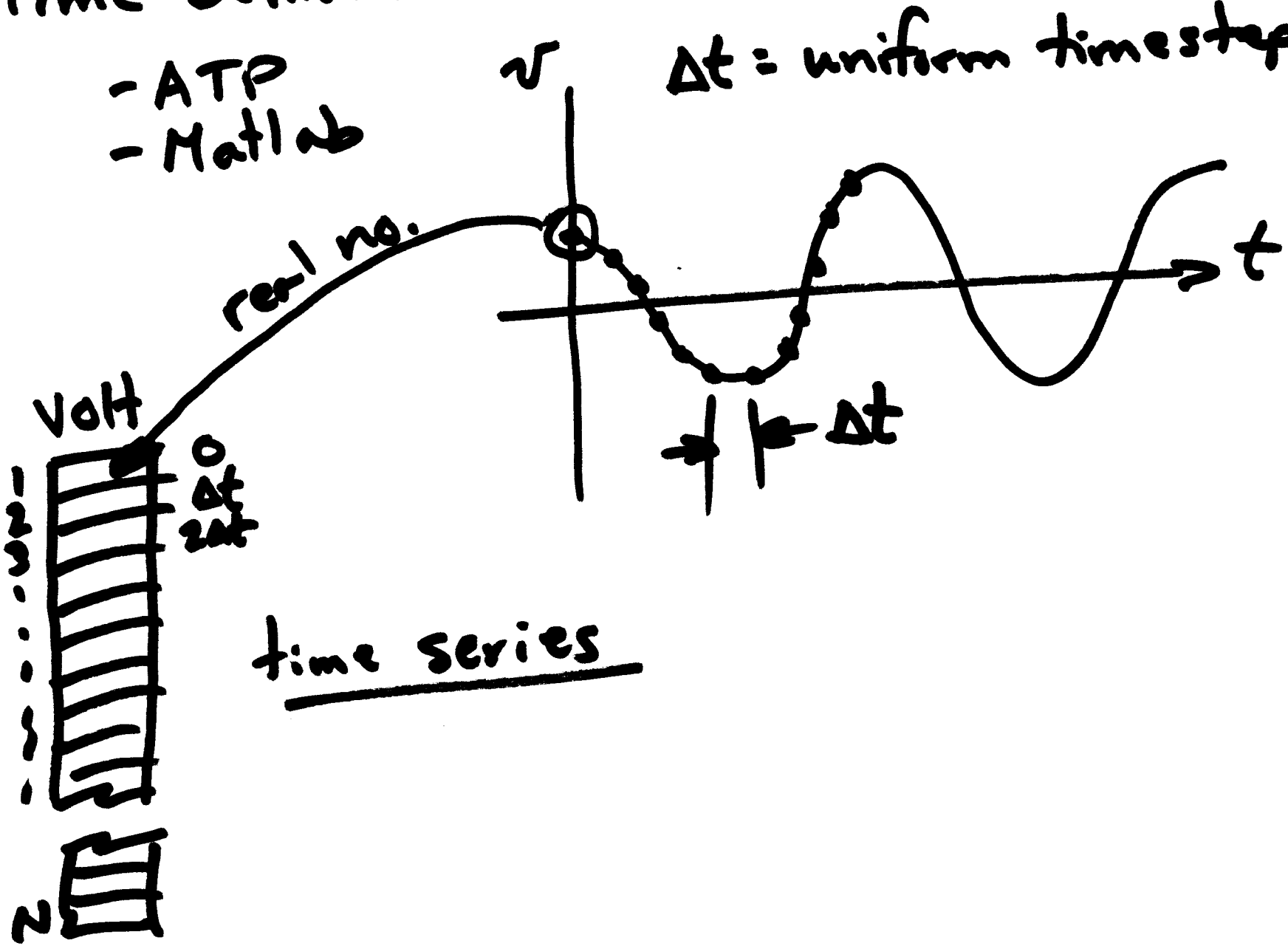


- Phasor Analysis
- $\tilde{V}$, $\tilde{I}$, Subscripts
- Polarity
- Flow direction of P, Q

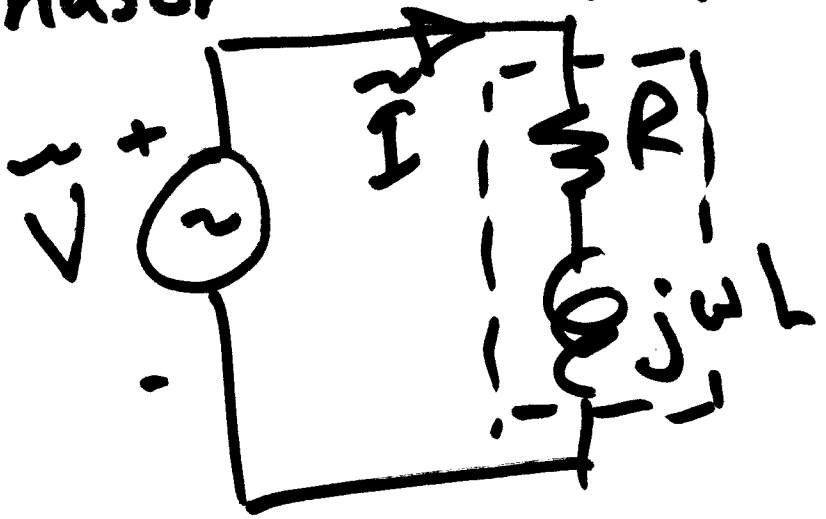

$\tilde{I}$
+
$\tilde{V}$
−
$\bar{S}_{IN} = \tilde{V}\tilde{I}^*$
R
jX
Q
LAG
$\bar{S}$
Q
θ
P
LEAD
$\theta = \angle\tilde{V} - \angle\tilde{I}$ (passive)
$= \angle\bar{S} - \angle P$
$\bar{S} = VI\cos\theta + jVI\sin\theta = \tilde{V}\tilde{I}^*$

Time Domain - Simulation

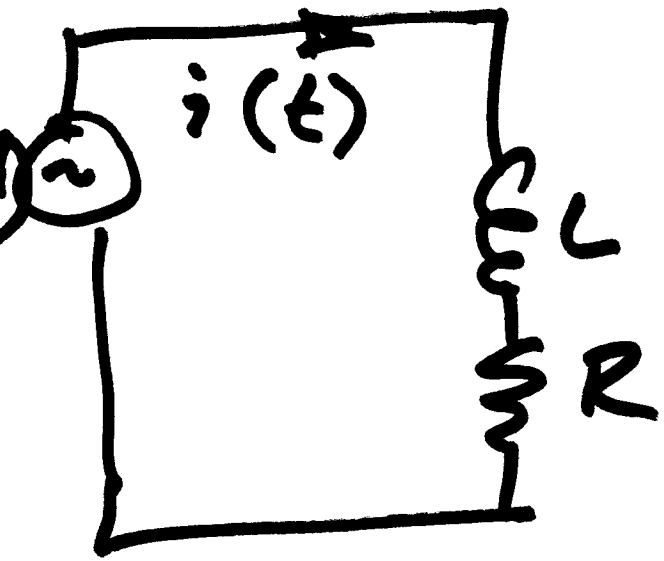
- ATP
- Matlab

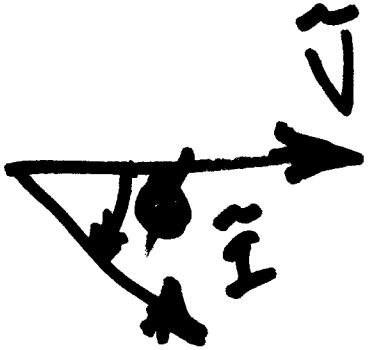


Phasor Domain

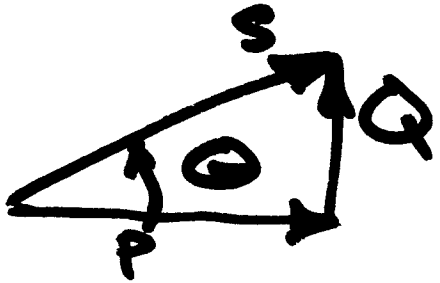


Time Domain

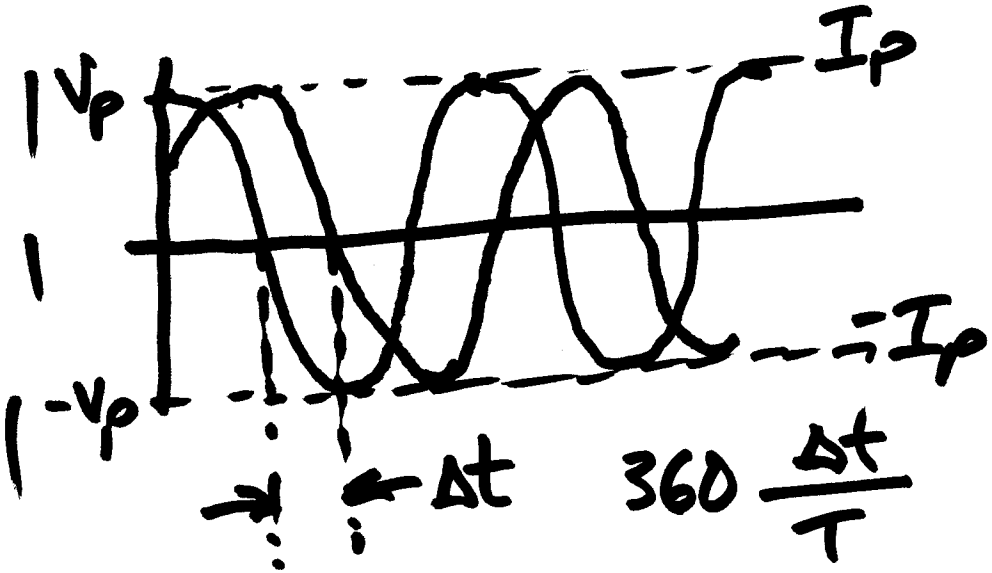




$$\angle\tilde{I} - \angle\tilde{V} = \phi = -\theta$$

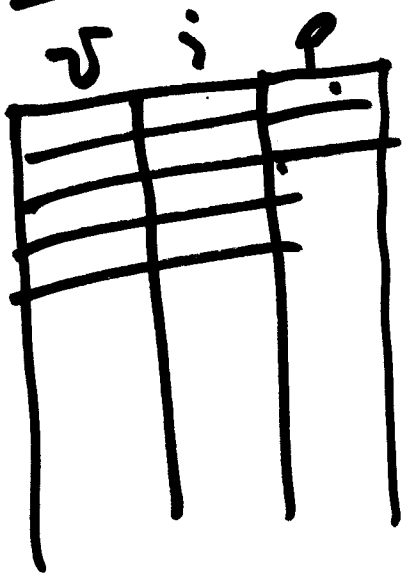


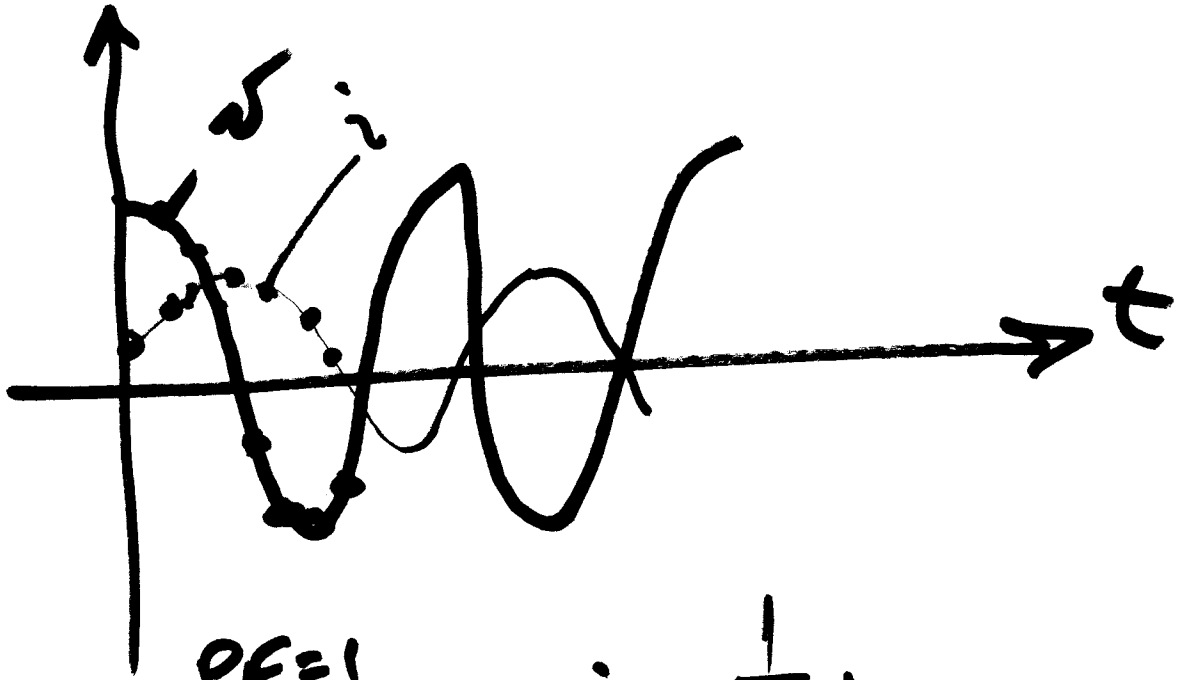
$$v(t) = V_p \cos(\omega t)$$



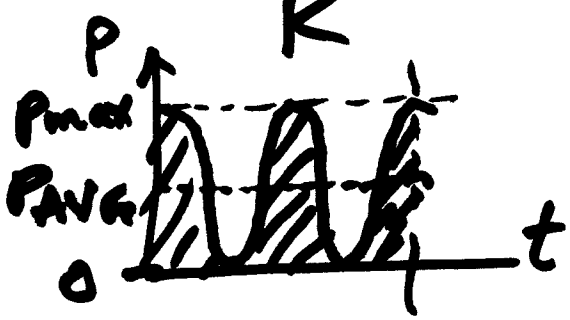
Power

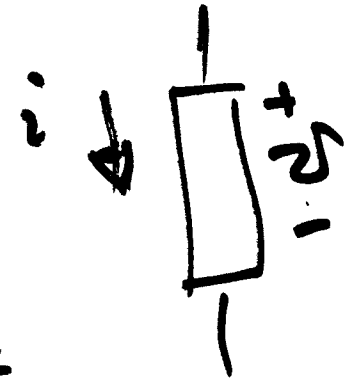
Matlab





PF = 1

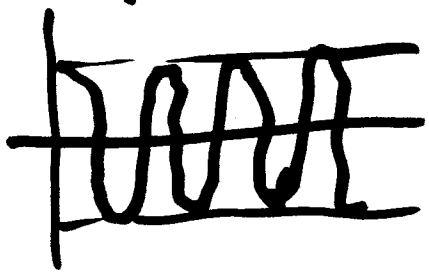




$$P_{AVG} = \frac{1}{T}\int_0^T p(t)\,dt$$

$$p(t) = v(t)\,i(t)$$

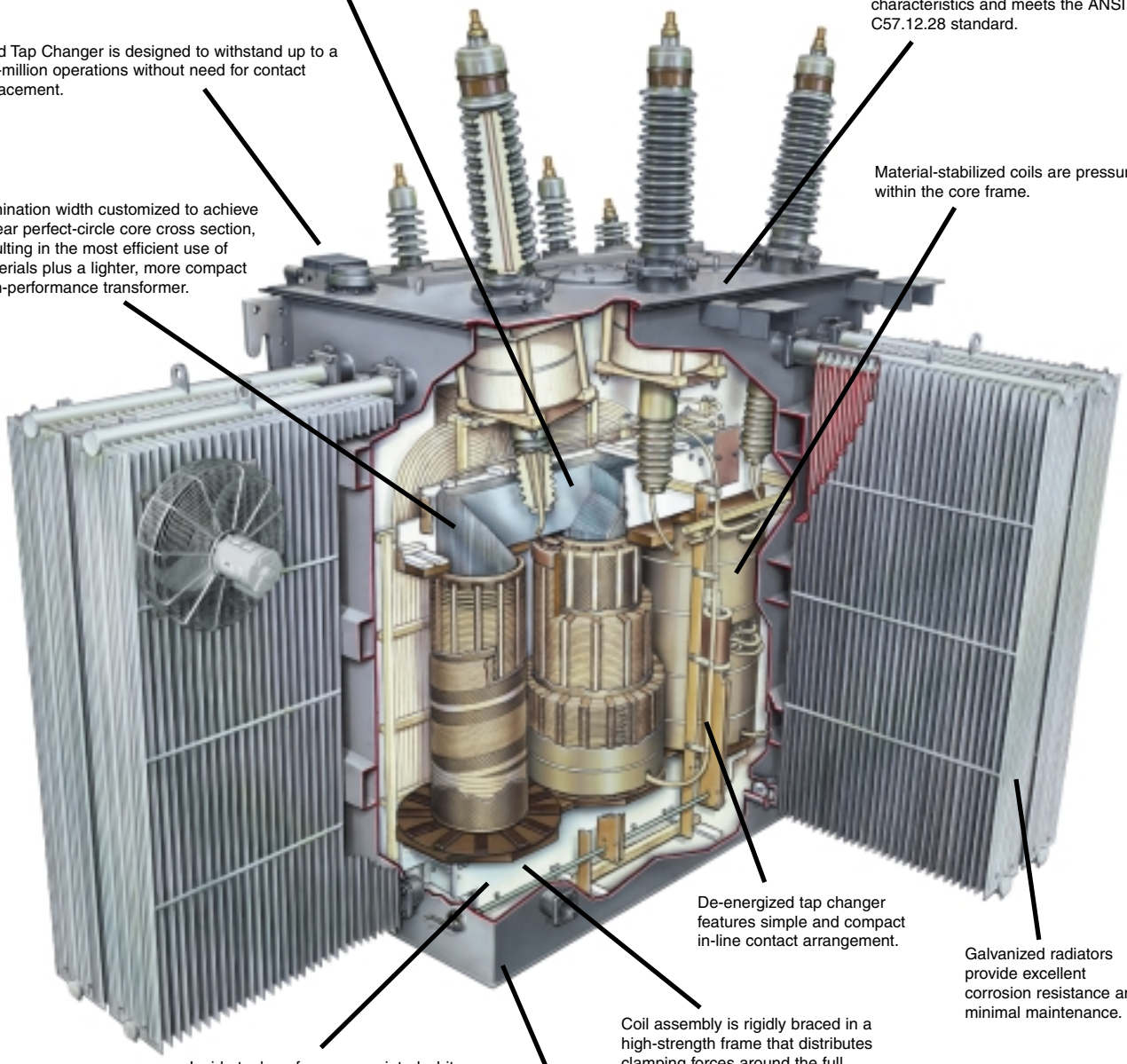
PF = 0



$P_{AVG} = 0$

Waukesha Quality Inside

Means Reliability Is On Your Side



Waukesha Electric Systems offers component parts for transformer upgrades and repair, as well as extensive field service support that includes transformer moving, hauling and rigging, vacuum filling and oil processing, inspection, testing and customer training.

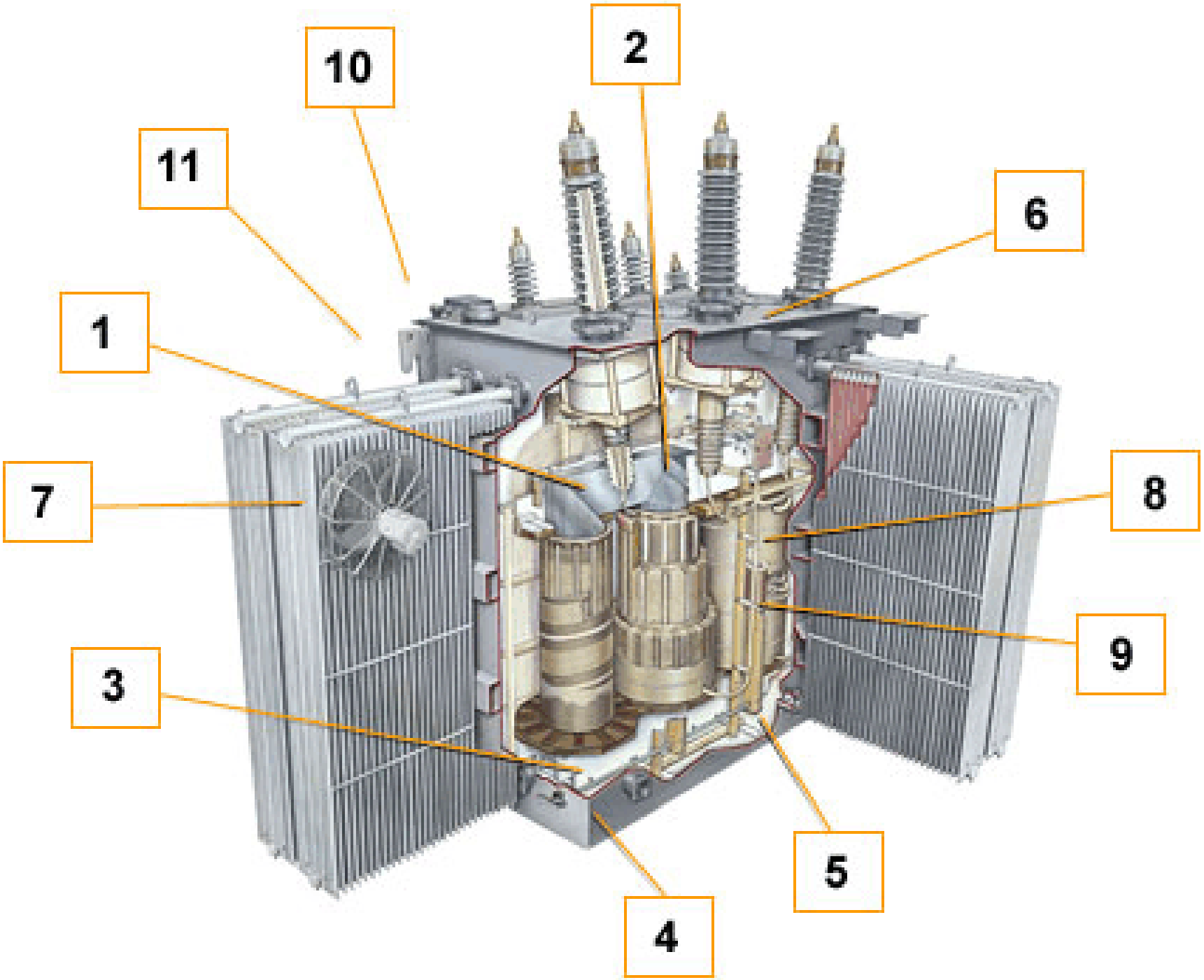
WAUKESHA ELECTRIC SYSTEMS

World Headquarters:
400 S. Prairie Avenue
Waukesha, WI 53186-5940
800.835.2732

U.S. Manufacturing:
Waukesha, WI 800.835.2732
Goldsboro, NC 800.758.4384

Service, Parts, Training:
High Voltage Supply
Dallas, TX 800.338.5526

energy ***solutions*** *...to power your future*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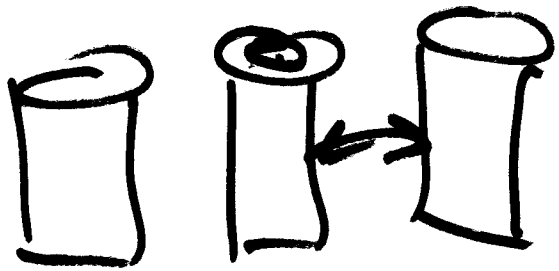
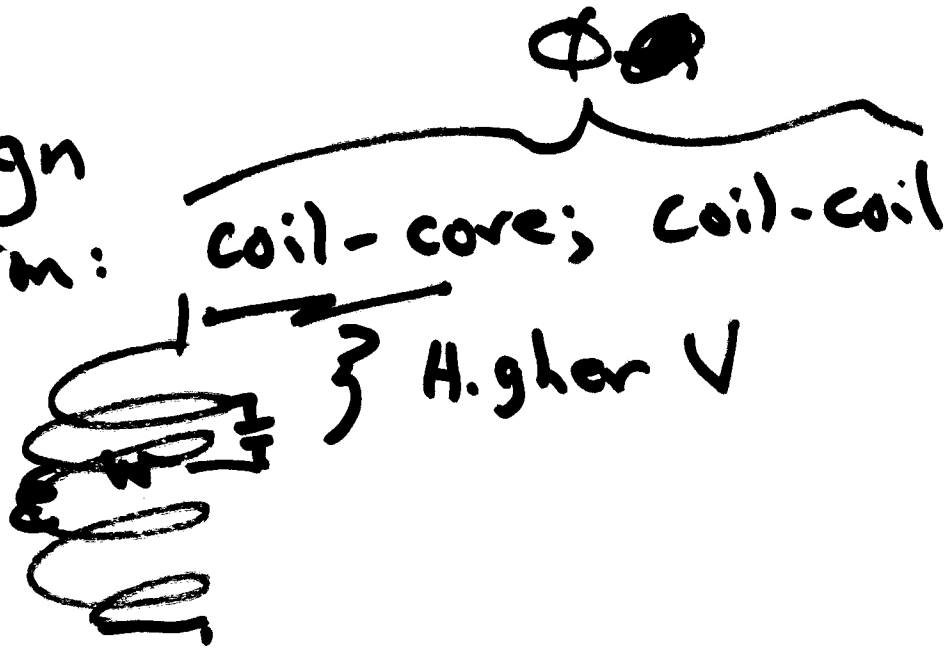
Cooling
- Oil
- Heat exch
- pumps, fans

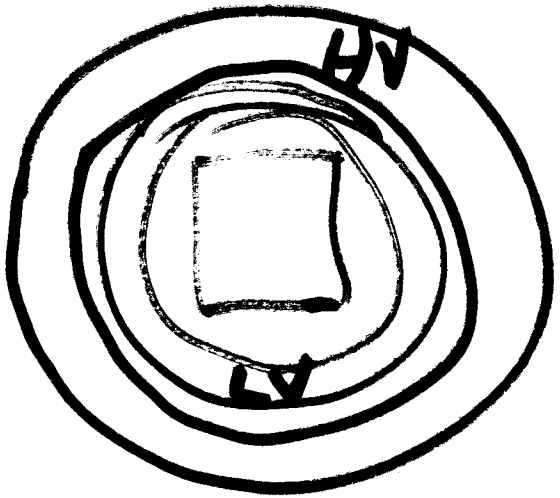
[±10% LTC's - LV
[±5% NLTC's - HV
(off-nominal turns ratio)

Monitoring
- Temp: oil, coils
- Oil gases
- N_2

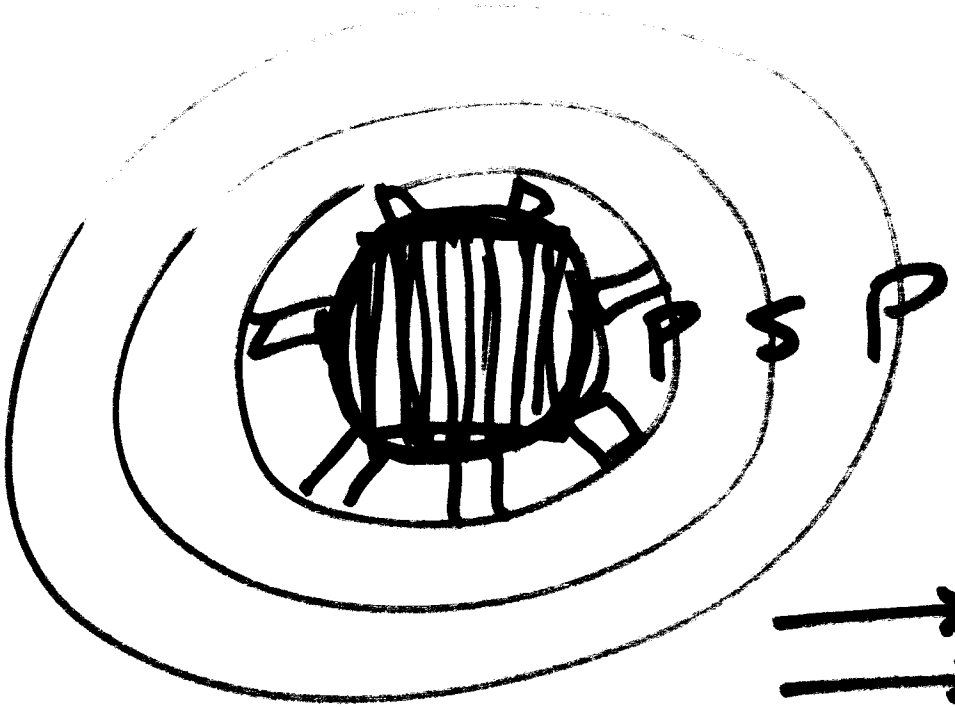


Coil Design
- insulation: coil-core; coil-coil, phase-phase

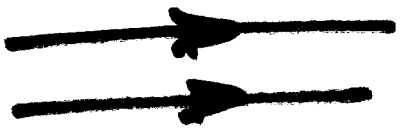




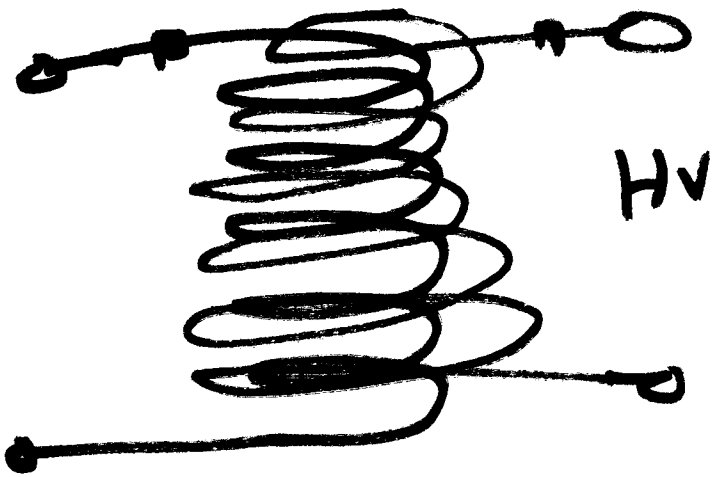
S-P



P-S-P



Cylindrical



How many possibilities are there for Δ-Y or Y-Δ phase shifts?

$\pm 30°$
$\pm 90°$
$\pm 150°$

6 each

$\Rightarrow$ 12 total.

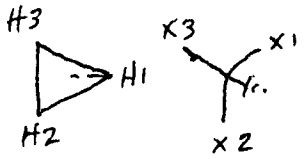
Auto-Δ
Zig-Zig
Extended Δ.

- Three-Phase Transformers

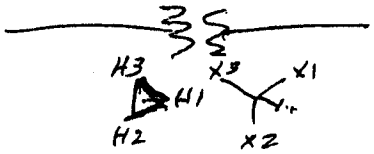
Mork

All of these can and are used to indicate the same winding connections:

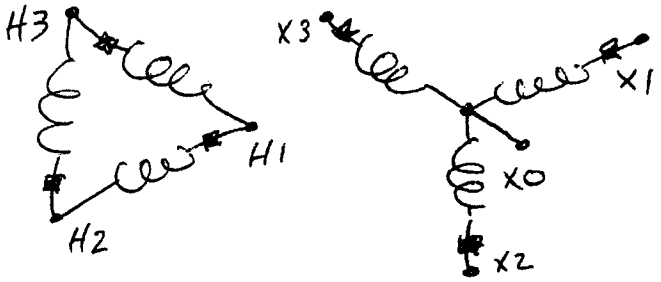
IEEE Stds:



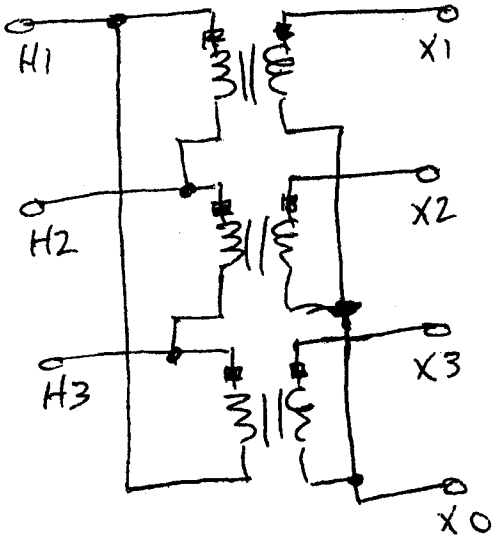
One-Line:



schematic



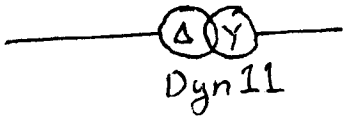
circuit 3-line diagram



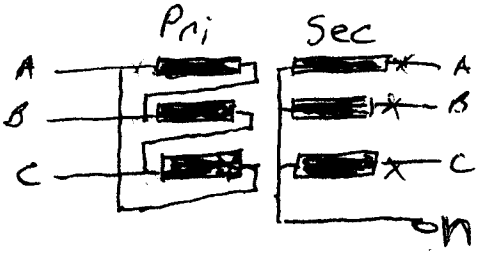
In Europe and much of the world:

IEC Stds: Dyn11

One-Line:



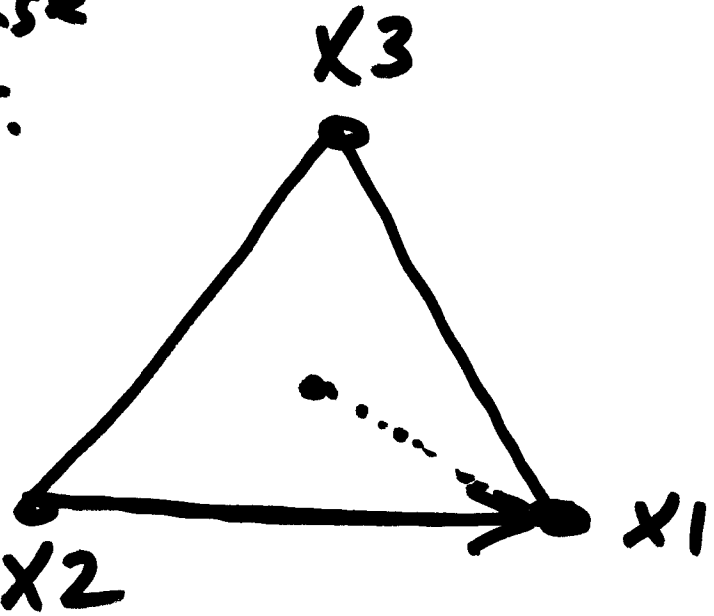
"Hold-down" diagram

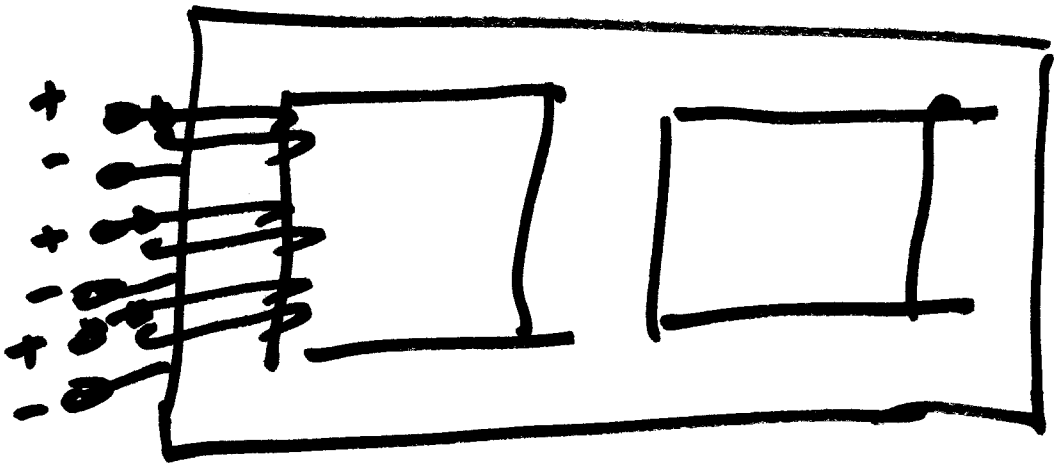


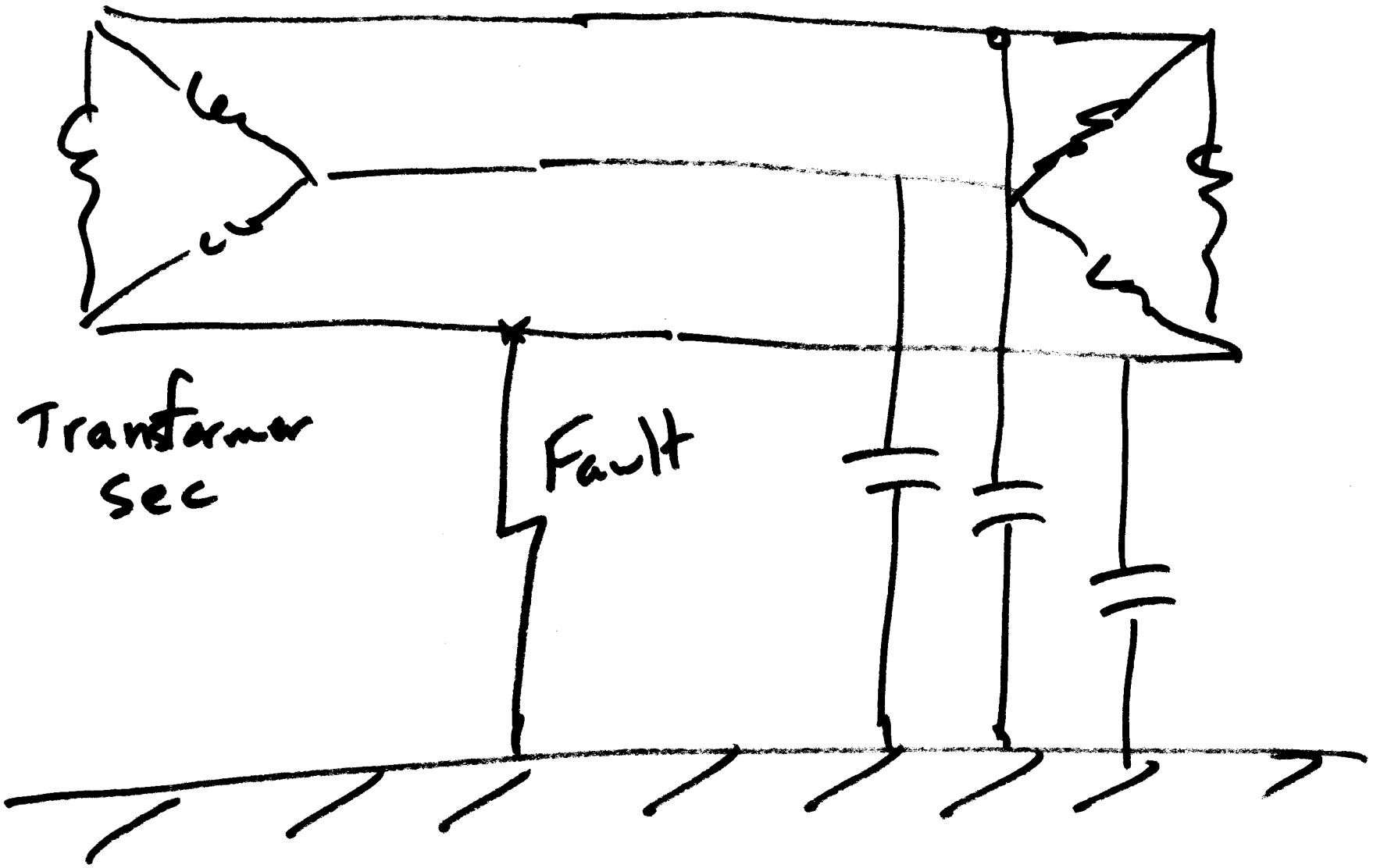
Zig - Zag

0° phase shift.

Delta

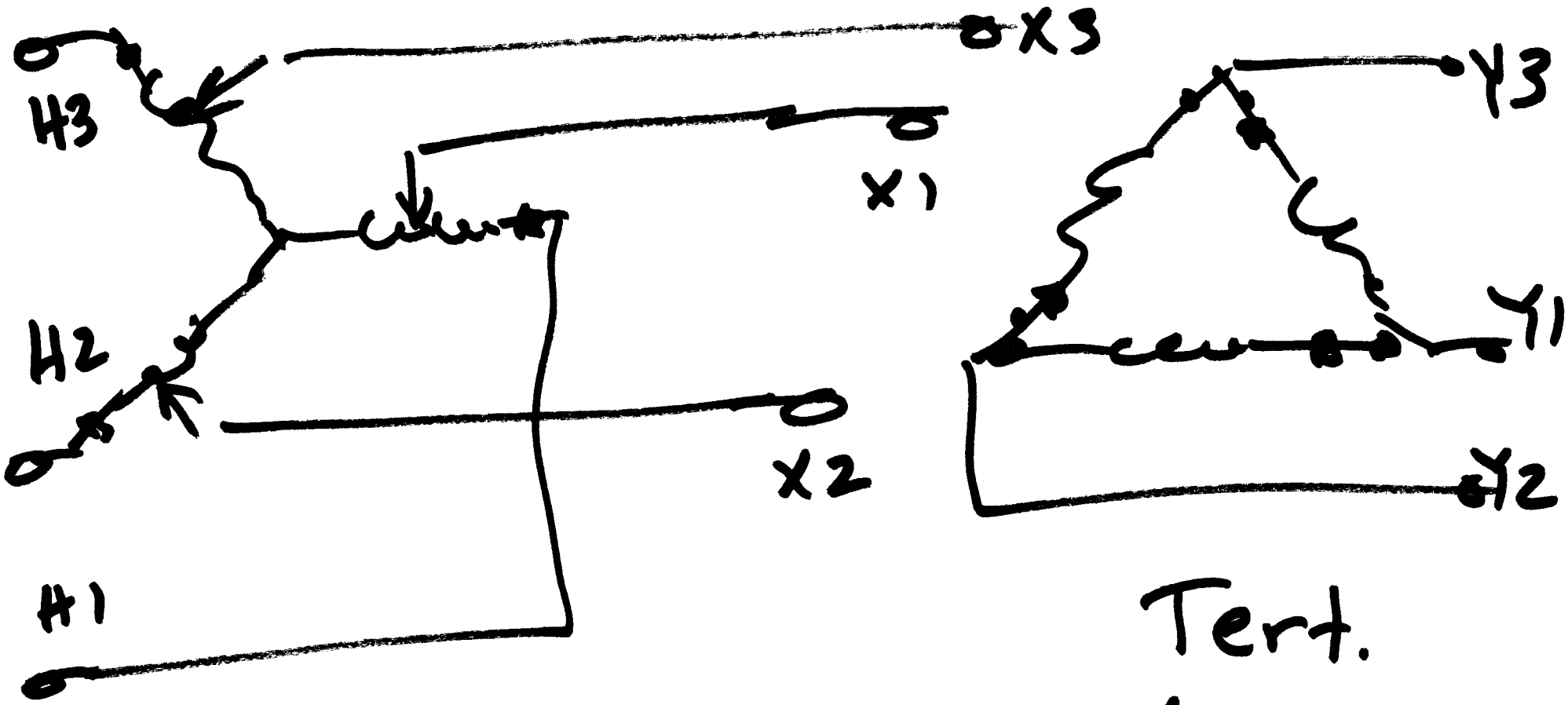




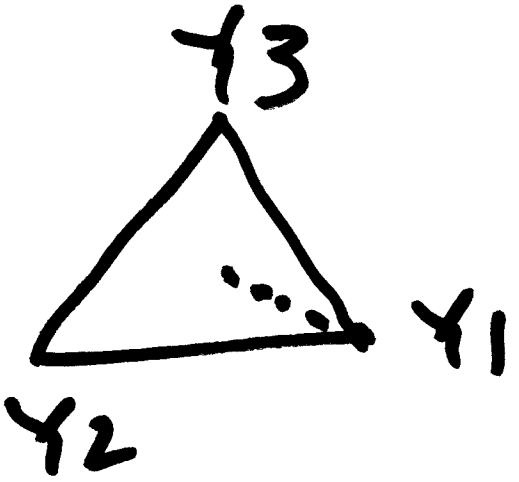


Balanced 3-ph voltages:

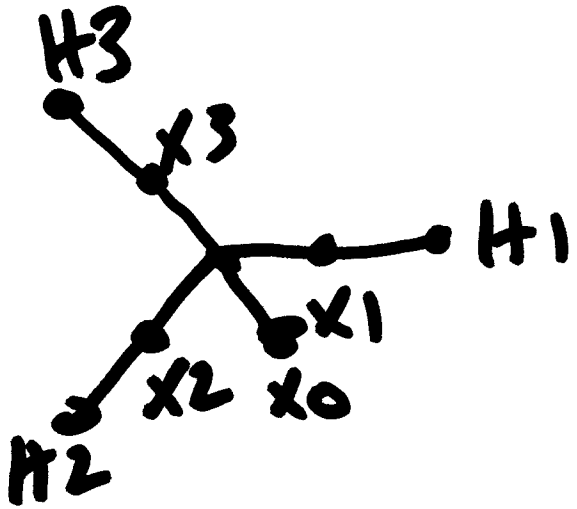
$$|\tilde{V}_{AG}| = |\tilde{V}_{BG}| = |\tilde{V}_{CG}|$$

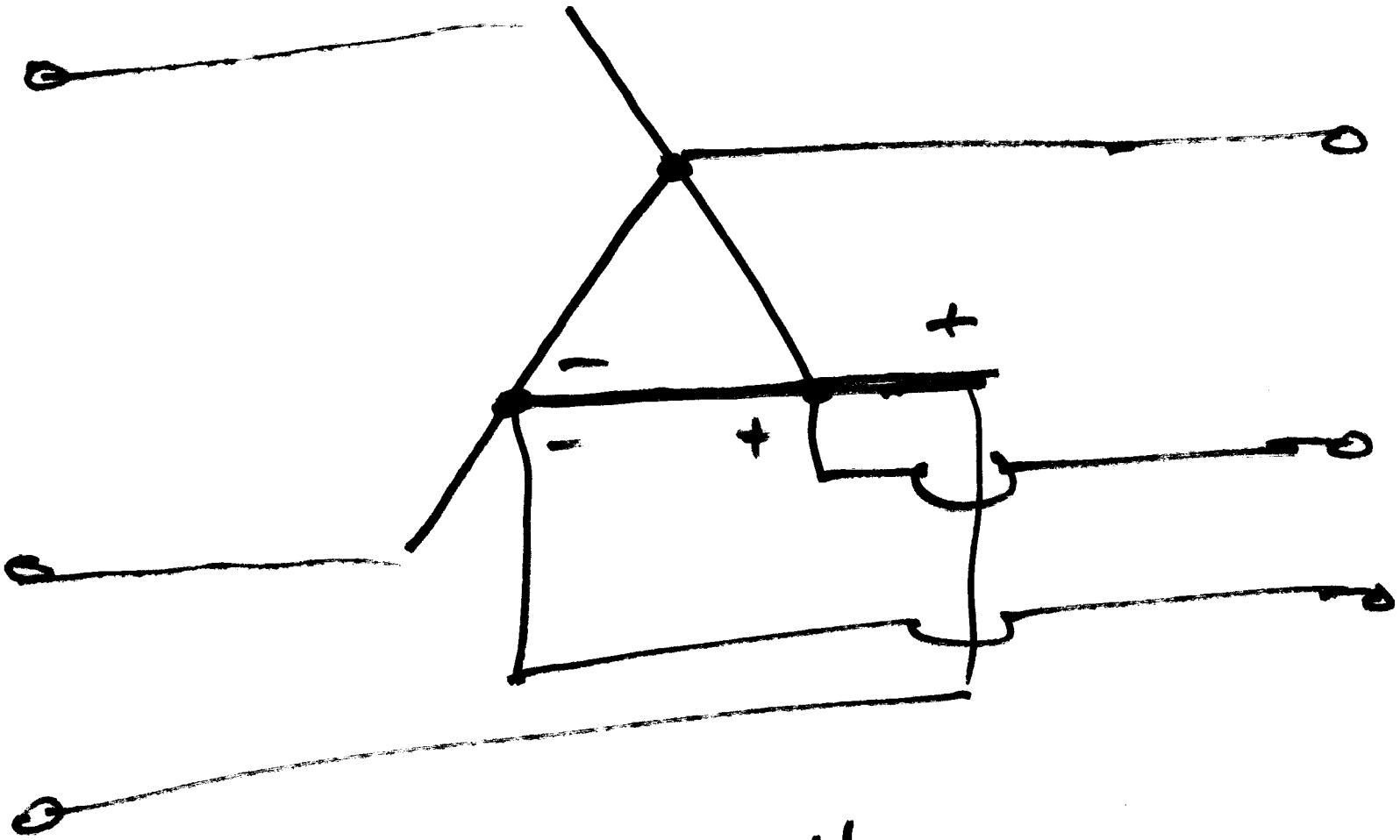


Tert.



Auto

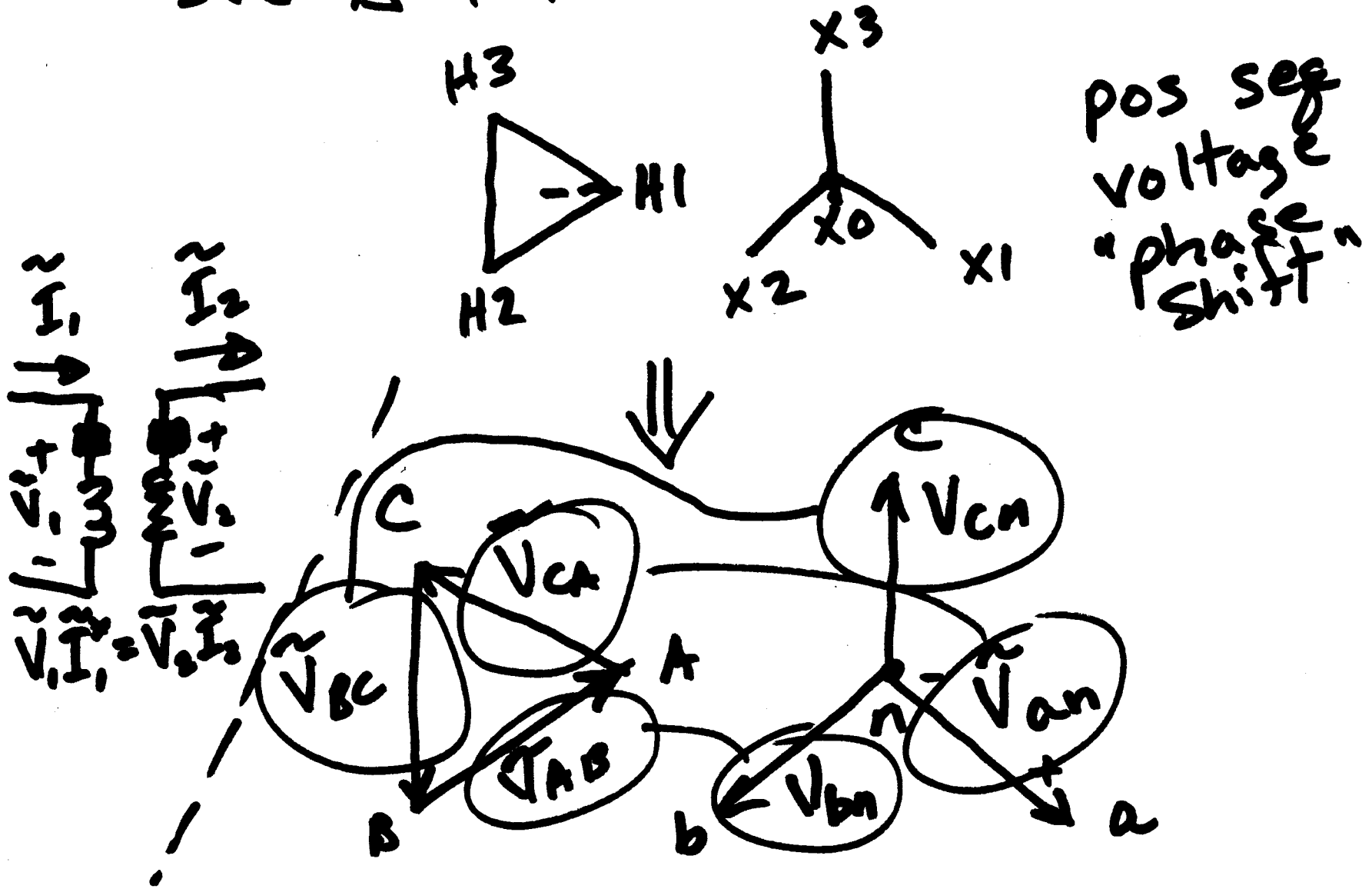


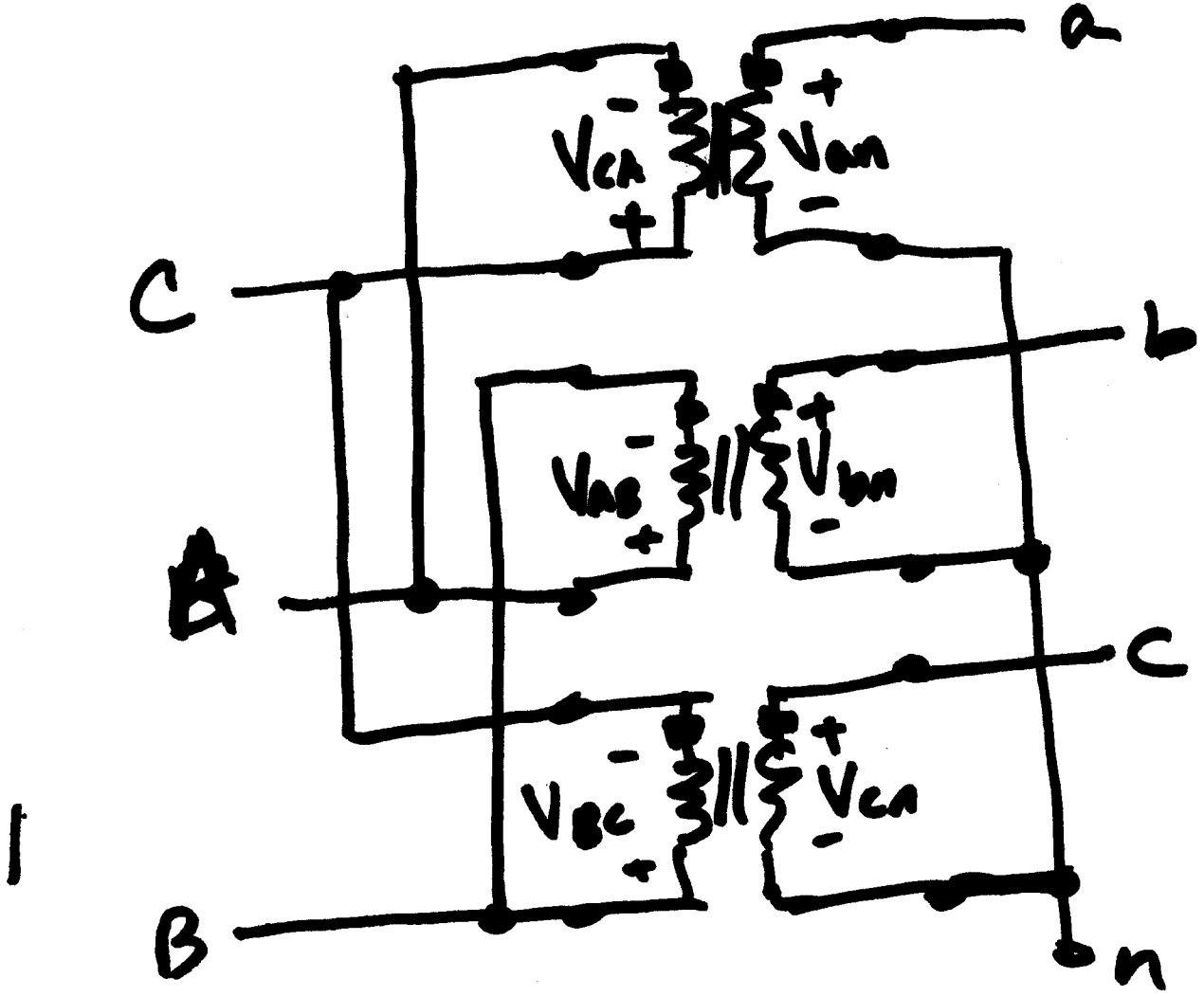


Extend Delta

Transformer Phase Shifts

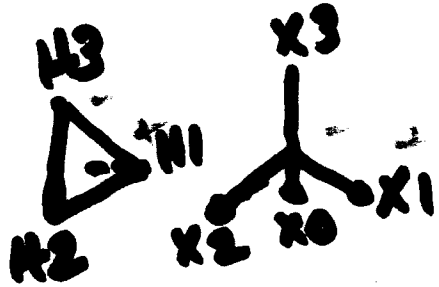
- See Δ-Y transformer nameplate



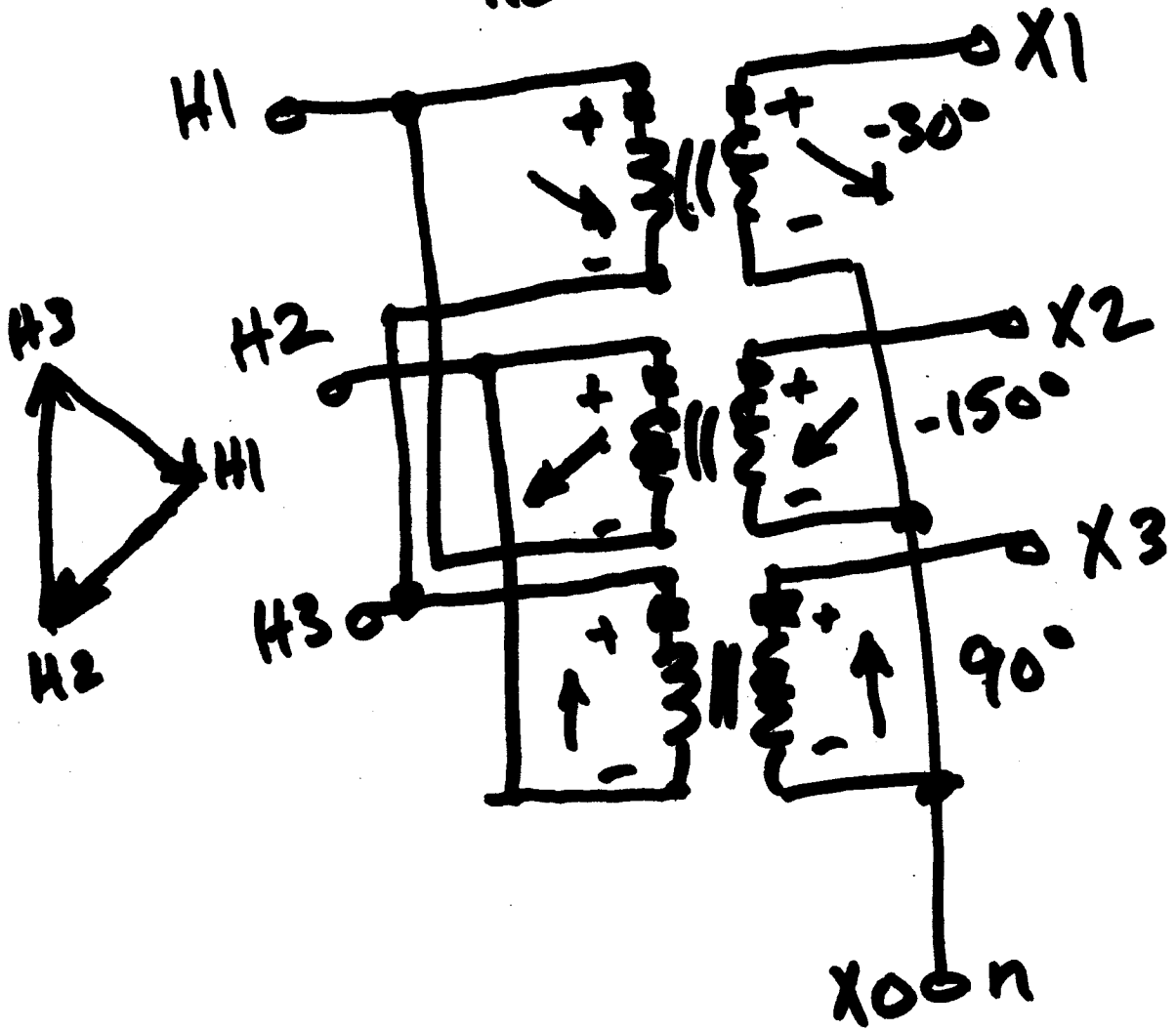

a
V_{ca}
V_{an}
C
b
V_{ab}
V_{bn}
A
C
V_{bc}
V_{cn}
B
n

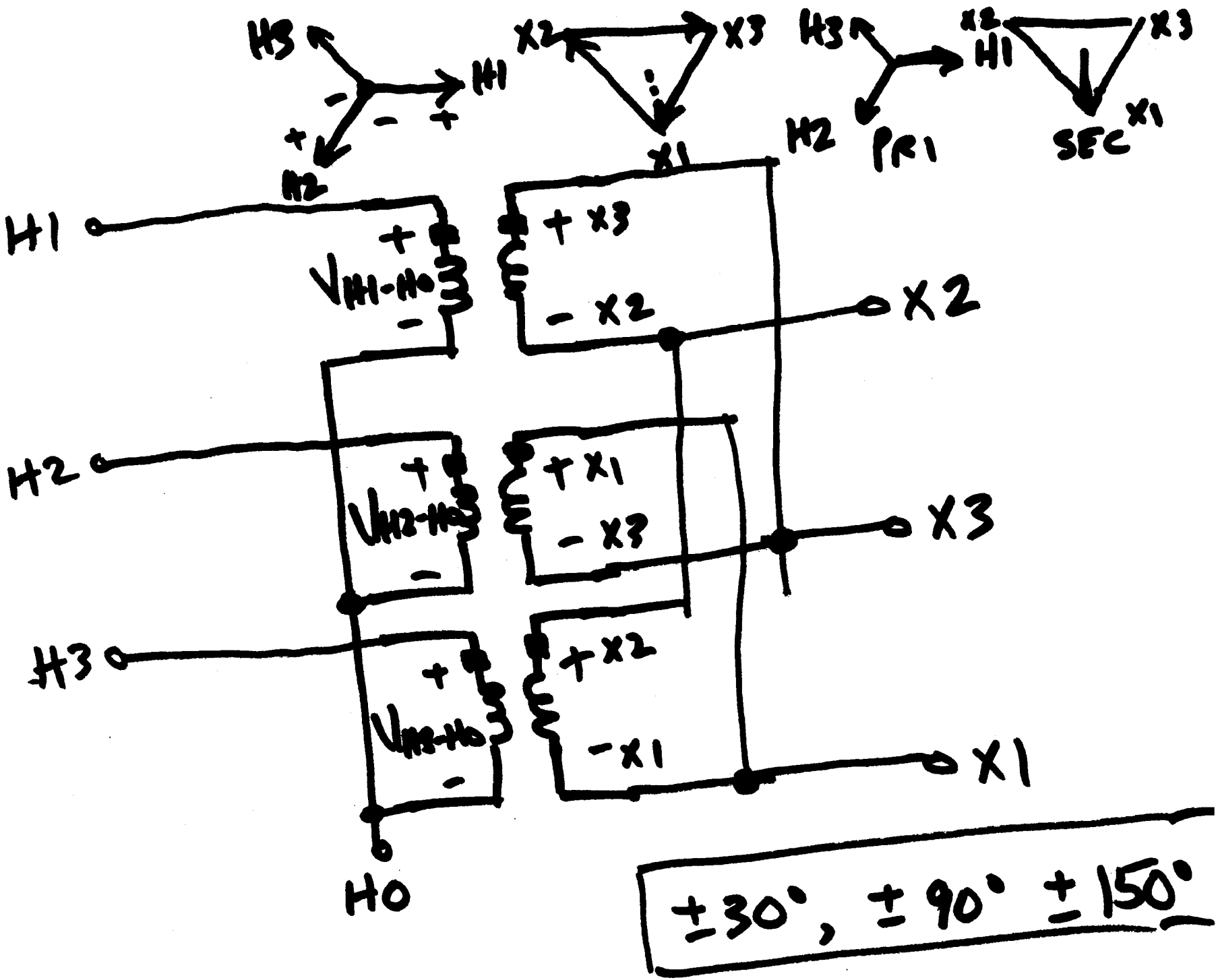
3-PHASE XFMR BANKS

Ex: Δ-Y (Dyn1)

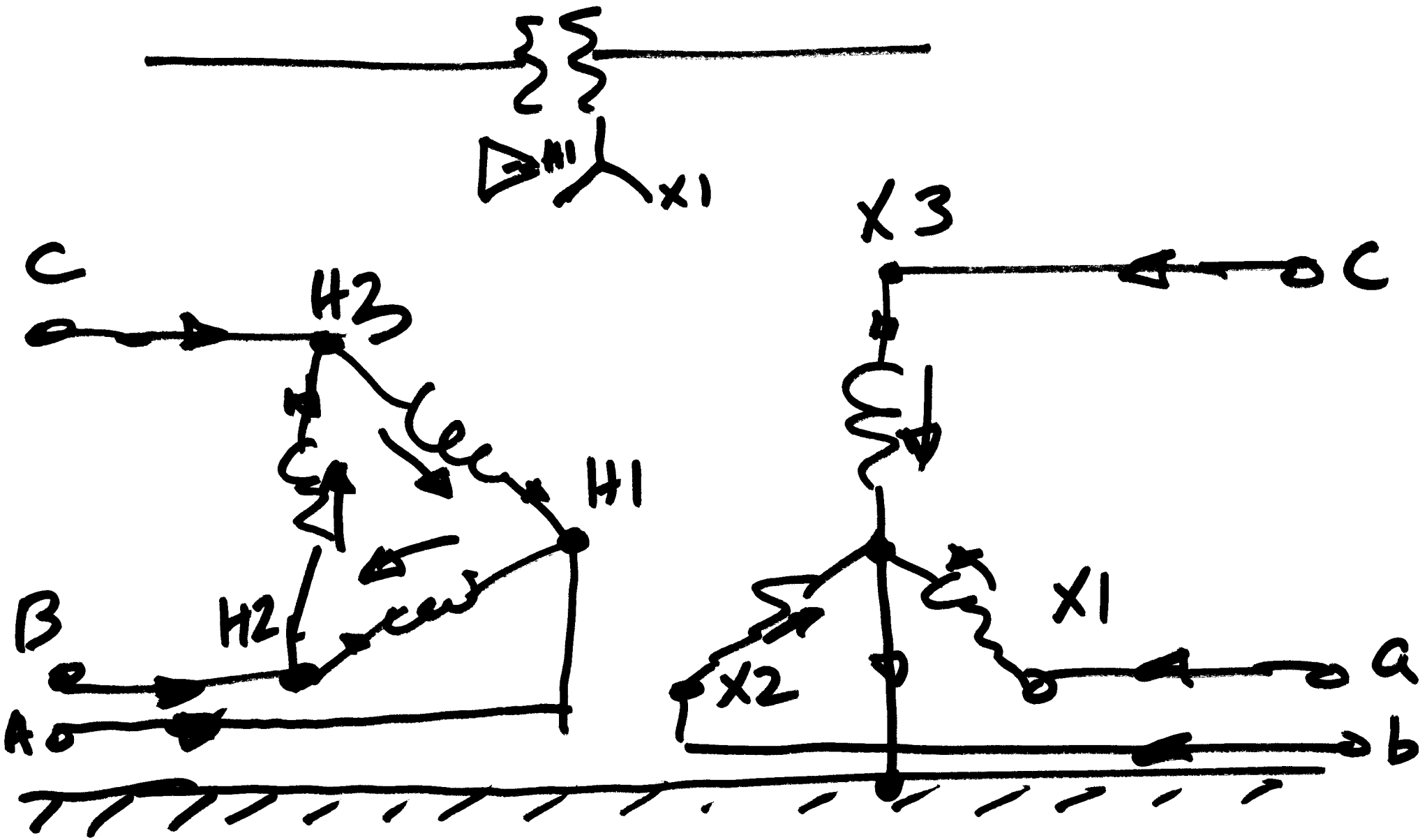


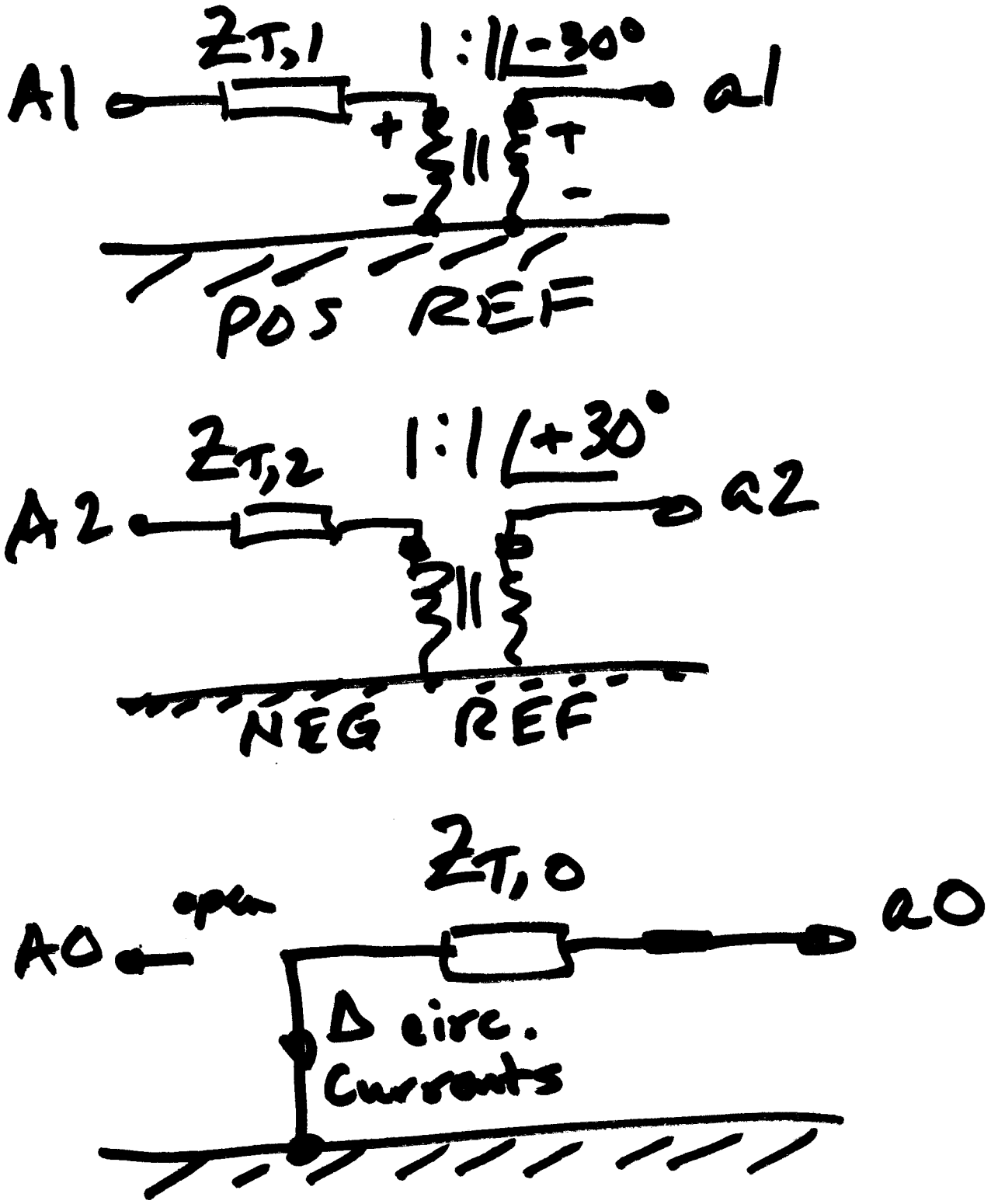
From: Review Lecture 5

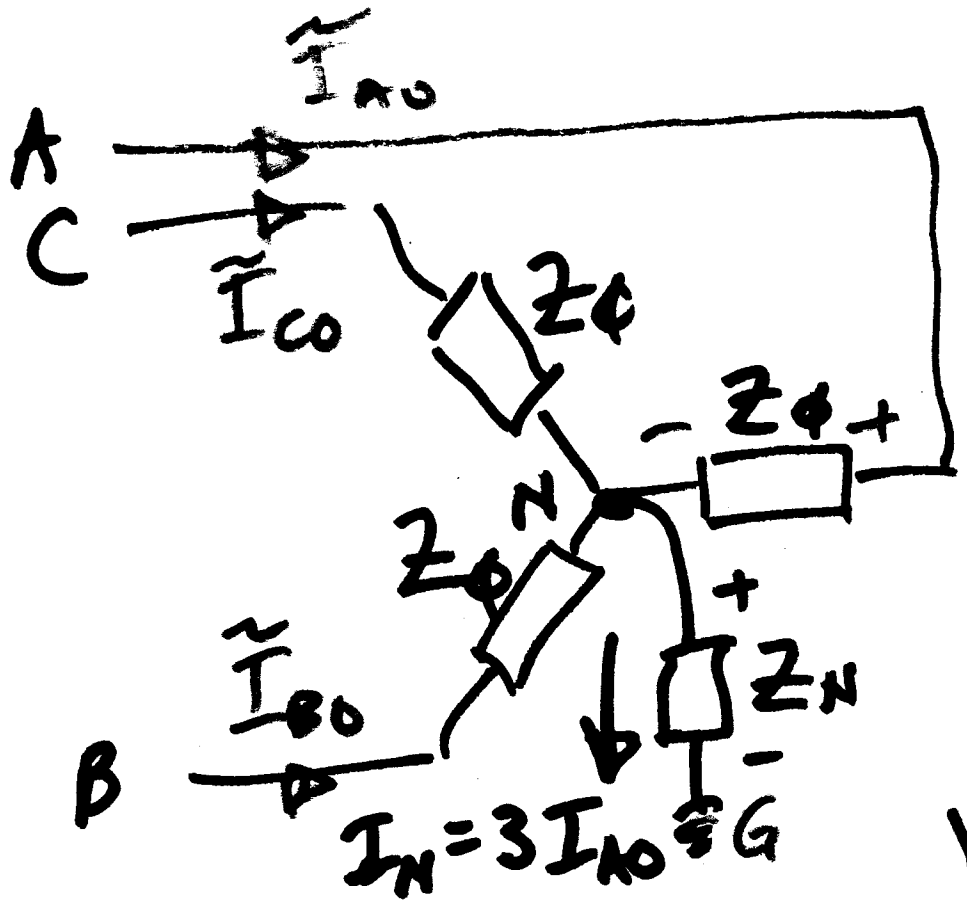



H3
H1
H2
X2
X3
X1
H3
H2
PRI
X2
H1
X3
SEC
X1
H1
H2
H3
H0
+
-
V_{H1-H0}
V_{H2-H0}
V_{H3-H0}
+ X3
- X2
+ X1
- X3
+ X2
- X1
X2
X3
X1
±30°, ± 90° ± 150°

SEQUENCE NETWORKS FOR TRANSFORMERS

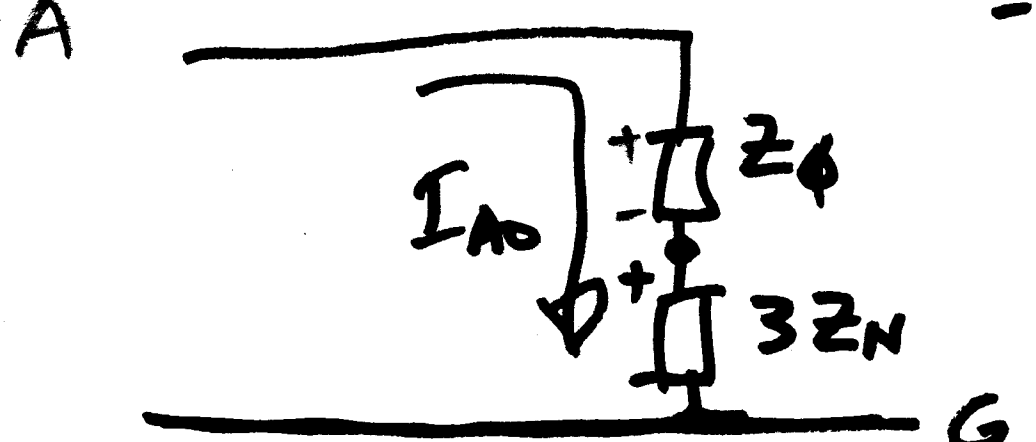



$Z_{T,1}$
$1:1\angle -30°$
A1
a1
+
-
+
-
POS REF
$Z_{T,2}$
$1:1\angle +30°$
A2
a2
NEG REF
$Z_{T,0}$
A0
open
a0
Δ circ.
Currents



$$V_{DROP} = 3I_{AO}Z_N$$

$$= V_{NG}$$



triplen harmonics

buried tertiary
buried delta

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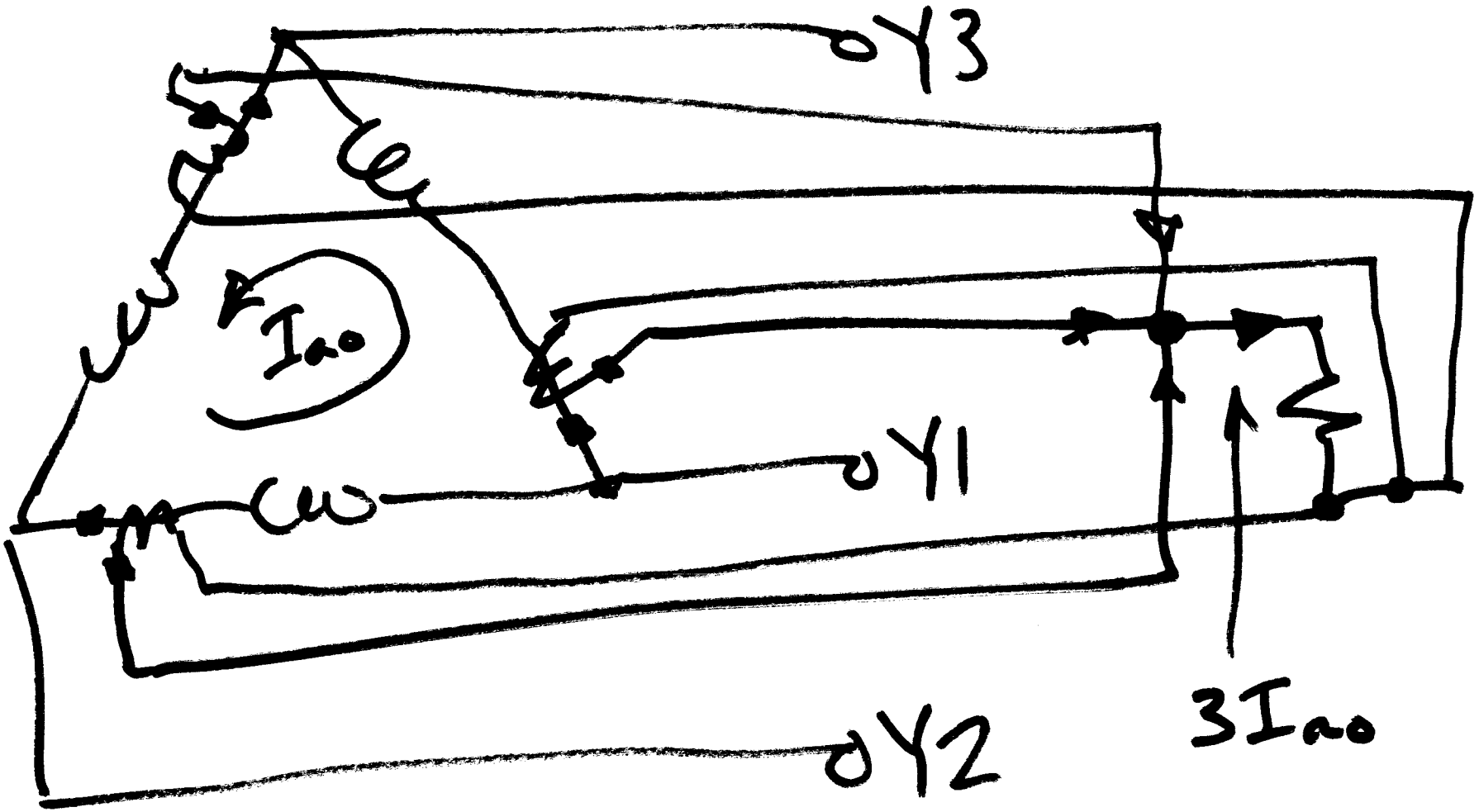
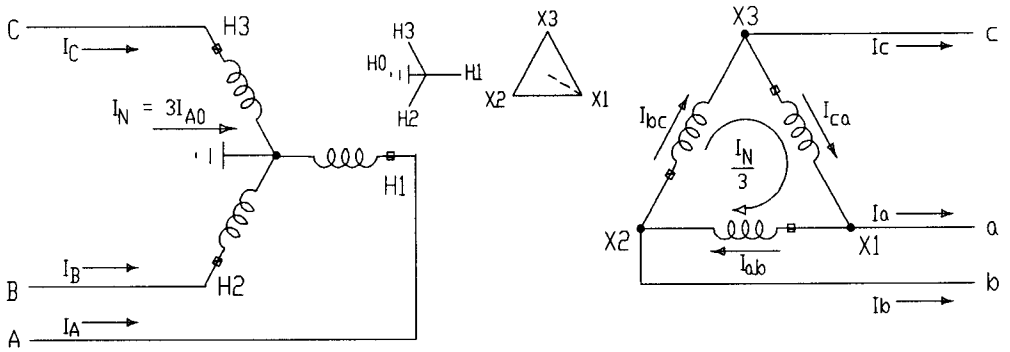
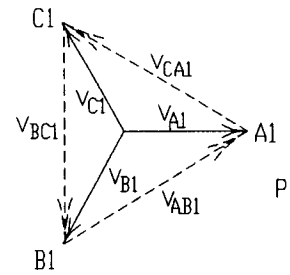
delta: - trap triplen harmonics
- zero seq circ path
- Aux power (station service)
- Protection
  - CTs


Y3
I_{a0}
Y1
Y2
$3I_{a0}$

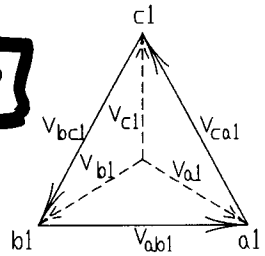
MORK



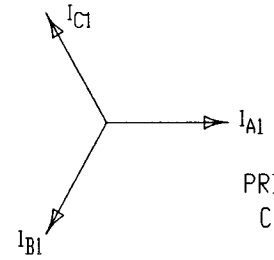


PRI POS SEQ VOLTAGES

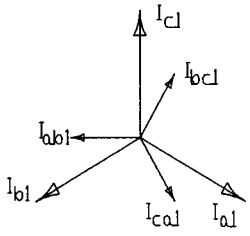
$V_{A1} = V_{a1} (1 \angle 30^\circ)$



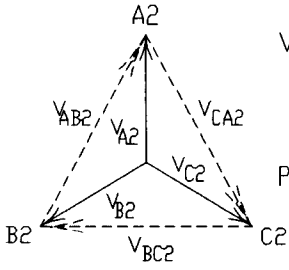
SEC POS SEQ VOLTAGES



PRI POS SEQ CURRENTS

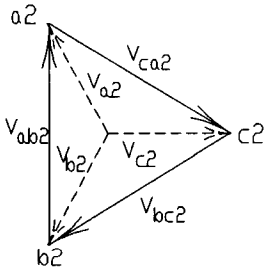


SEC POS SEQ CURRENTS

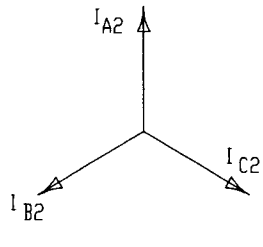


PRI NEG SEQ VOLTAGES

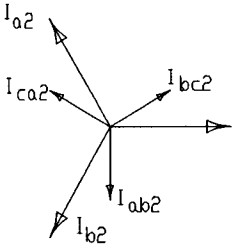
$V_{A2} = V_{a2} (1 \angle -30^\circ)$



SEC NEG SEQ VOLTAGES



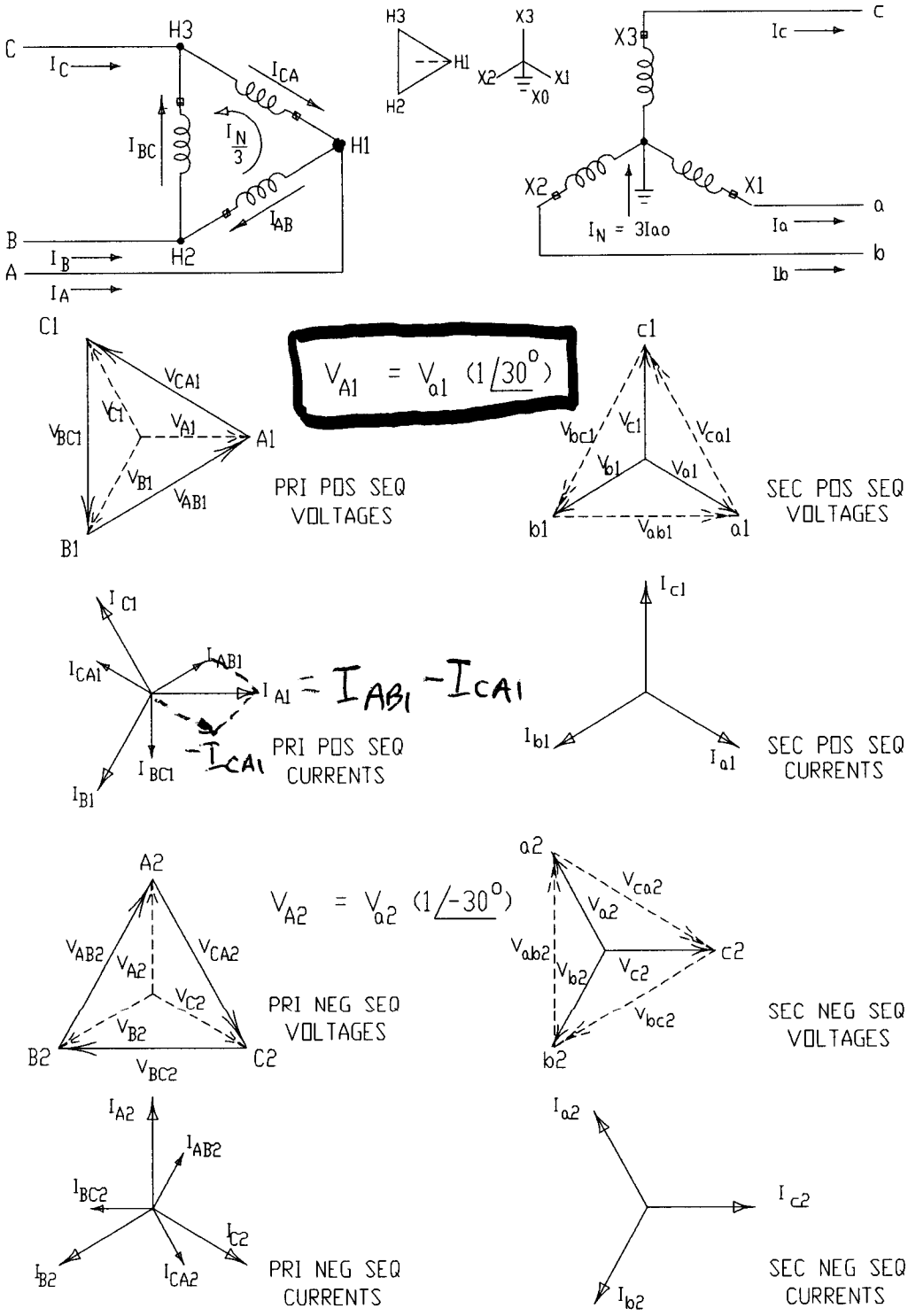
PRI NEG SEQ CURRENTS



SEC NEG SEQ CURRENTS

ANSI STANDARD 30-DEGREE SHIFT WYE-DELTA

MARK



ANSI STANDARD 30-DEGREE SHIFT DELTA-WYE