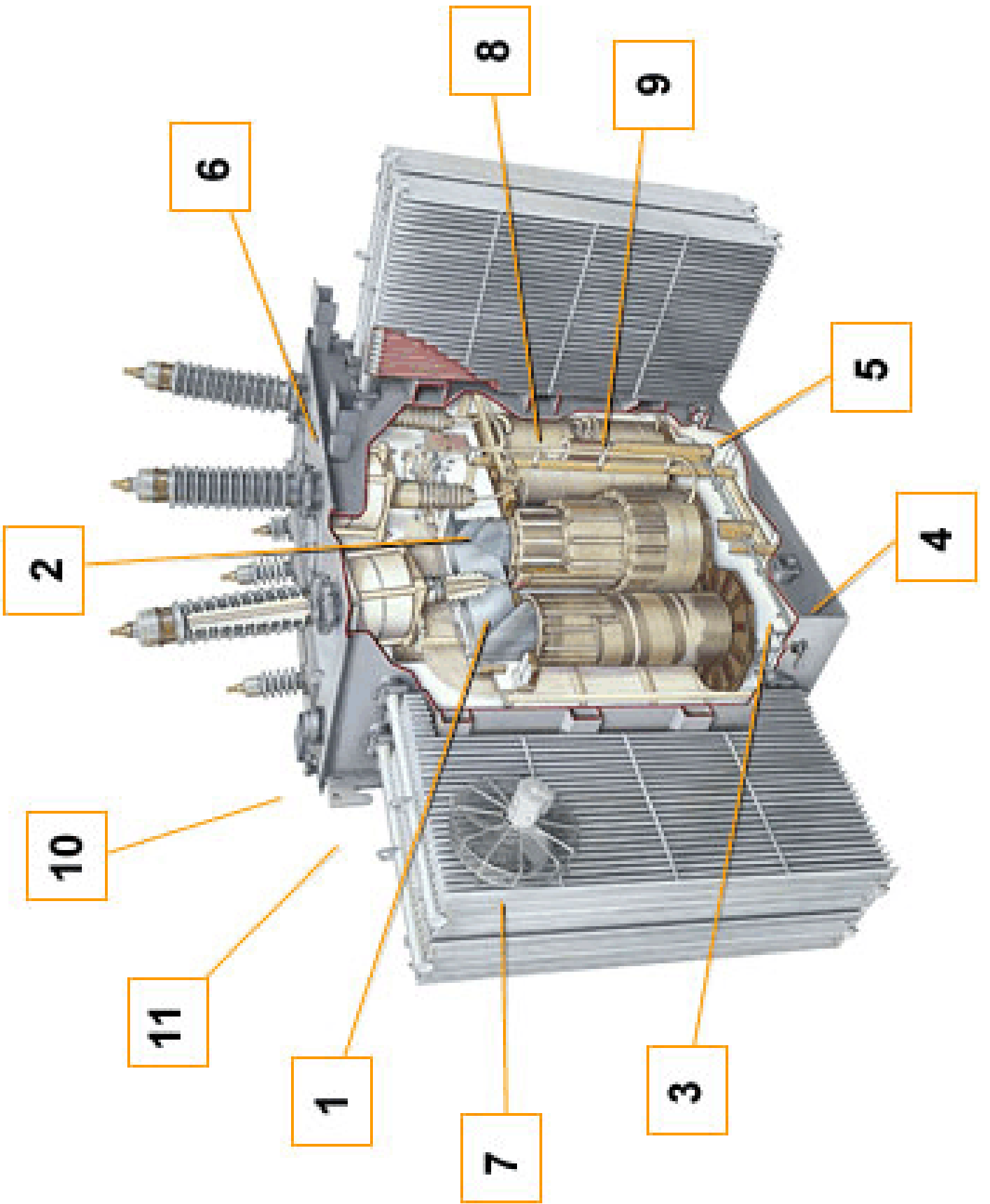


**Topics for Today:**

- 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



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.
3. Coil assembly rigidly braced in a high-strength frame that distributes clamping forces around the full circumference of the windings.
4. Submerged-arc welding process produces deep penetration welds, virtually eliminating leakage from welded tank joints.
5. Inside tank surfaces are painted white to facilitate internal inspection.
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.
9. Patented DETC (De-Energized Tap Changer) features simple and compact in-line contact arrangement (Patent Number: 5,744,764)
10. Waukesha® Type UZD Load Tap Changer designed to withstand up to a half-million operations without the need for contact replacement.
11. Worldbox® Control Enclosure features IEC standard components and is easy to maintain and service in the field.

Loadflow - Phasor

S.C. - "

Stability - Both Phasor (Grid Cases)  
and time (machine dynamics)

$\Delta t, 2\Delta t, \dots$

Lightning - time (impulse)

Switching - time (step)

Insulation Design -

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# EE 5200 TEXT

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*Handwritten notes:*

- closed** (circled)
- open**
- V Phasors**
- 6 review videos** (in a box)

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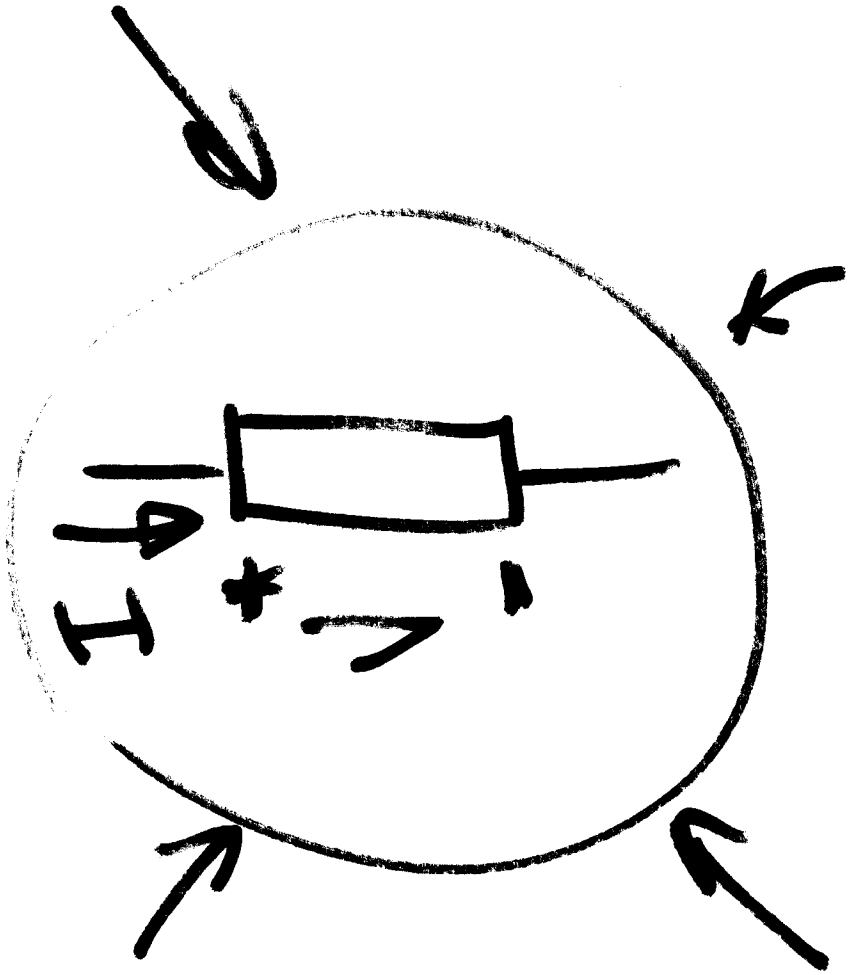
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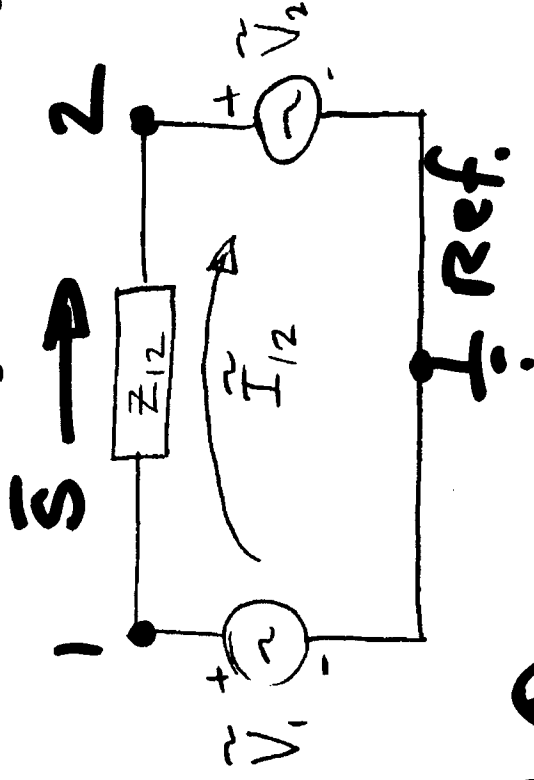
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1) [15pts] For the following circuit,  $v_1(t) = 100 \cos(\omega t + 0^\circ)$ ,  $v_2(t) = 120 \sin(\omega t - 30^\circ)$  and  $Z_{12} = 0.5 - j0.5\Omega$ .

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



- Phasor Analysis

-  $\tilde{V}, \tilde{I}$ , Subscripts

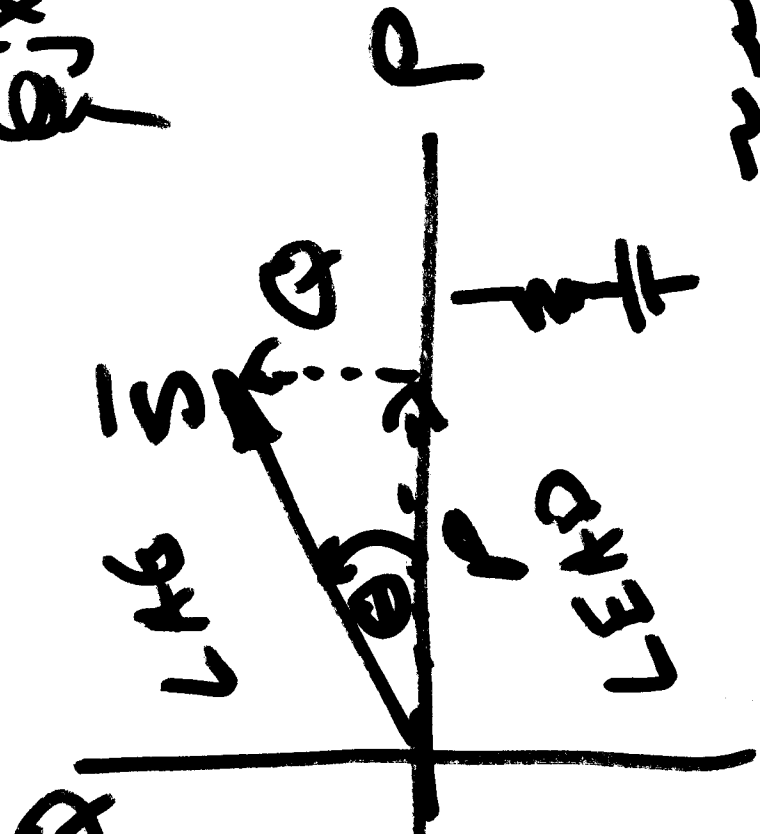
- Polarity

- Flow direction of P, Q



$$S_{in} = VI^*$$

or  
 $Q_{ij}$



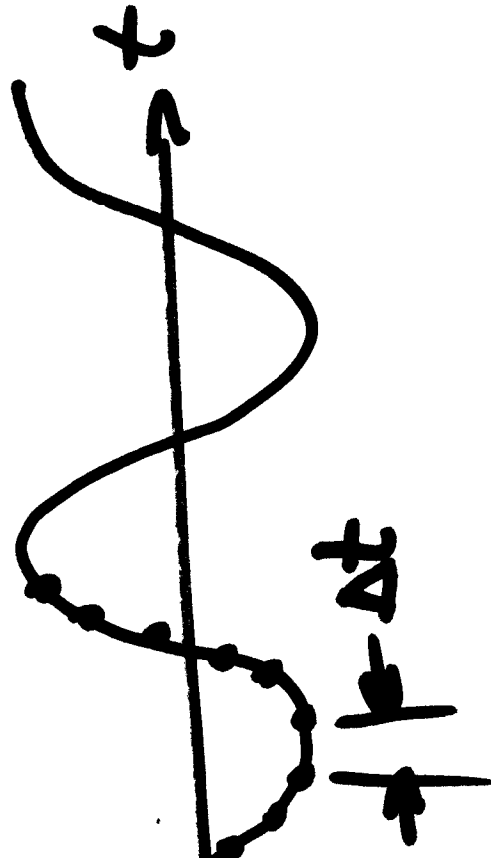
$$\theta = \angle \vec{V} - \angle \vec{I} \text{ (passive)}$$

$$= \angle \vec{S} - \angle \vec{P}$$

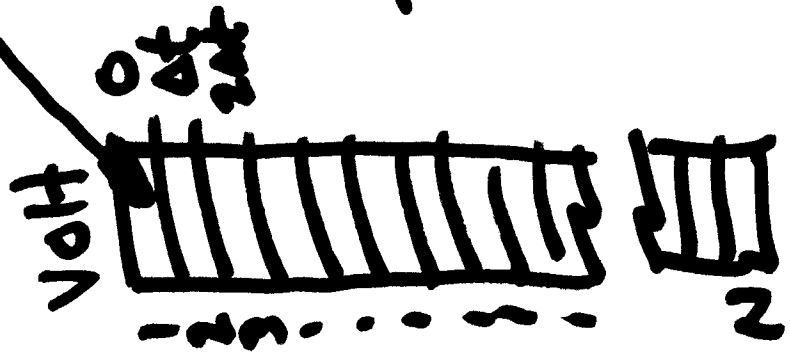
$$S = VI \cos \theta + j VI \sin \theta = \underline{\underline{VI^*}}$$

# Time Domain - Simulation

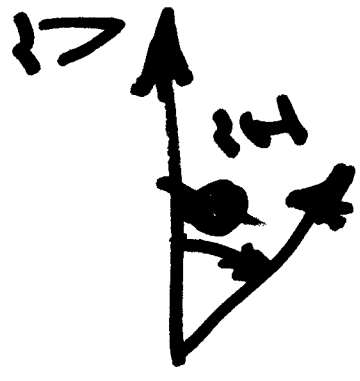
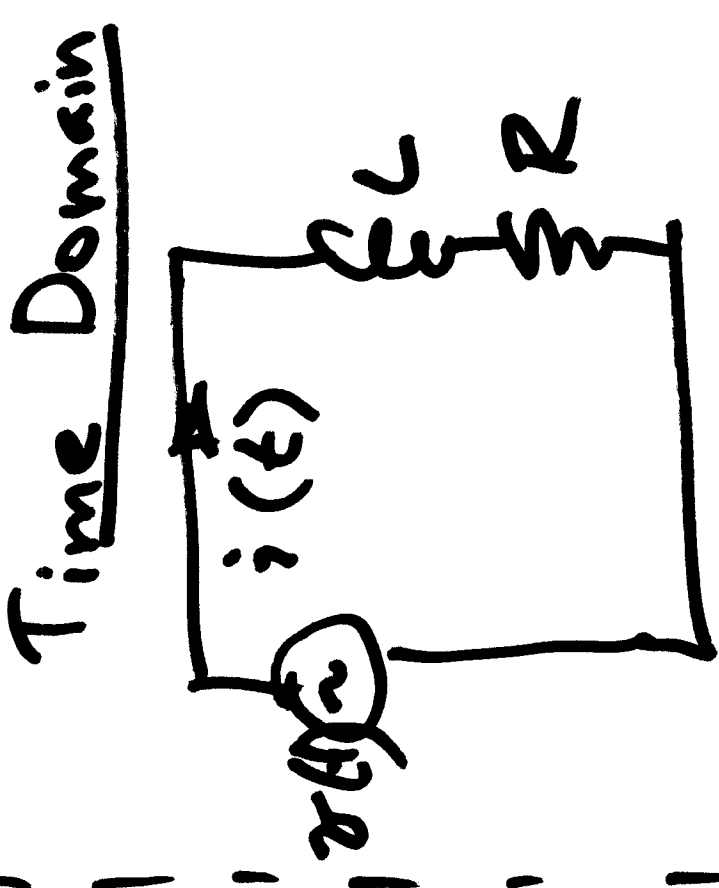
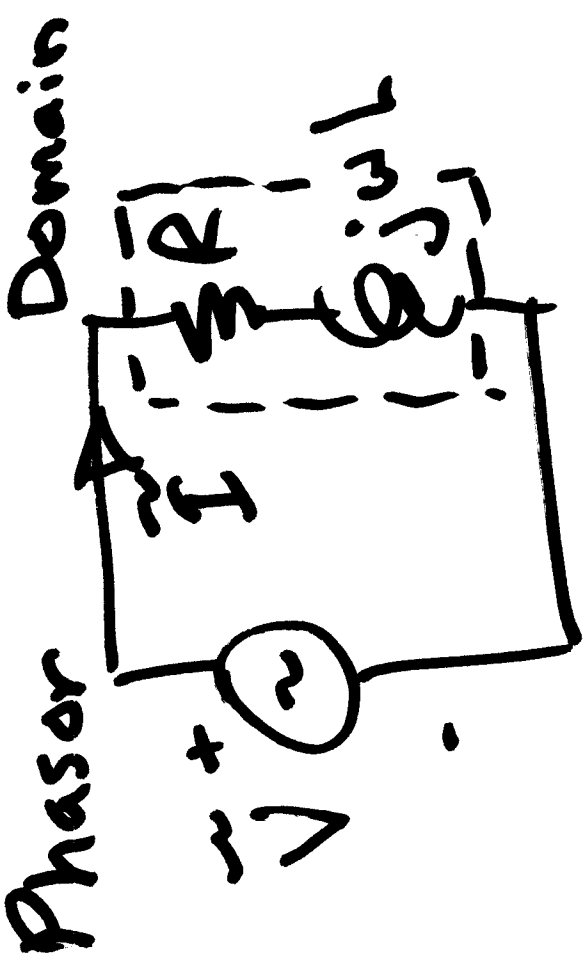
- ATP
  - Matlab
- $\Delta t = \text{uniform timestep}$



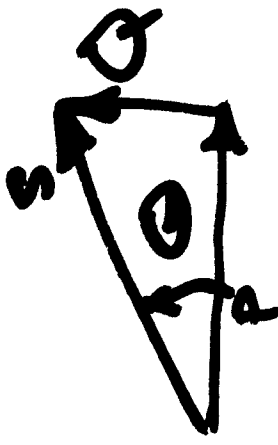
real no:



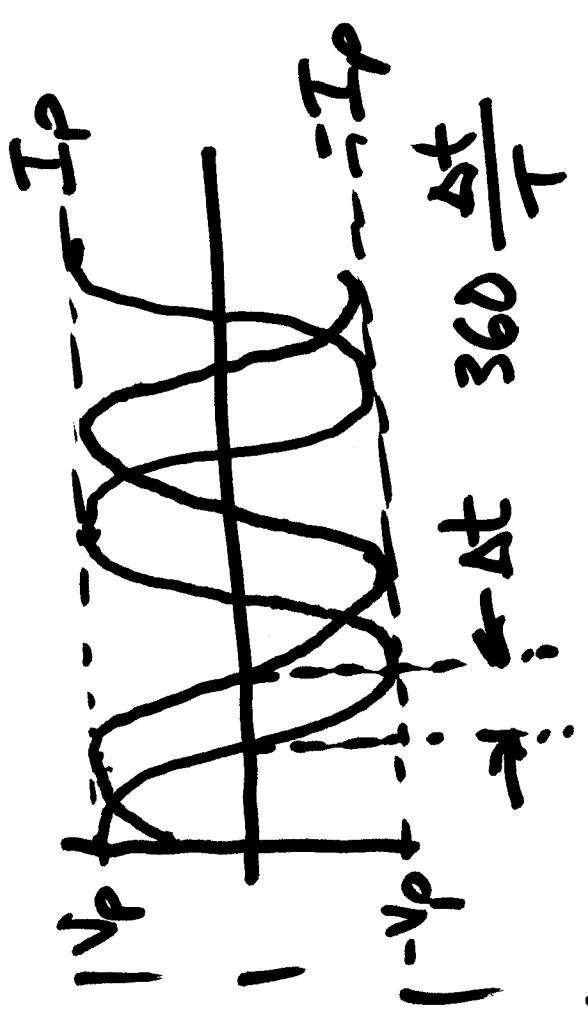
time series



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

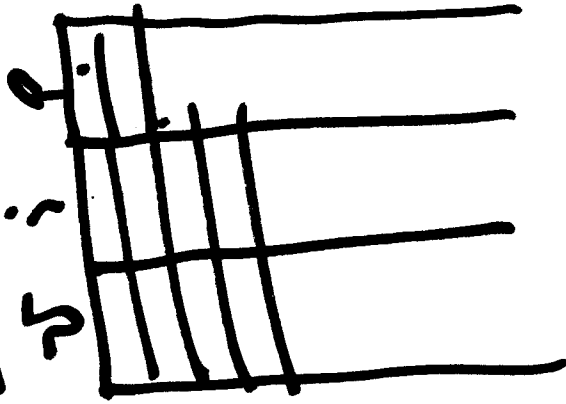


$$v(t) = V_p \cos(\omega t)$$

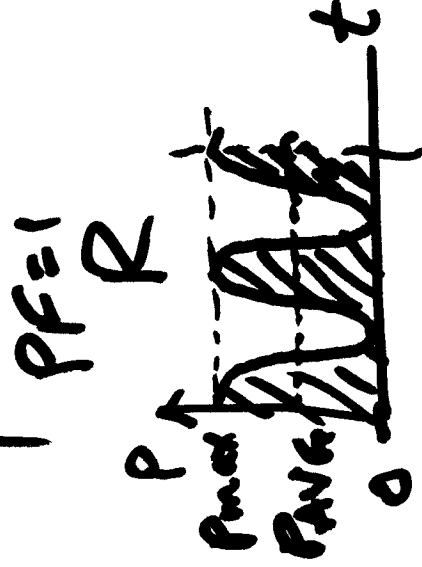
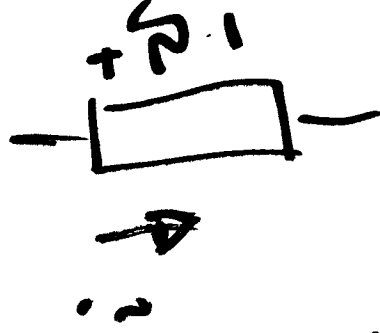


# Power

## Matlab

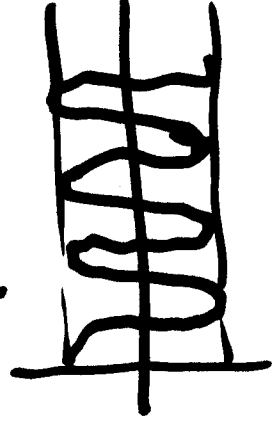


$$P_{AVG} = \frac{1}{T} \int_0^T P(t) dt$$



$$P(t) = v(t) \cdot i(t)$$

$P_{AVG} = 0$



$P_{AVG} = 0$

# Waukesha Quality Inside

## Means Reliability Is On Your Side

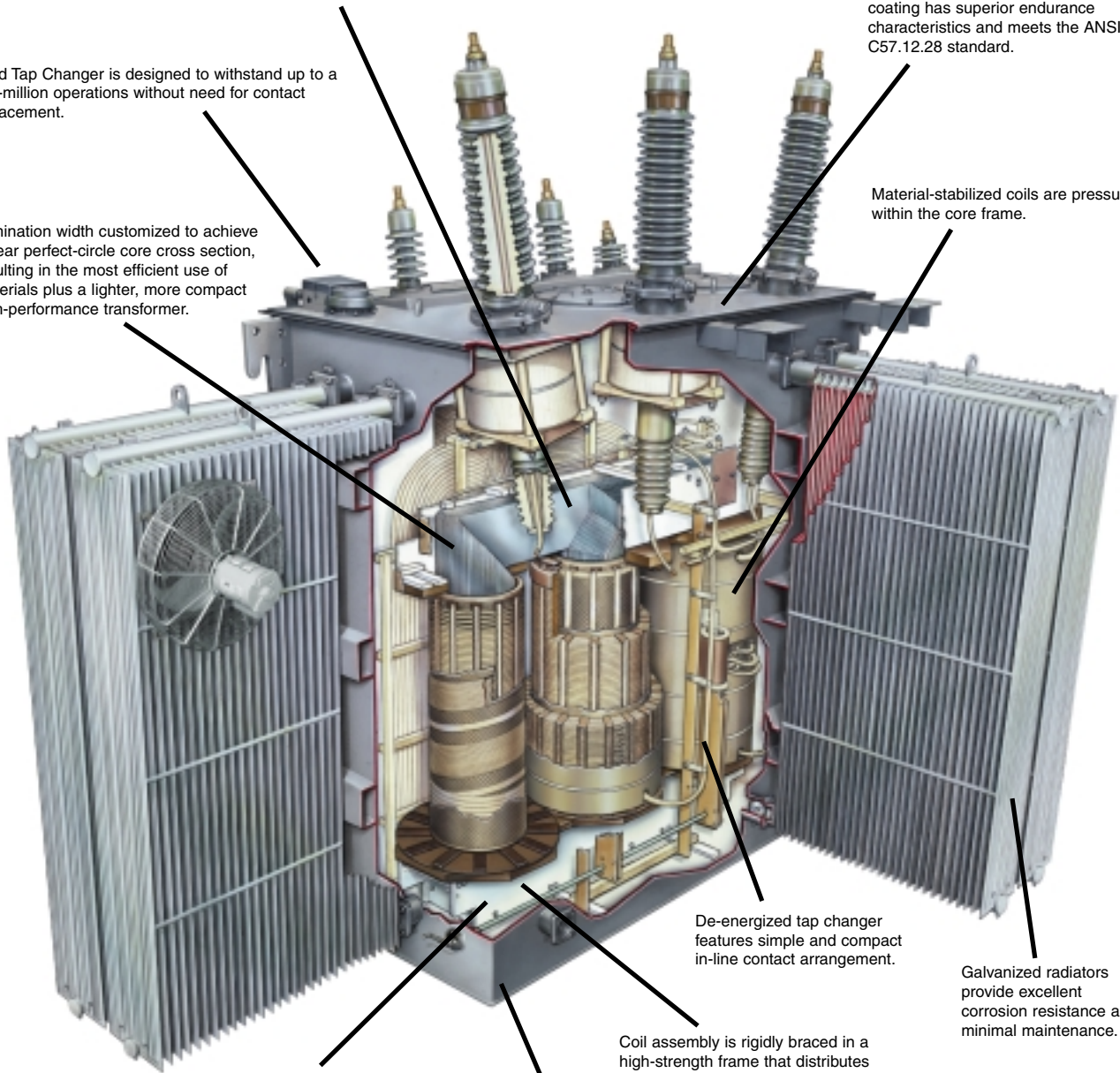
Low no-load losses result from use of laser-scribed, super-grain-oriented steel.

Transformer exterior is coated to a minimum thickness of 3 mils. This coating has superior endurance characteristics and meets the ANSI C57.12.28 standard.

Load Tap Changer is designed to withstand up to a half-million operations without need for contact replacement.

Lamination width customized to achieve a near perfect-circle core cross section, resulting in the most efficient use of materials plus a lighter, more compact high-performance transformer.

Material-stabilized coils are pressure-fit within the core frame.



Inside tank surfaces are painted white to facilitate internal inspection.

De-energized tap changer features simple and compact in-line contact arrangement.

Galvanized radiators provide excellent corrosion resistance and minimal maintenance.

Coil assembly is rigidly braced in a high-strength frame that distributes clamping forces around the full circumference of the windings.

Submerged-arc process produces deep weld penetration, virtually eliminating leakage from welded tank joints.

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.



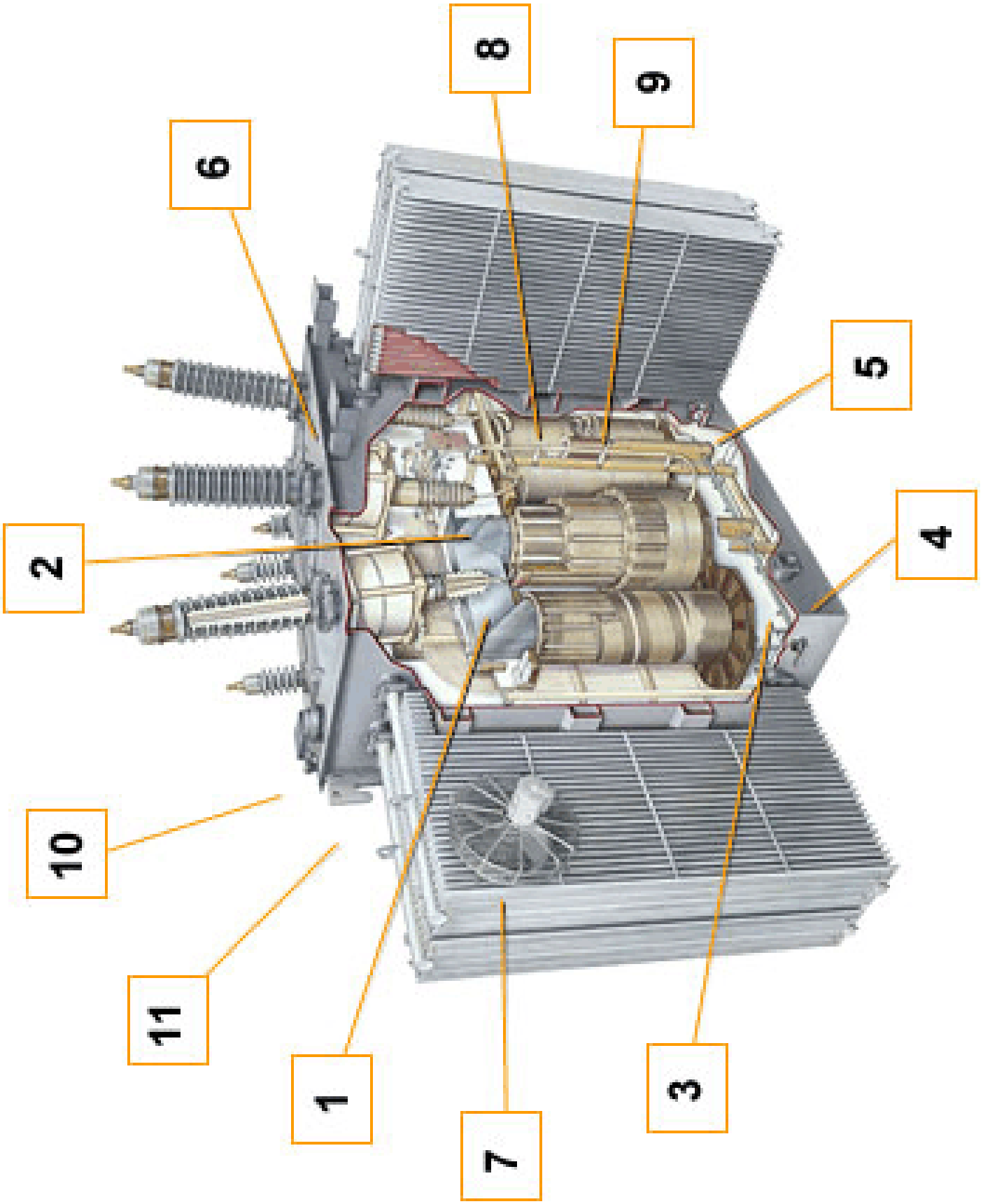
### WAUKESHA ELECTRIC SYSTEMS

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



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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10. Waukesha® Type UZD Load Tap Changer designed to withstand up to a half-million operations without the need for contact replacement.
11. Worldbox® Control Enclosure features IEC standard components and is easy to maintain and service in the field.



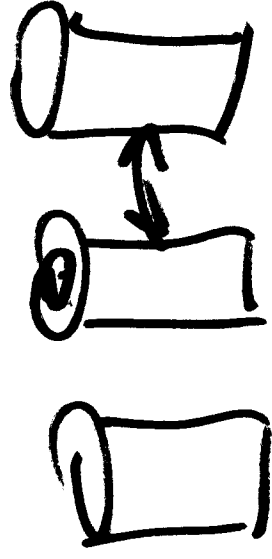
## Cooling

- Oil
- Heat exch
- pumps, fans

$\pm 10\%$  LTC's - LV  
 $\pm 5\%$  NLTC's - HV  
(off-nominal  
turns ratio)

## Monitoring

- Temp: oil, coils
- Oil gases
- N<sub>2</sub>



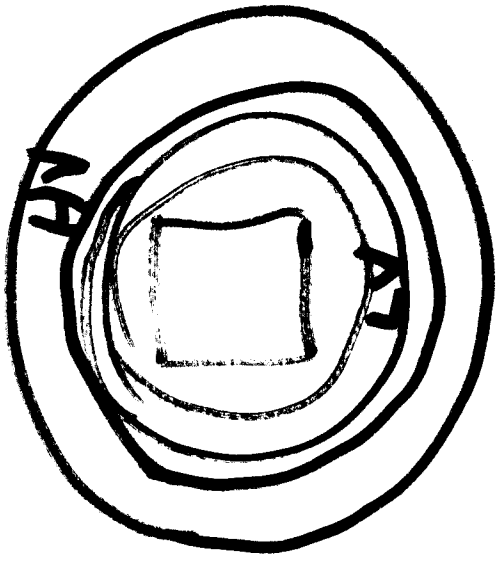
## Coil Design

- insulation:

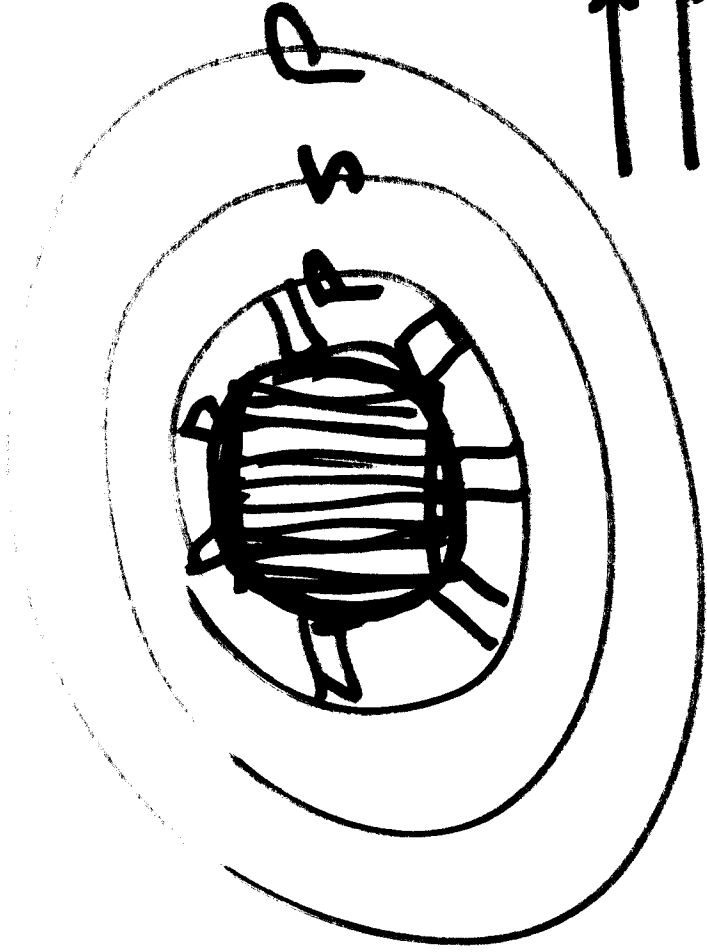
$\Phi$  } coil-core; coil-coil, phase-phase

} Higher V

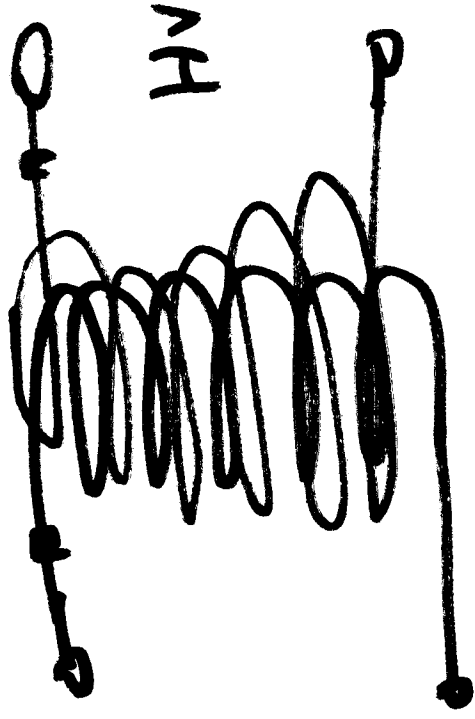
BIT  
Bst



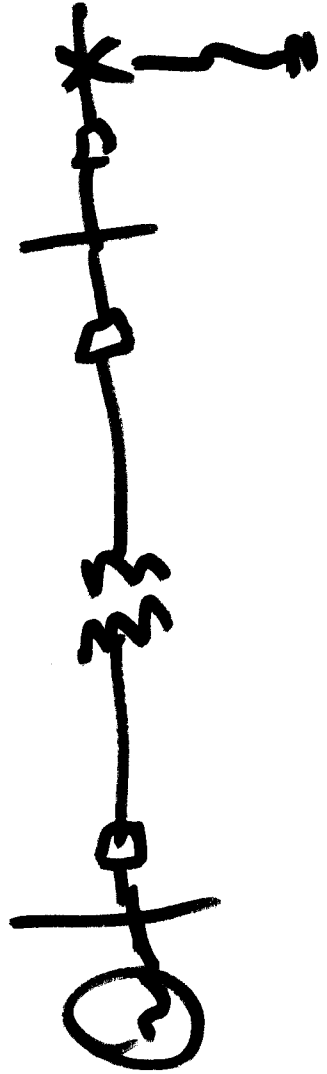
S-P



P-S-P



cylindrical



How many possibilities are there  
for  $\Delta$ - $Y$  or  $Y$ - $\Delta$  phase shifts?

$\pm 30^\circ$   
 $\pm 90^\circ$   
 $\pm 150^\circ$  ) 6 each  $\Rightarrow$  12 total.

Auto- $\Delta$

Zig-Zig

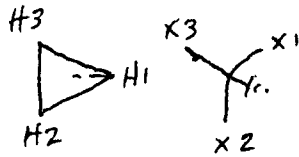
Extended  $\Delta$ .

- Three-Phase Transformers

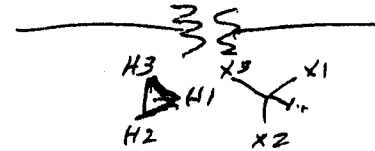
Mark

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

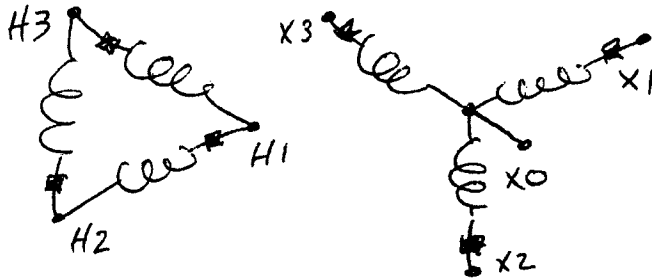
IEEE Stds:



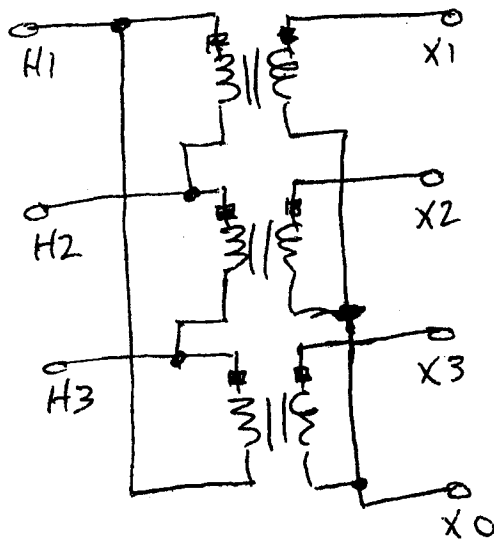
One-Line:



Schematic



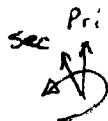
Circuit 3-line diagram



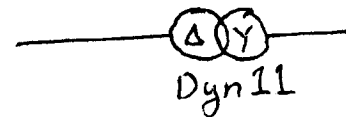
In Europe and much of the world:

IEC Stds:

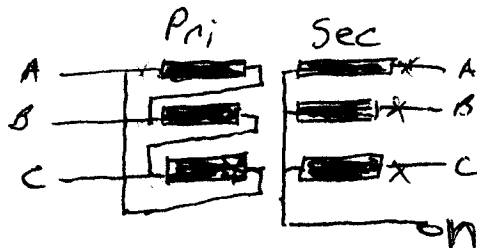
Dyn11



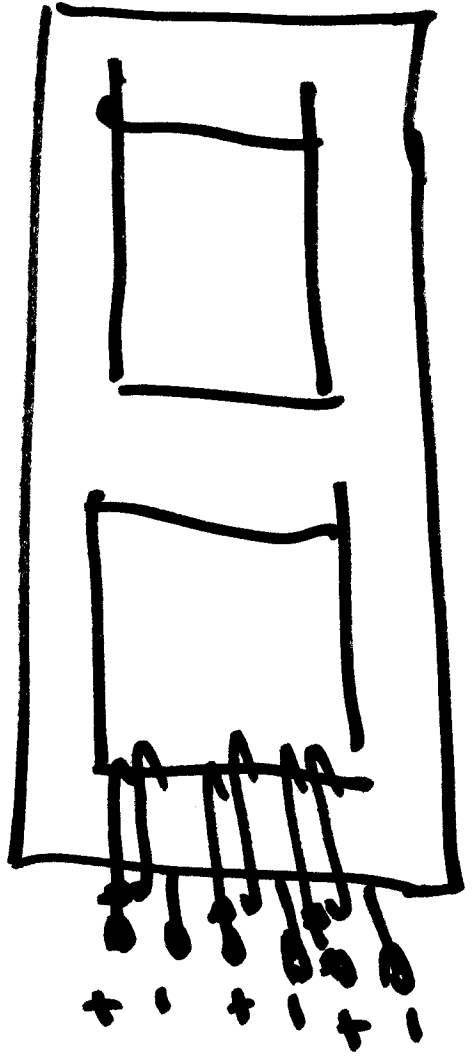
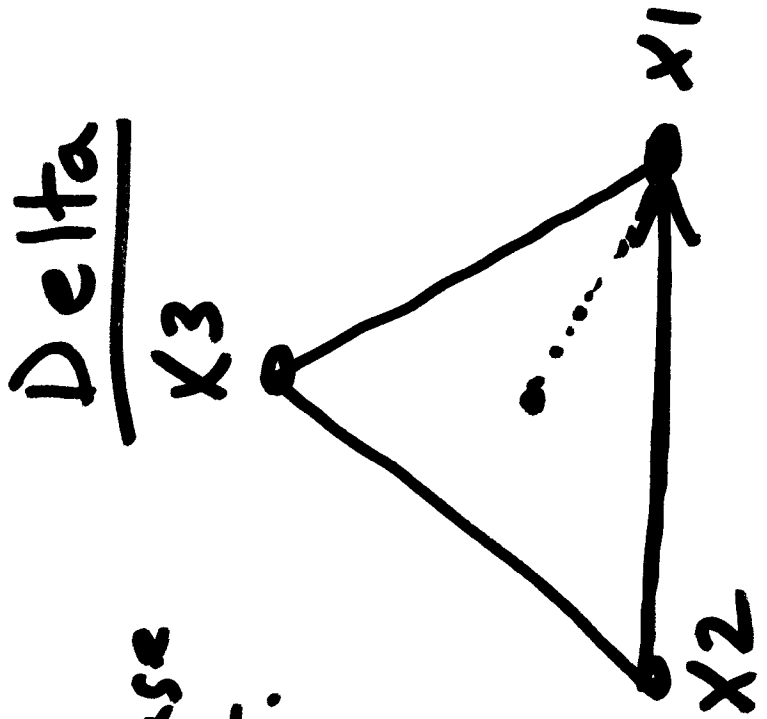
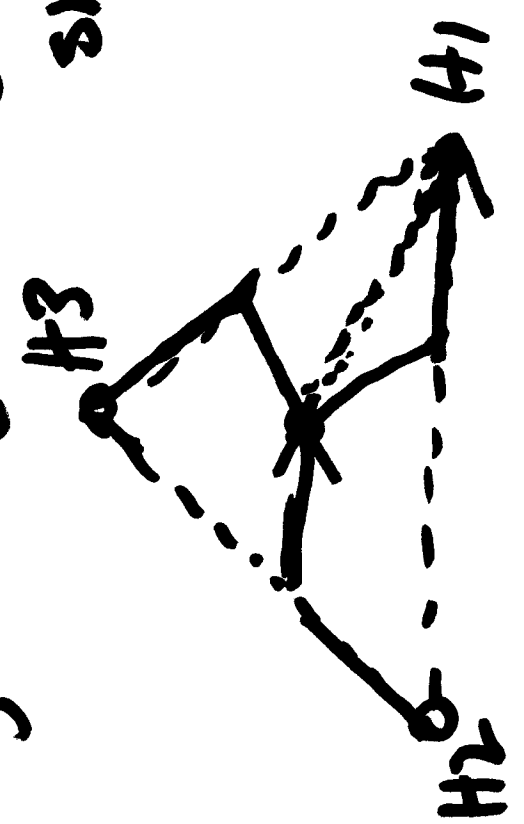
One-Line:

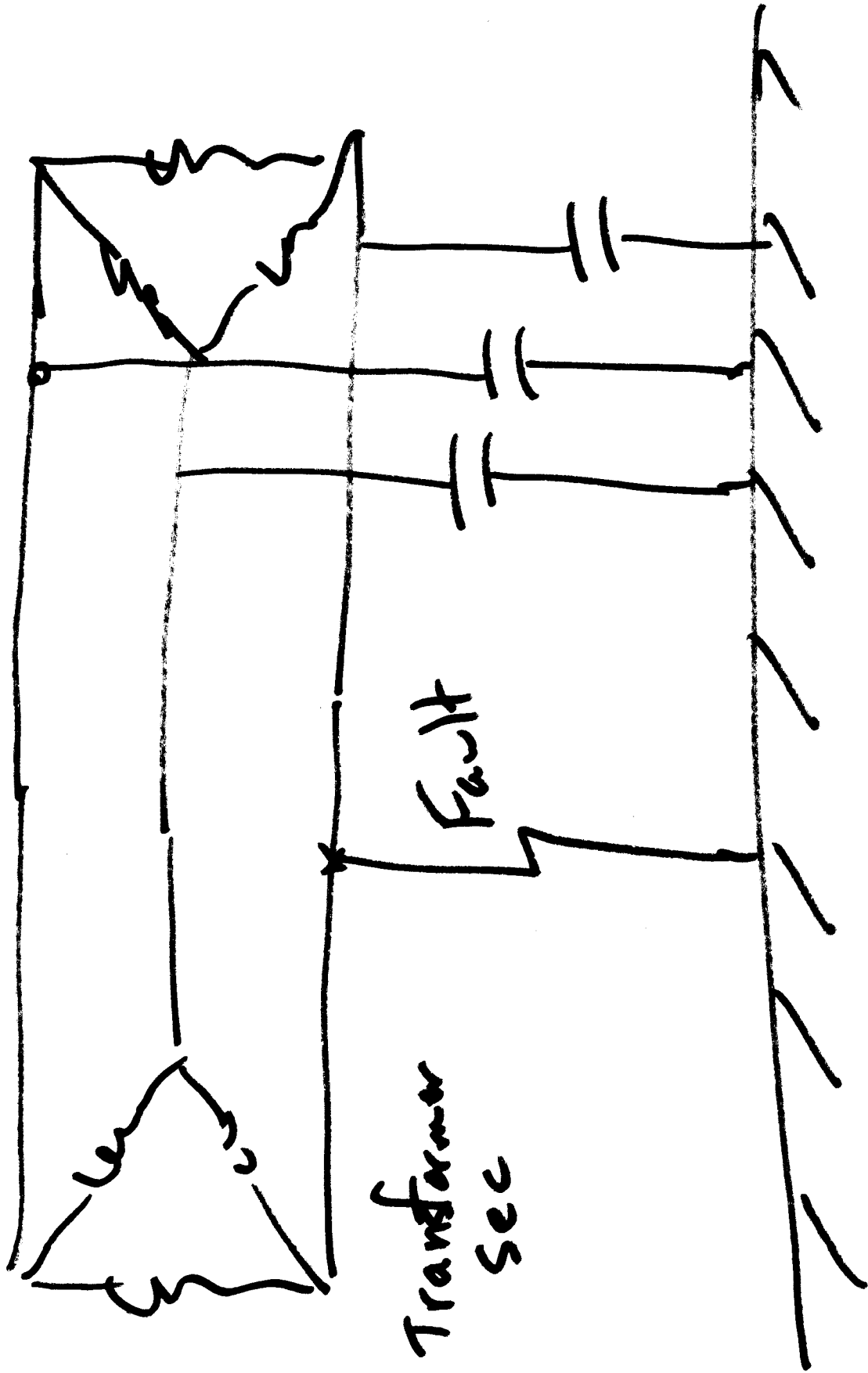


"old-down" diagram



Zig-Zag  $0^\circ$  phase shift.



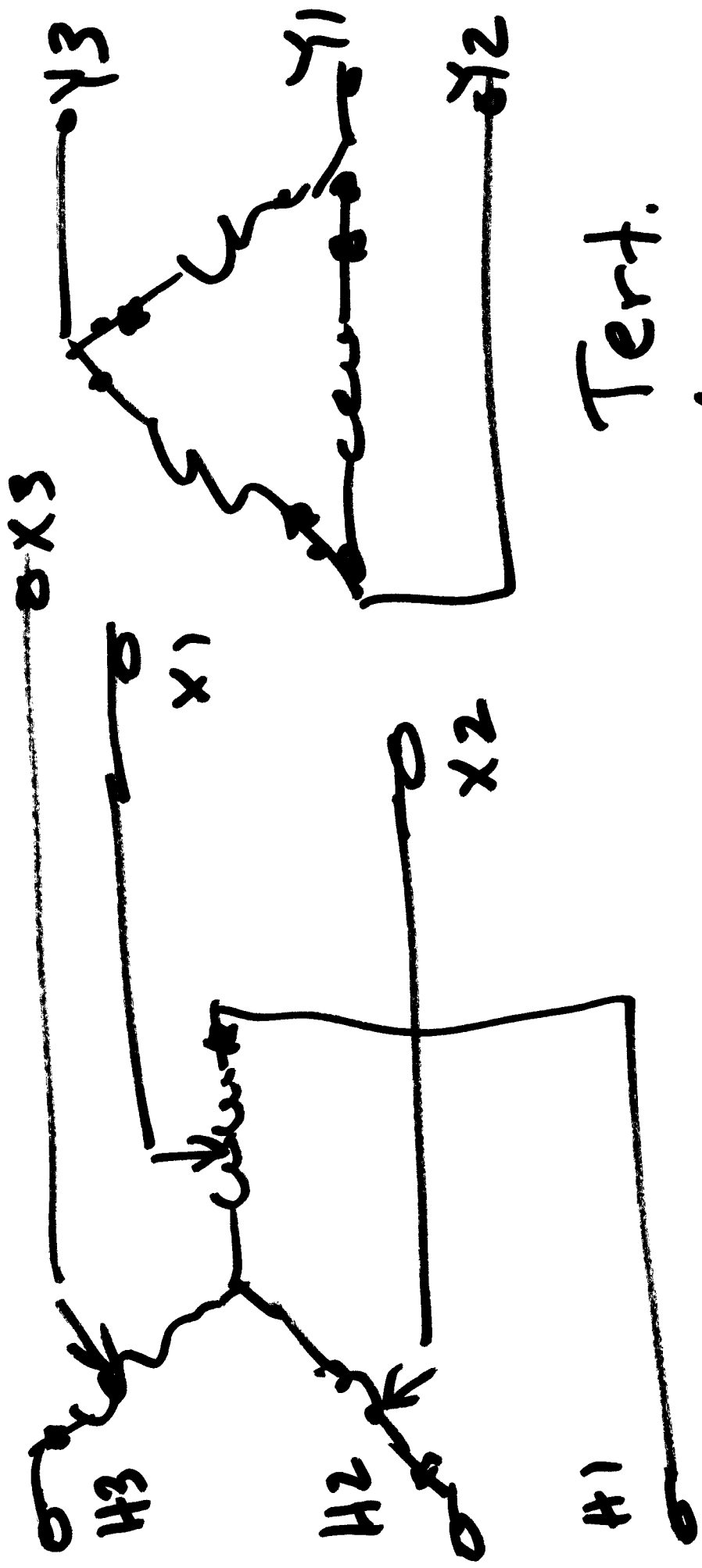


Transformer  
sec

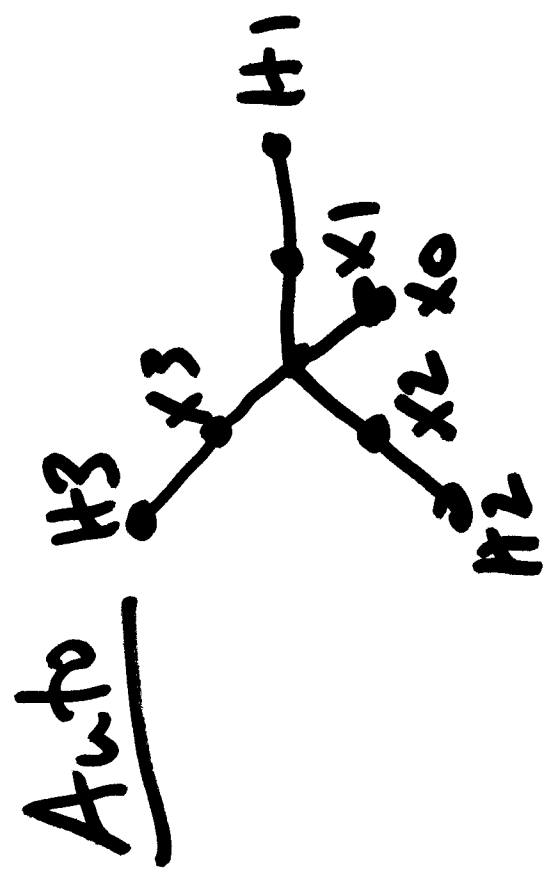
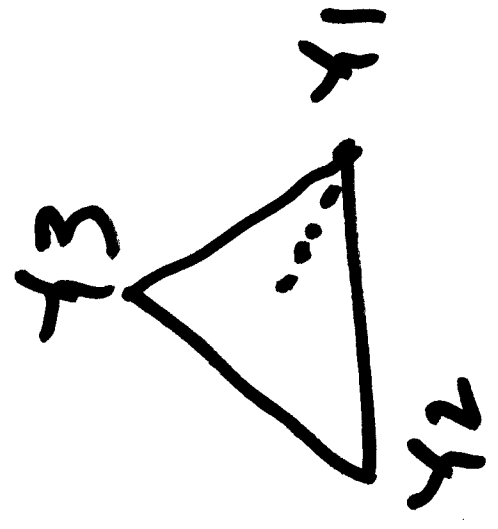
Fault

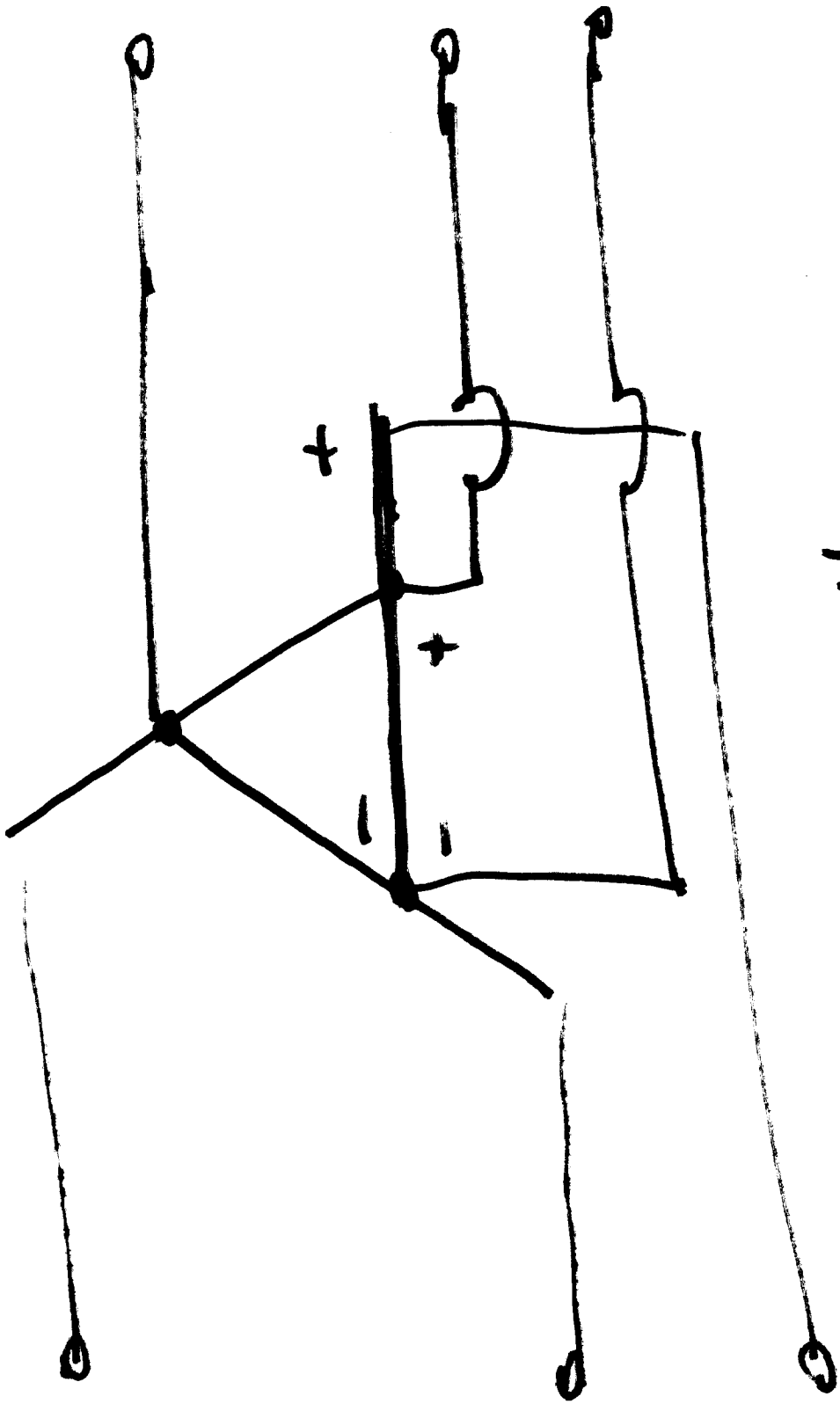
Balanced 3-ph voltages:

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



Tert.



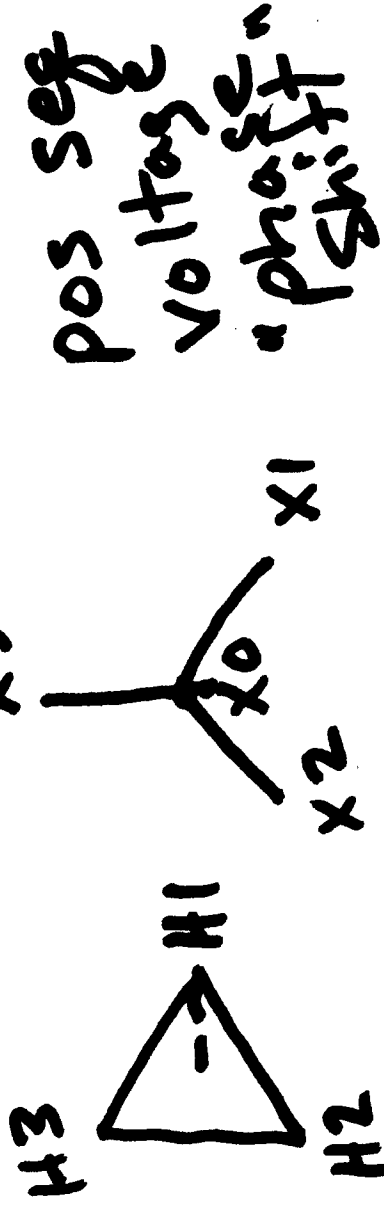


Extend Delta



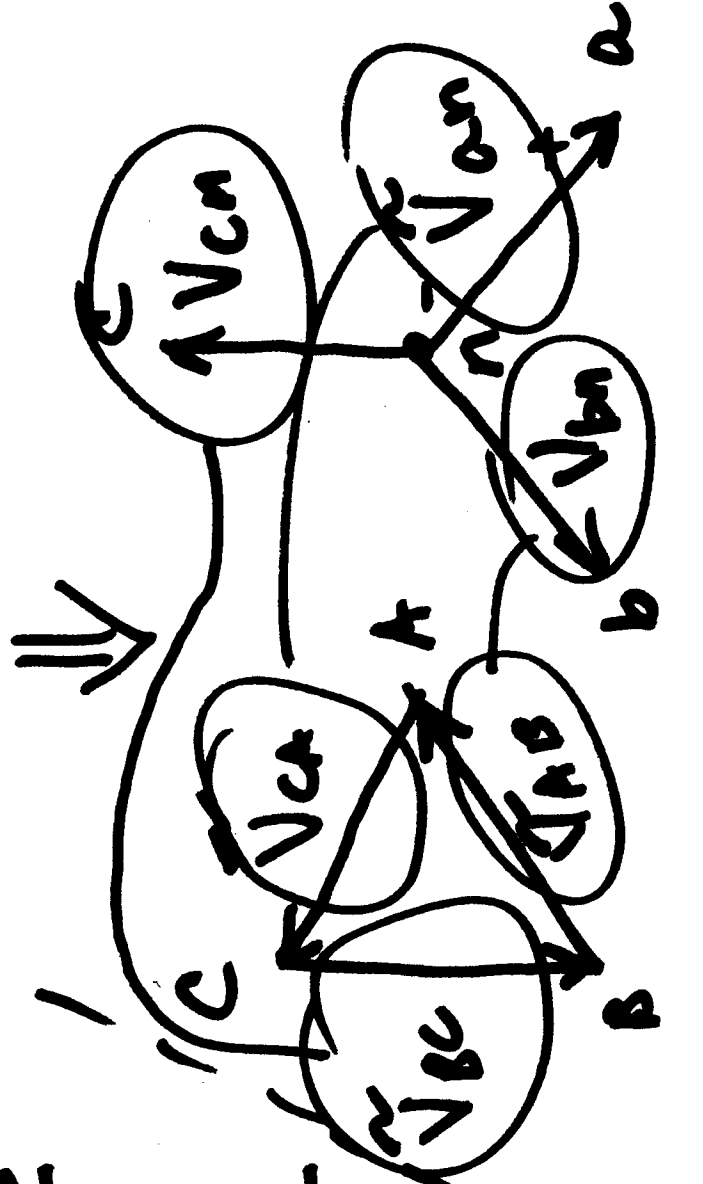
# Transformer Phase Shifts

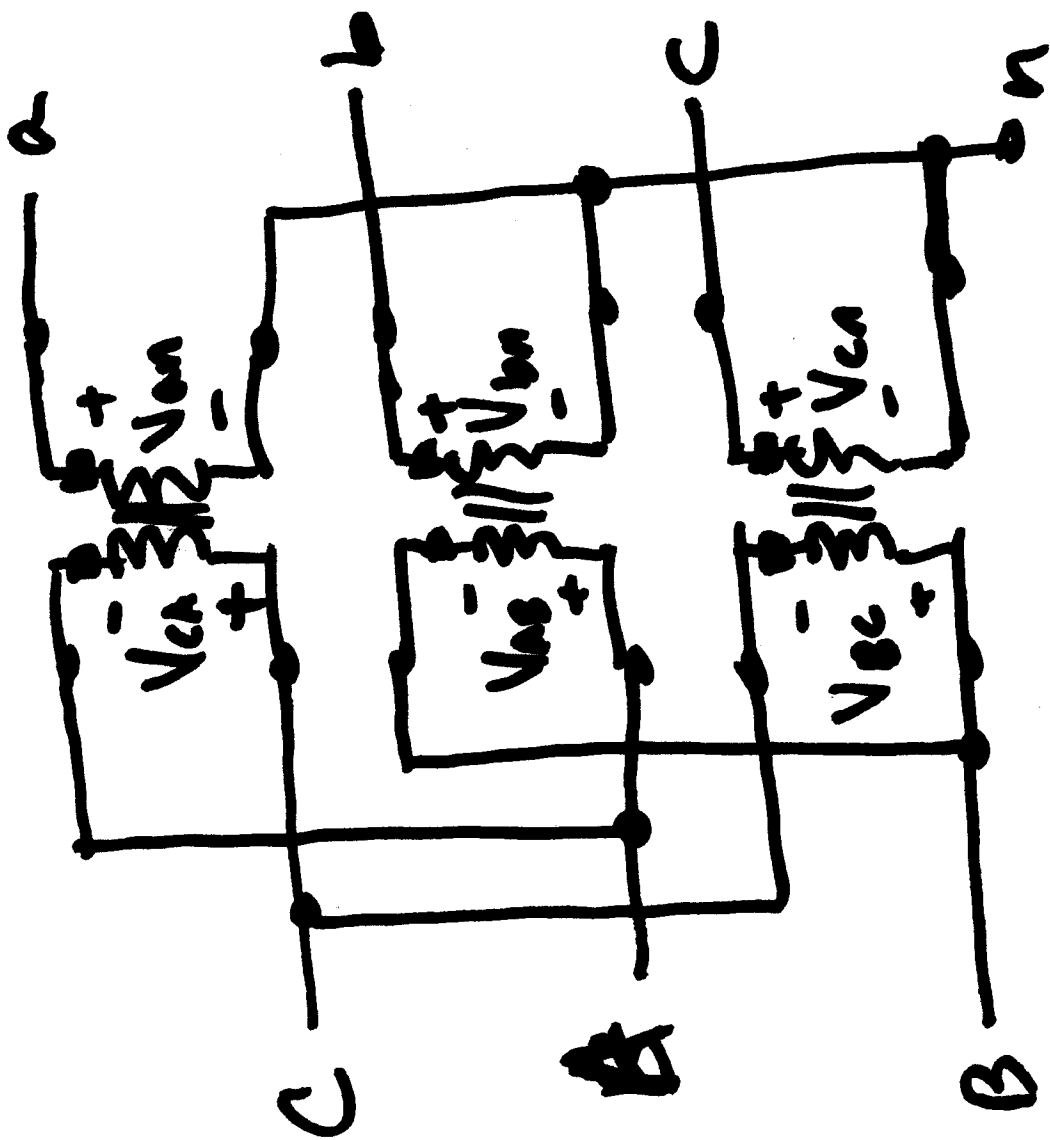
- See  $\Delta$ -Y transformer nameplate



$$\vec{I}_1 \rightarrow \vec{V}_1 = \vec{V}_2 \vec{I}_2$$

$$\vec{I}_2 \rightarrow \vec{V}_2 = \vec{V}_1 \vec{I}_1$$

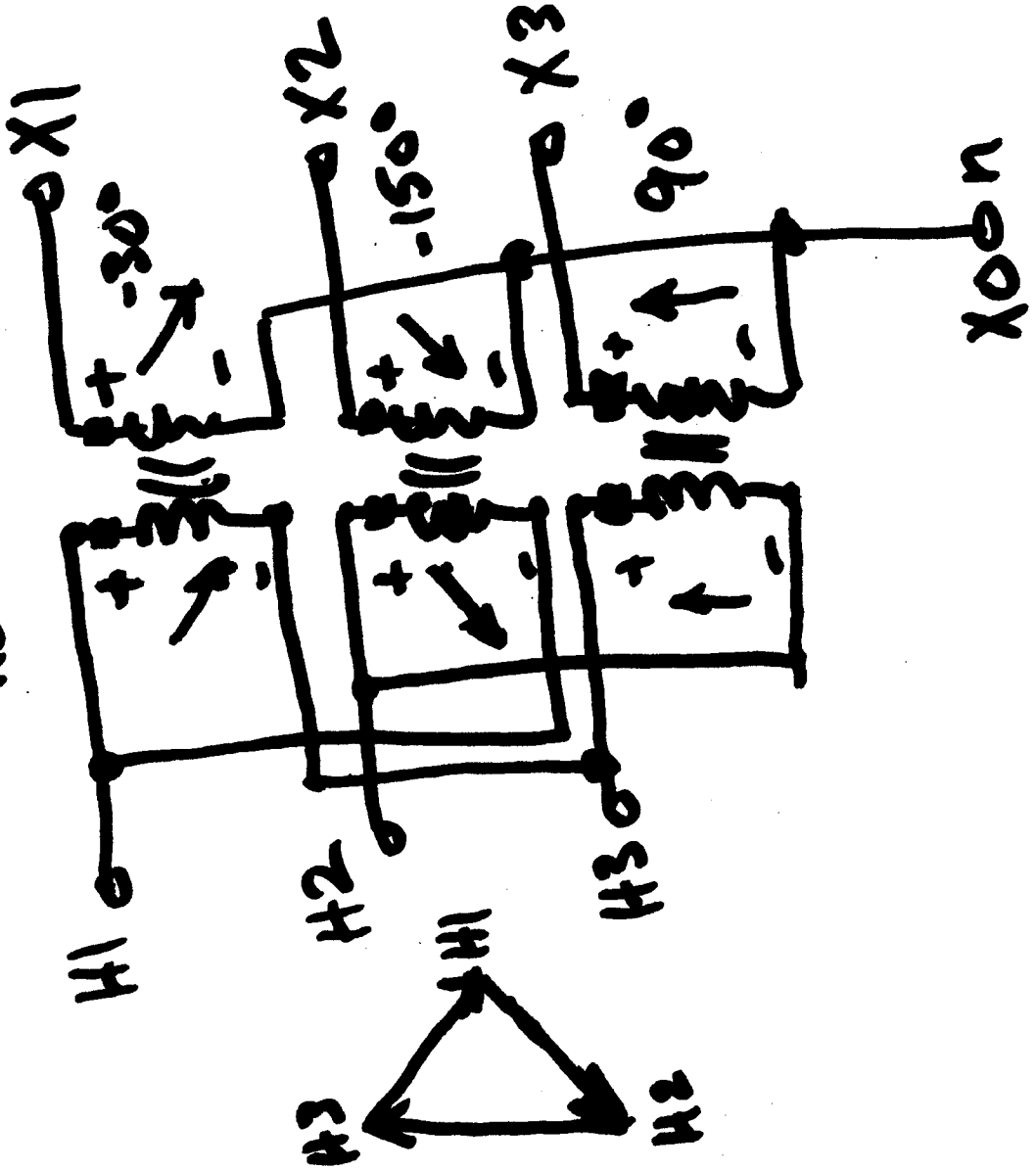




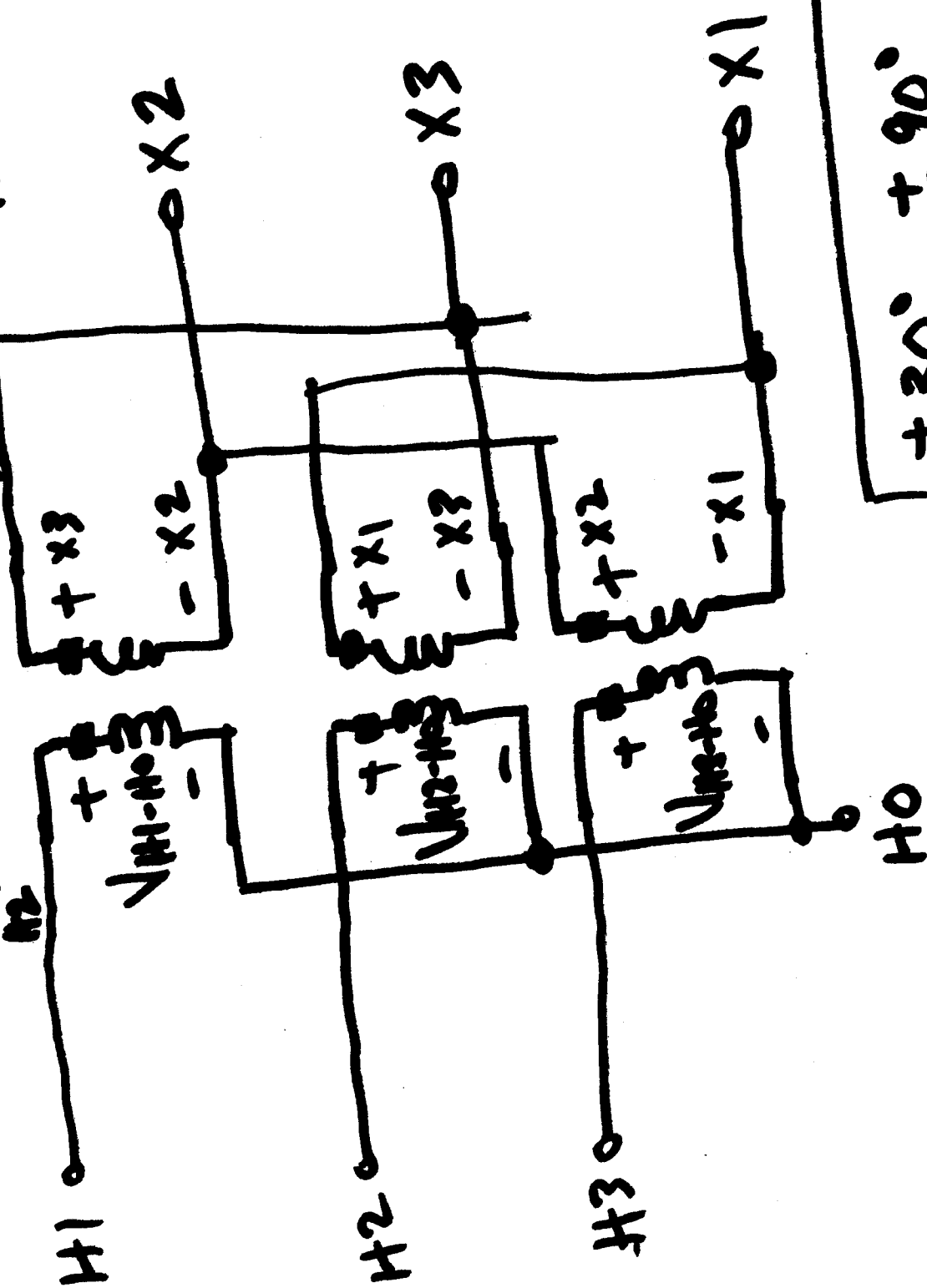
1

# 3-PHASE XFMR BANK

Ex:  $\Delta$ -Y (Dyn1)

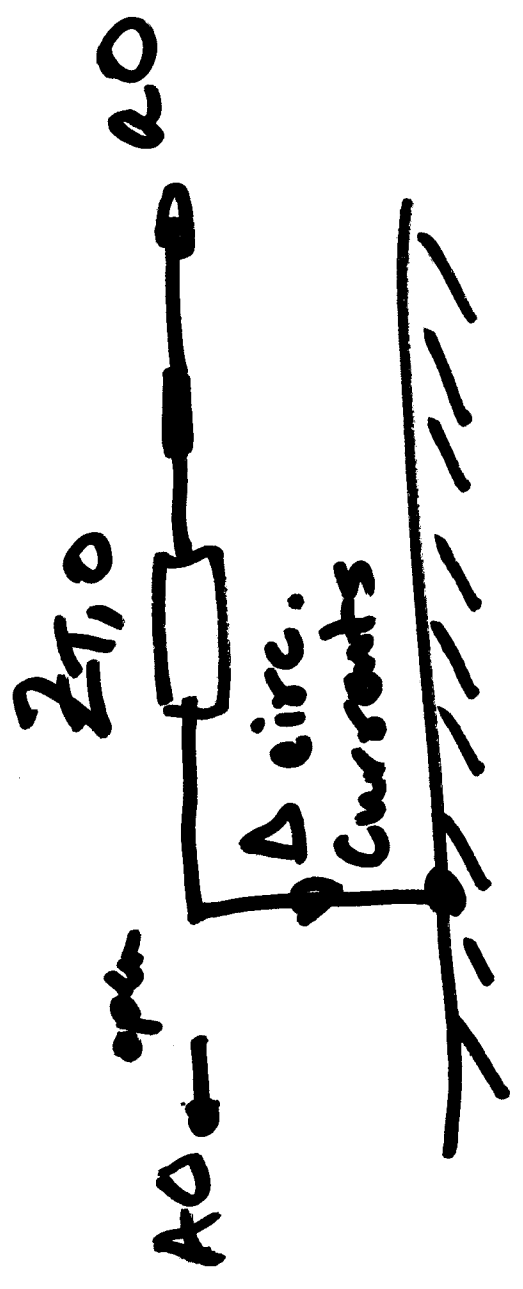
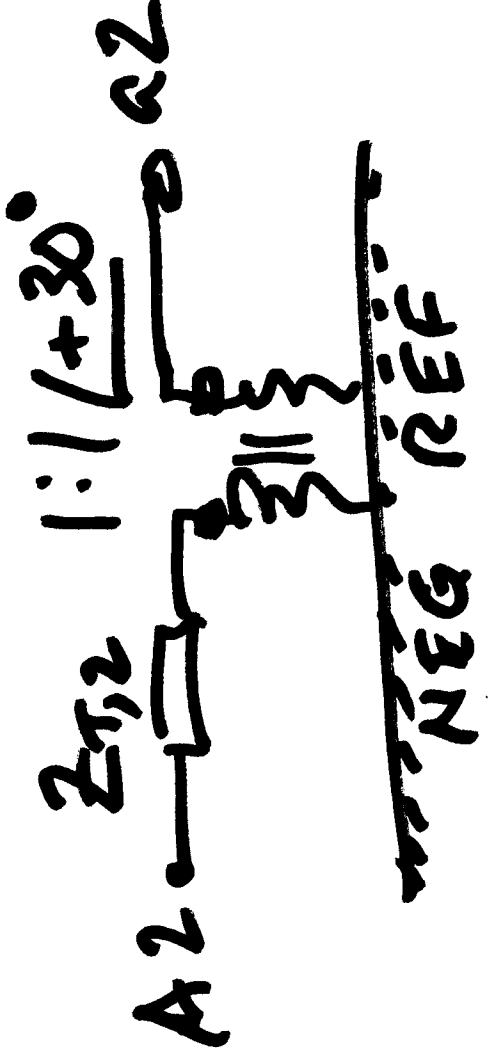
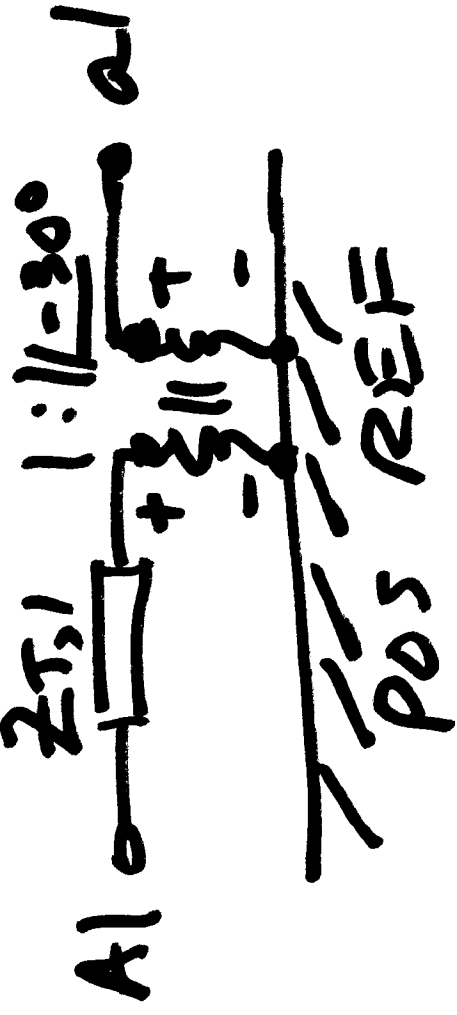


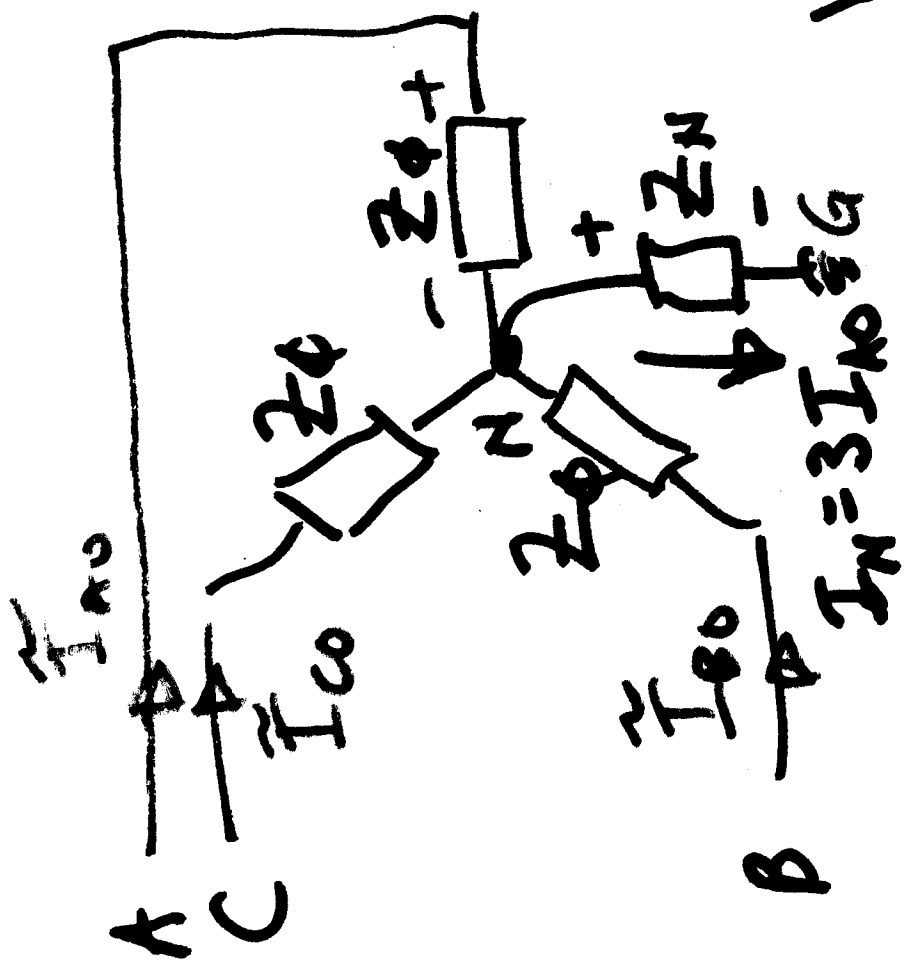
From:  
Review  
Lecture 5



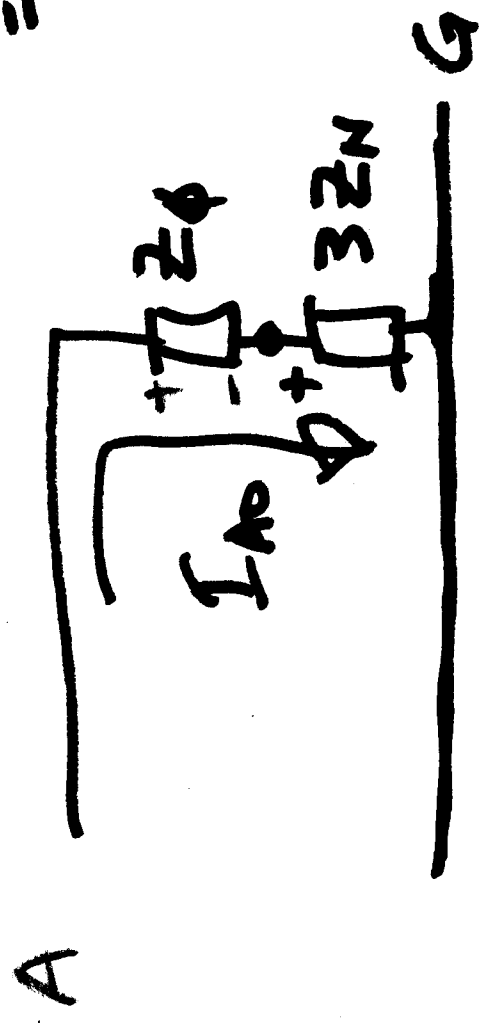
$\pm 30^\circ, \pm 90^\circ, \pm 150^\circ$







$= V_{NG}$



triplex harmonics

buried tertiary

buried delta

---

delta: - trap triplen harmonics

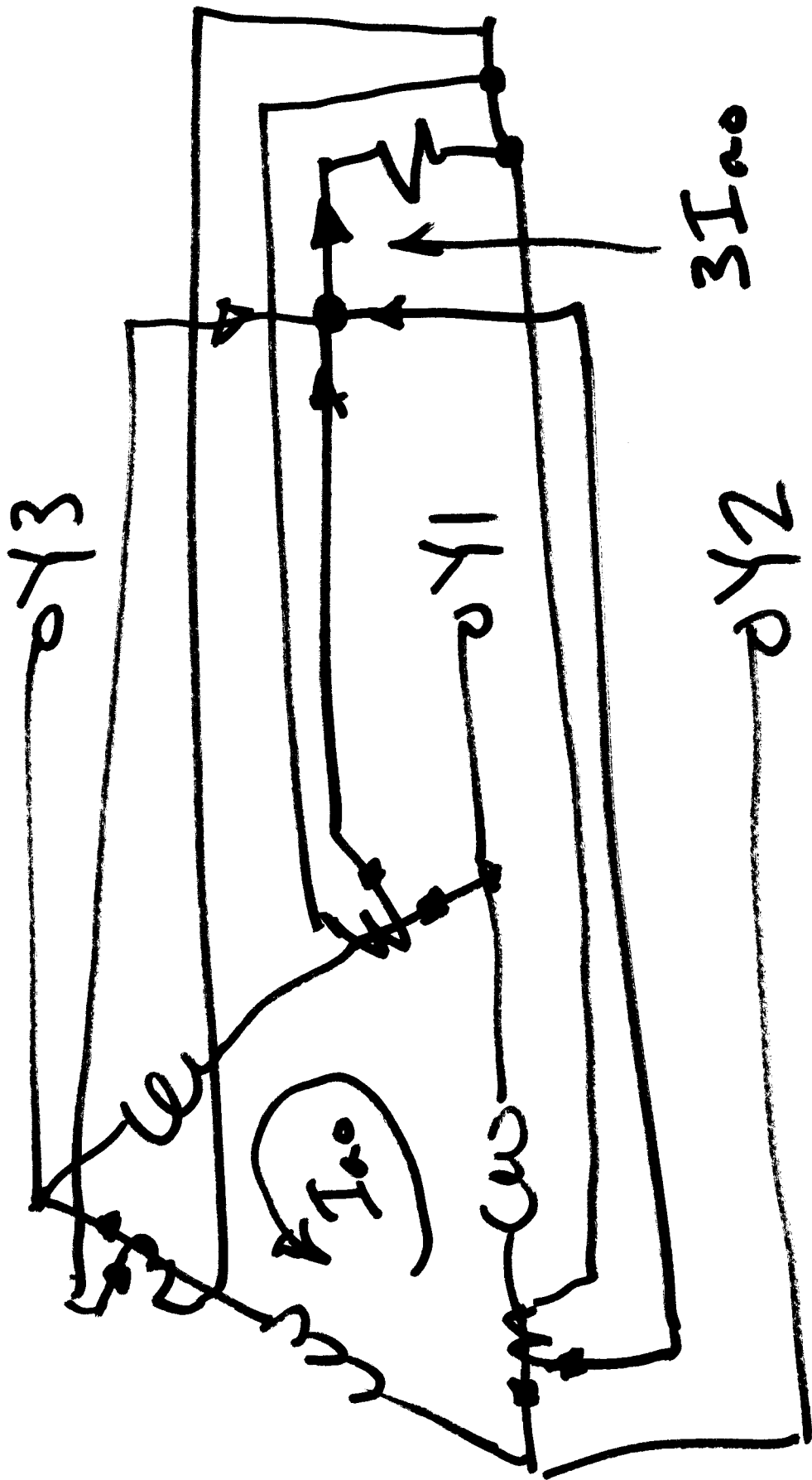
- zero seq circ path

- Aux power (station service)

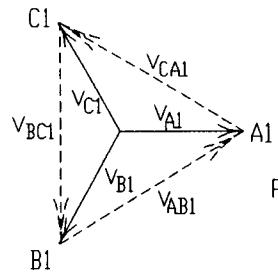
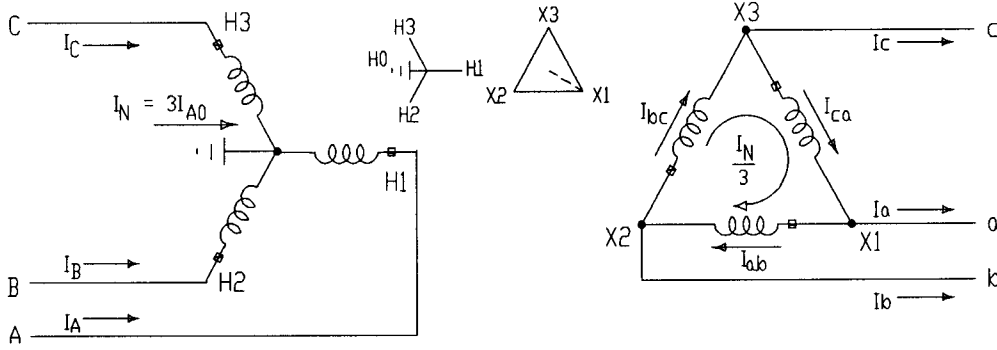
- Protection

- CTS



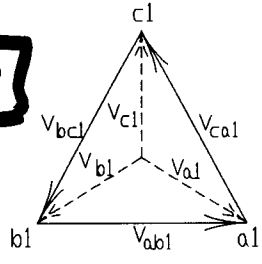


MORK

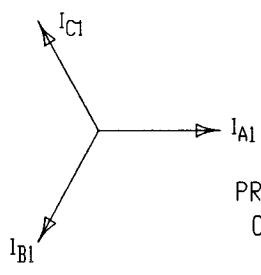


$$V_{A1} = V_{a1} (\angle 30^\circ)$$

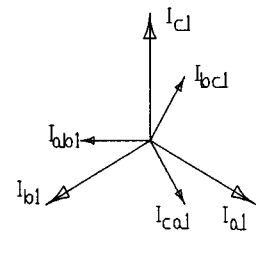
PRI POS SEQ VOLTAGES



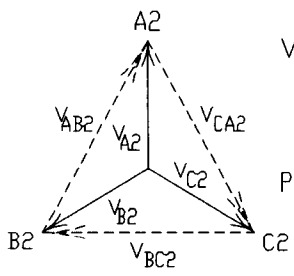
SEC POS SEQ VOLTAGES



PRI POS SEQ CURRENTS

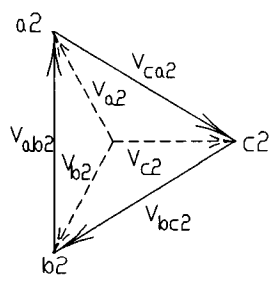


SEC POS SEQ CURRENTS

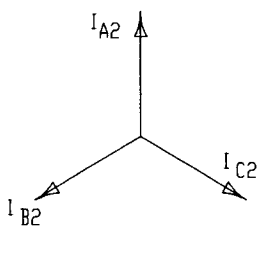


$$V_{A2} = V_{a2} (\angle -30^\circ)$$

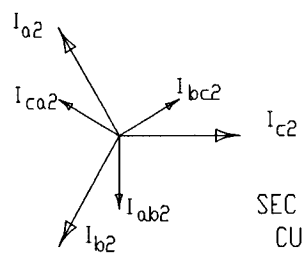
PRI NEG SEQ VOLTAGES



SEC NEG SEQ VOLTAGES



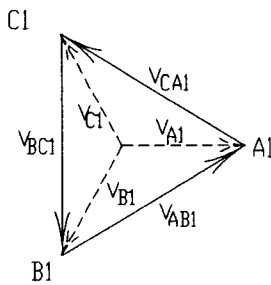
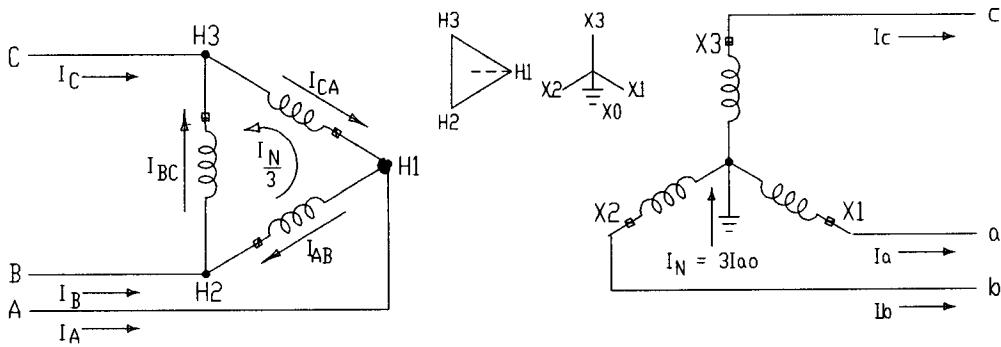
PRI NEG SEQ CURRENTS



SEC NEG SEQ CURRENTS

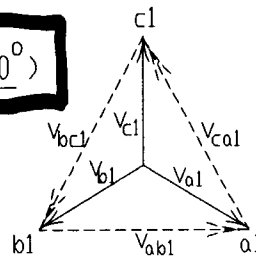
ANSI STANDARD 30-DEGREE SHIFT WYE-DELTA

WORK

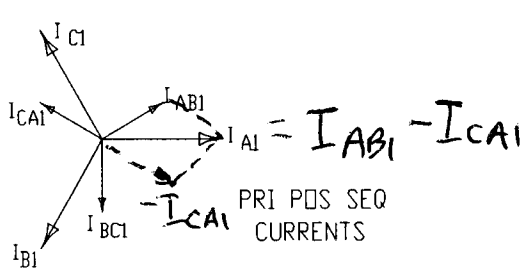


$$V_{A1} = V_{a1} (1/\sqrt{3}) \angle 30^\circ$$

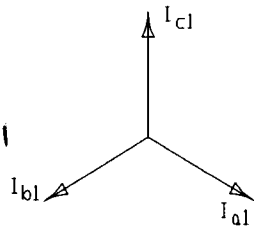
PRI POS SEQ VOLTAGES



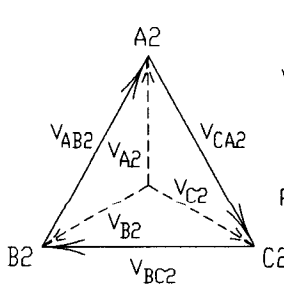
SEC POS SEQ VOLTAGES



PRI POS SEQ CURRENTS

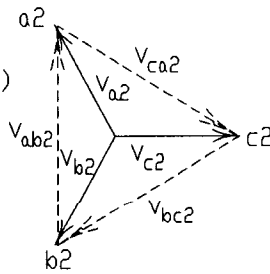


SEC POS SEQ CURRENTS

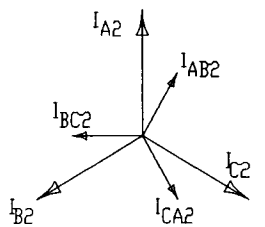


$$V_{A2} = V_{a2} (1/\sqrt{3}) \angle -30^\circ$$

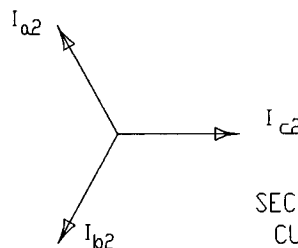
PRI NEG SEQ VOLTAGES



SEC NEG SEQ VOLTAGES



PRI NEG SEQ CURRENTS



SEC NEG SEQ CURRENTS

ANSI STANDARD 30-DEGREE SHIFT DELTA-WYE