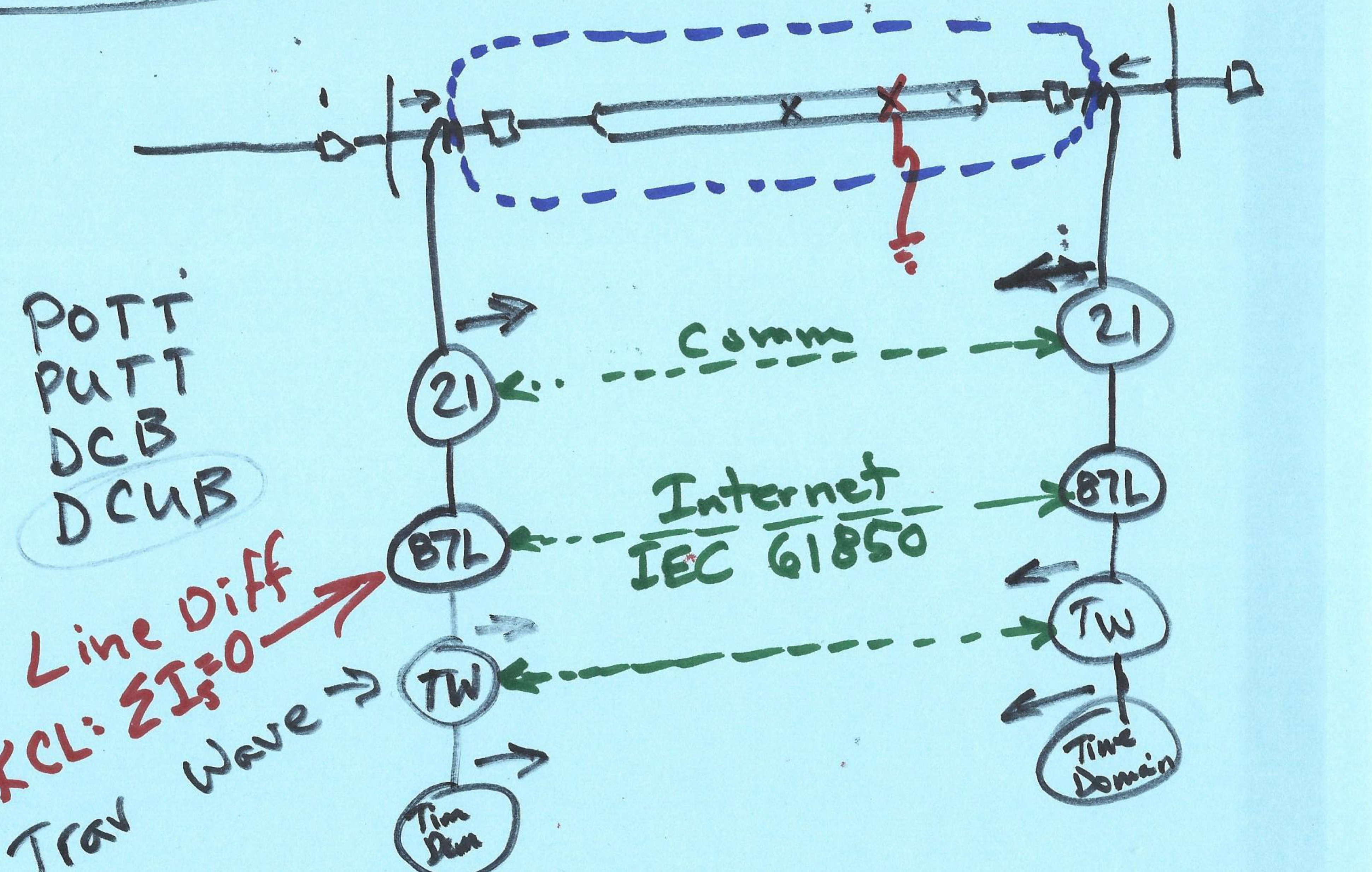
EE 5223 - Lecture 21 Fri Feb 24, 2023

Ongoing List of Topics:

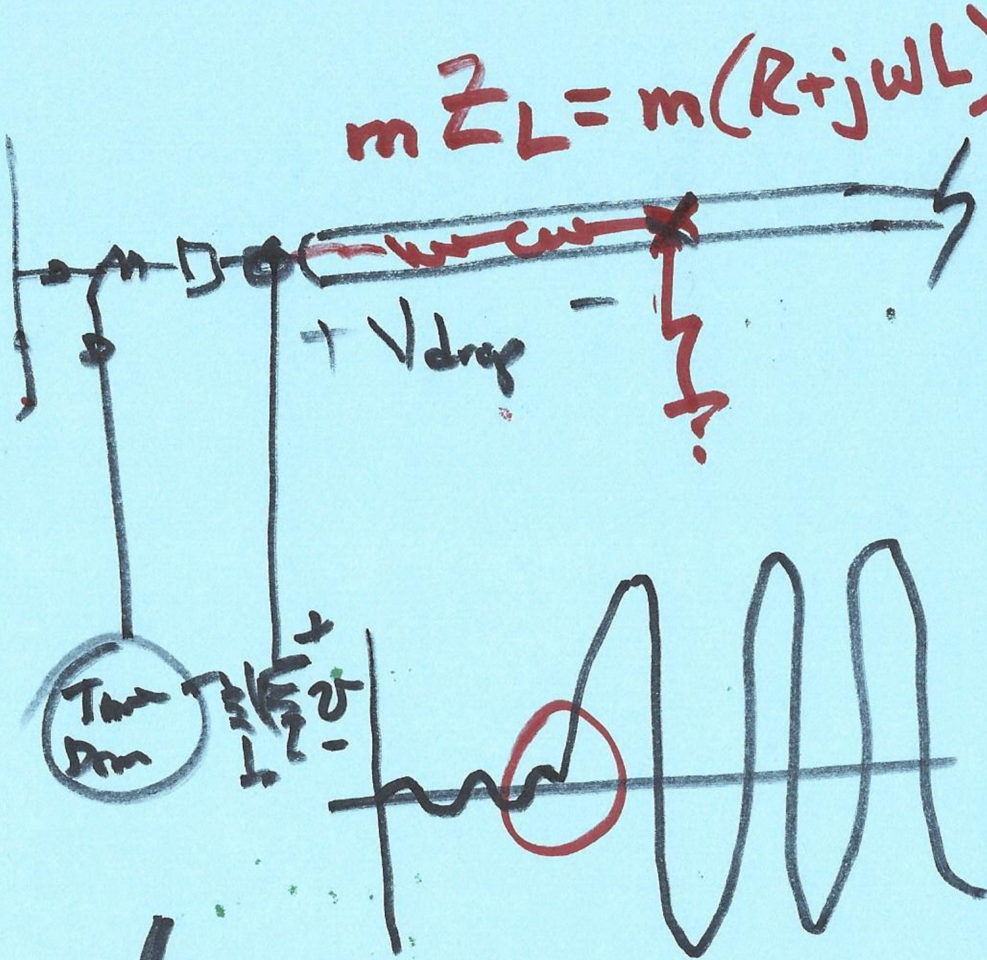
- URL: https://pages.mtu.edu/~bamork/EE5223/
- Term Project - Be sure that work plan has all team members contributing - both technical and non-technical!
- Sequence networks and fault calcs for 2-winding transformers
- Symmetrical Components overview issues for today.
  - Sequence networks, 3-winding transformers, §4.14, Prob 4.4.
- Protection fundamentals (cont'd):
  - Distance relaying fundamentals: §6.5.6, §6.5.7
  - Observed vs actual Z: Three-terminal lines, series caps
  - Bus diff, xfmr diff, synch check, capacitor banks, generators, motors, etc. (take a quick run through Ch.6, also Glover & Sarma, Ch.10).

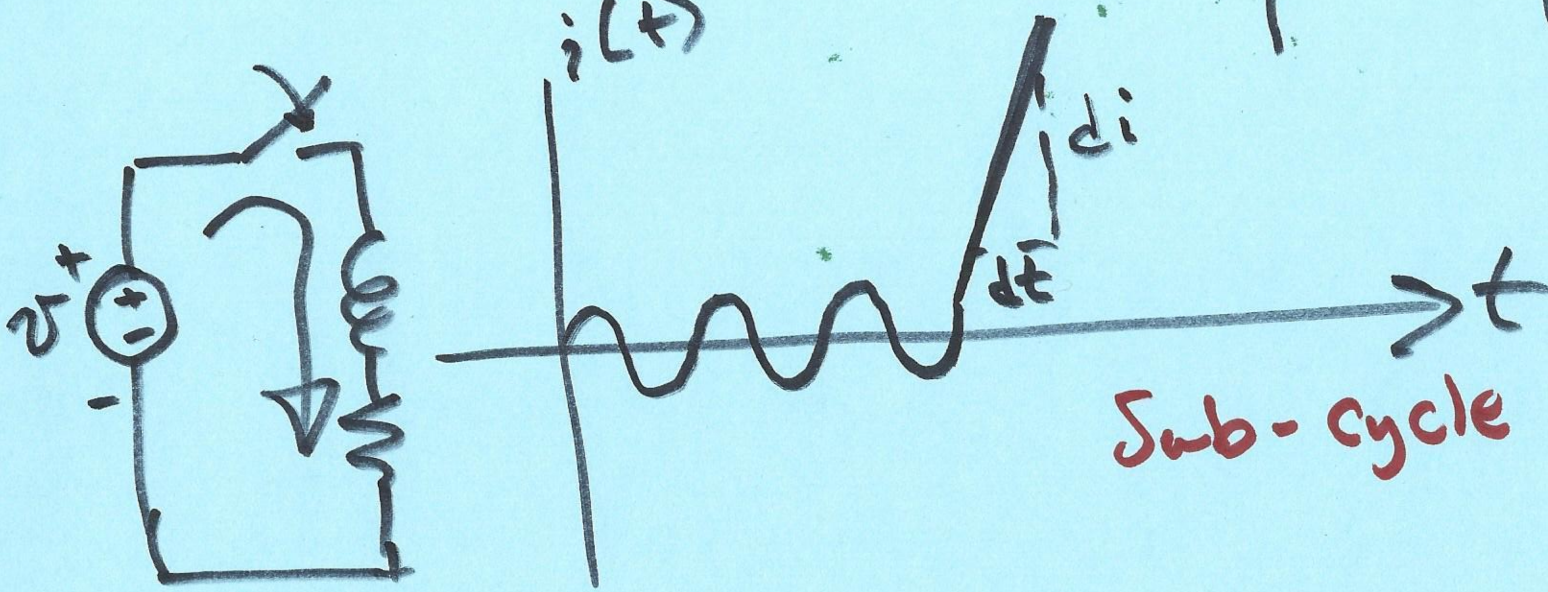
Line Protection



Time Domain

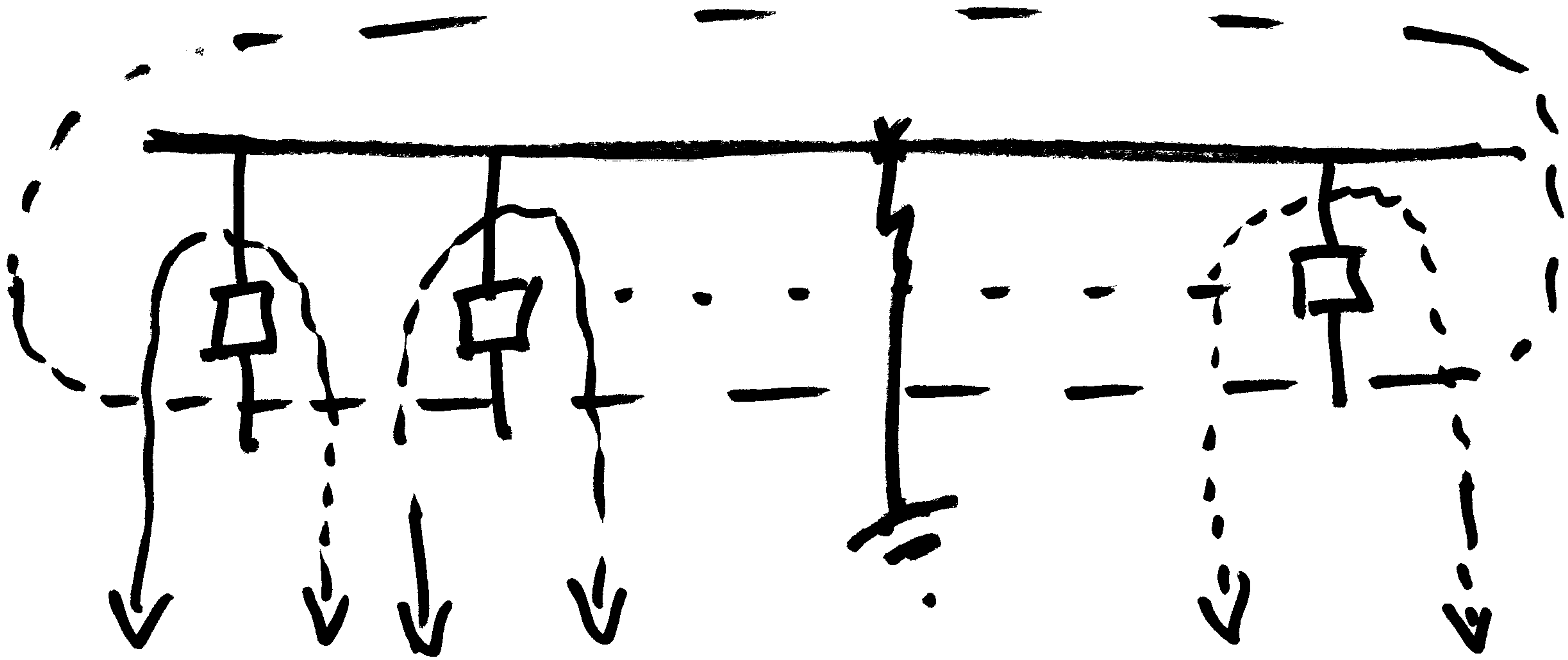
$$v = L \frac{di(t)}{dt}$$





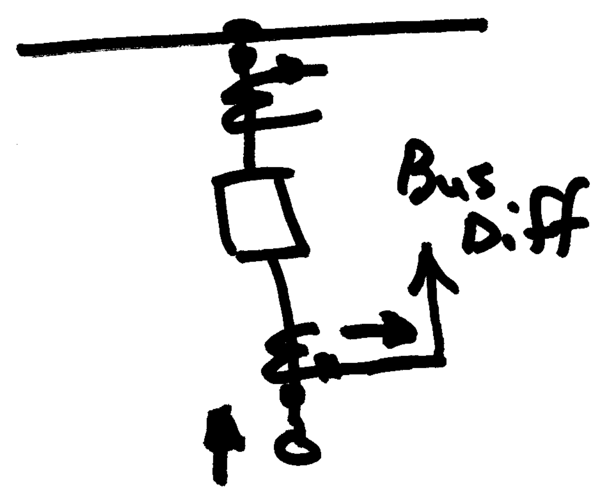
Sub-cycle detection.

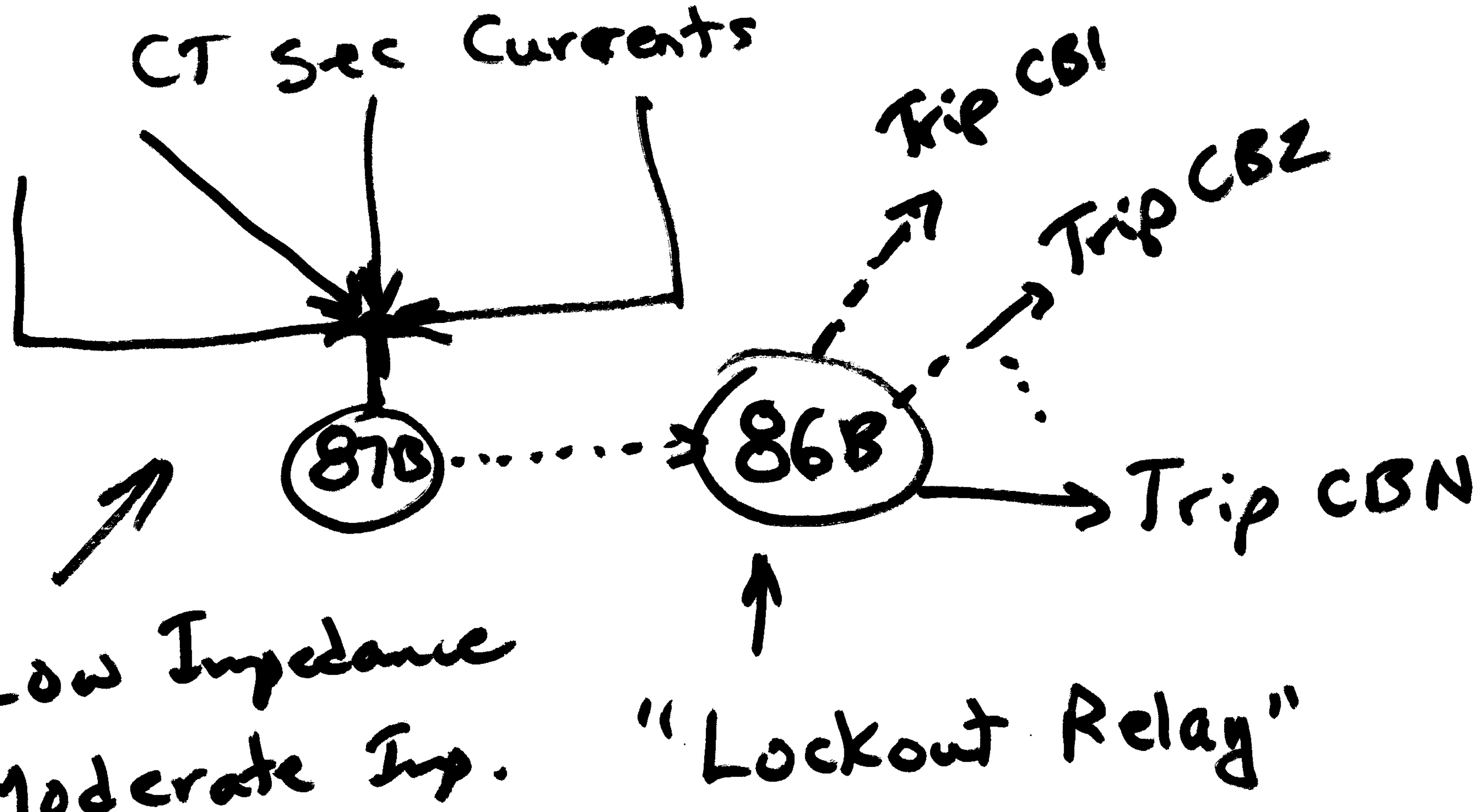
Bus Diff:



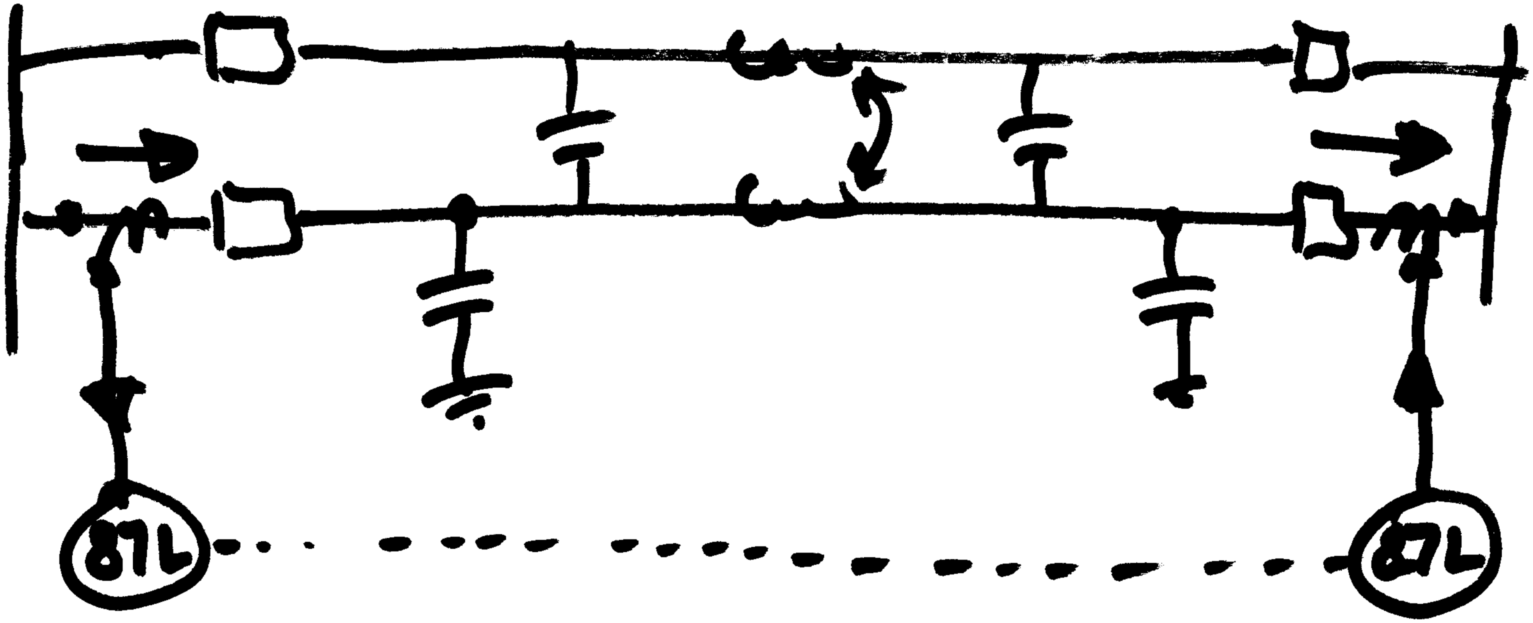
KCL: $\Sigma_{IN} I's = 0$

Trip if $\Sigma I_s > I_{pickup}$





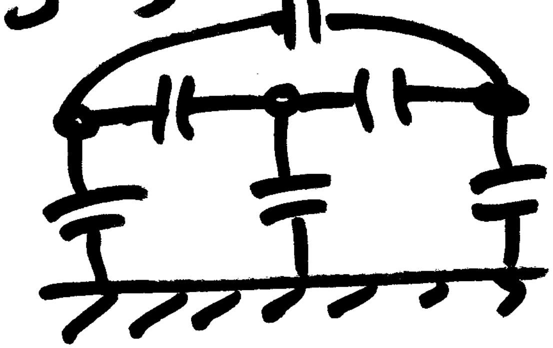
- Low Impedance
- Moderate Imp.
- High Impedance.



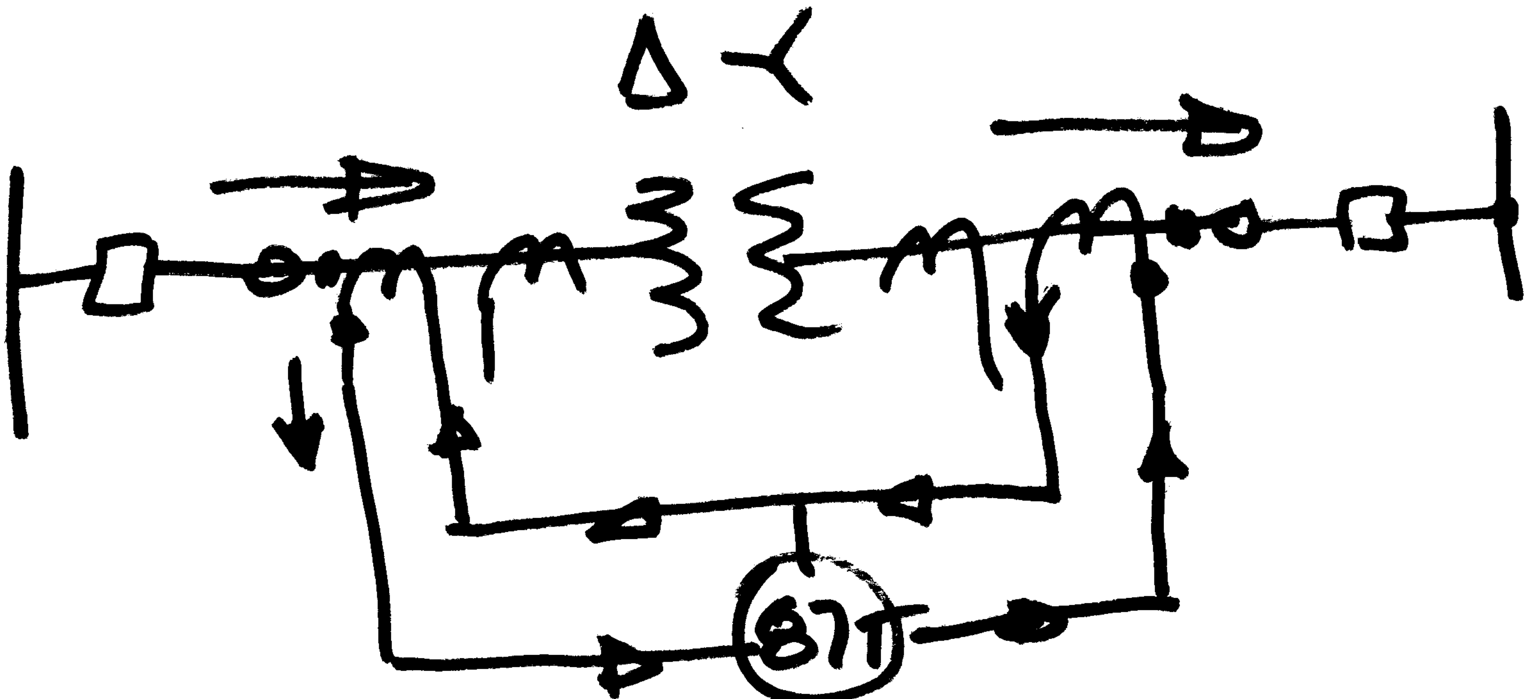
Complications:

- Shunt Cap (Line-Chging Current)
- Phase imbalance
- Parallel Lines

  ⋮



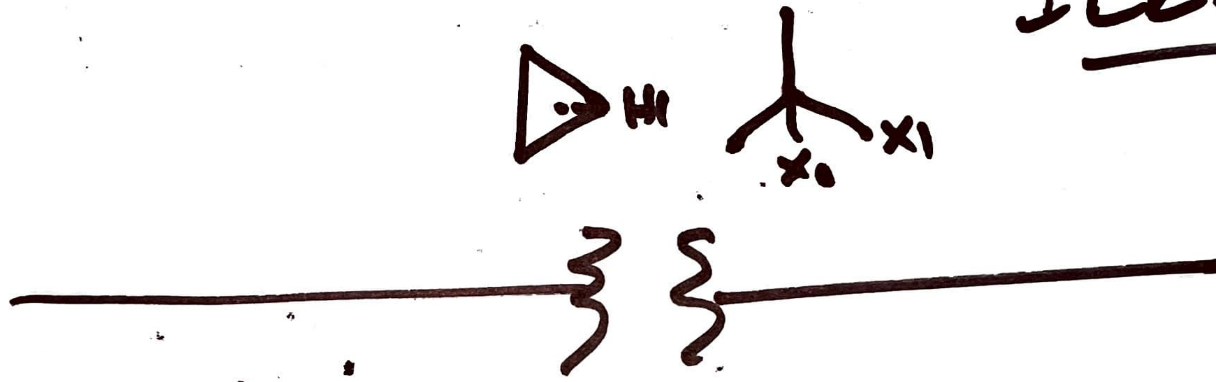
- Failure of Comm



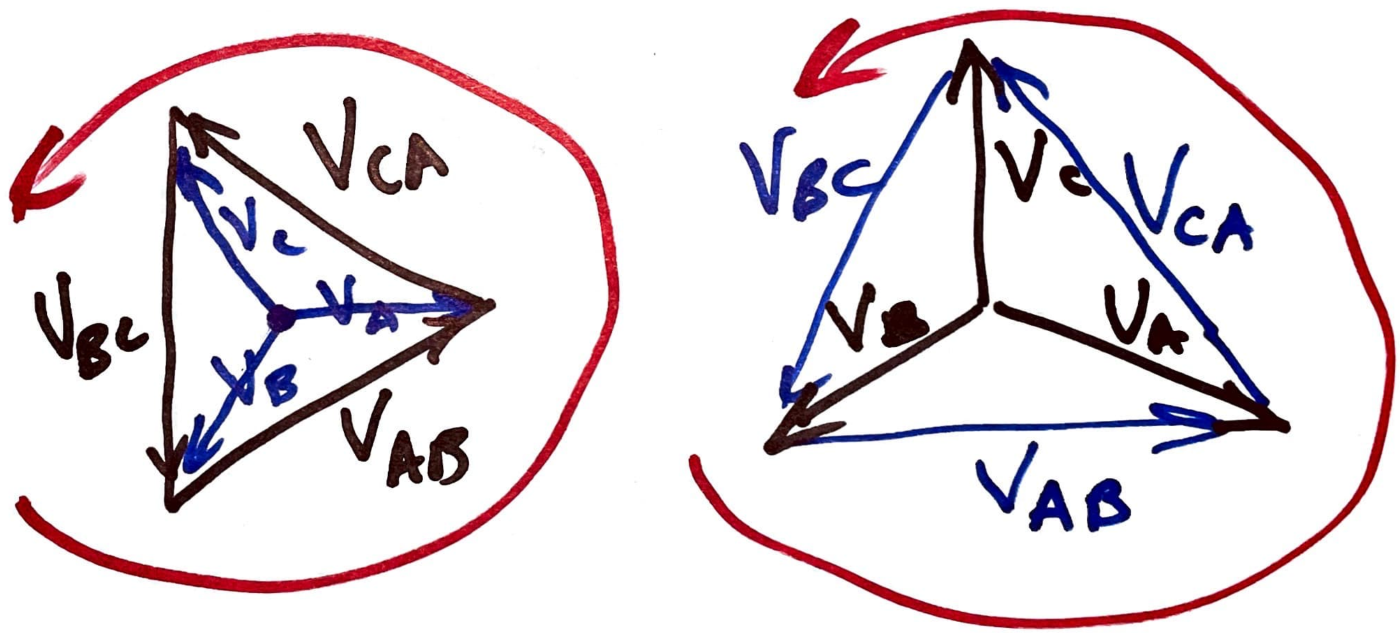
Complications / Details:

- Turns Ratio
- Phase Shift
- CT Ratios

IEEE Std.



H_1 leads X_1 by 30°



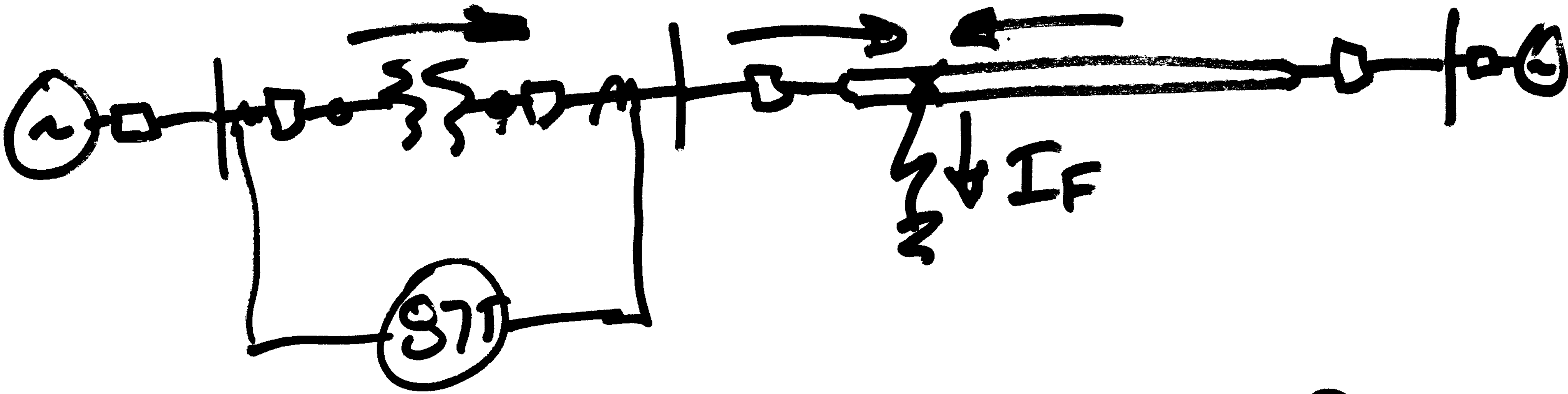
$$v = \frac{1}{\sqrt{\mu \varepsilon}}$$

$$= \frac{1}{\sqrt{\mu_r \mu_0 \varepsilon_r \varepsilon_0}} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = c$$

$\mu_r \to 1$, $\varepsilon_r \to 1$

Glass

$$v = \frac{1}{\sqrt{\mu_0 \varepsilon_r \varepsilon_0}} = \underline{\underline{65\% \, c}}$$



- Avoid false trip due to thru-fault or to normal load current.

"Through-Fault"

associated system. The wye point has no physical meaning. Quite often, one of the values will be negative and should be used as such in the network. It does not represent a capacitor.

The positive- and negative-sequence connections are all the same and independent of the actual bank connections. However, the connections for the zero-sequence network are all different and depend on the transformer bank connections. If the neutrals are solidly grounded, then the Z_N and $3Z_N$ components shown are shorted-out in the system and sequence circuits.

Find

APPENDIX 4.3 SEQUENCE PHASE SHIFTS THROUGH WYE–DELTA TRANSFORMER BANKS

As has been indicated, positive and negative sequences pass through the transformer bank, and in the sequence networks, the impedance is the same independently of the bank connection. This is shown in Figs. A4.2-1 and A4.2-3. In these networks the phase shift is ignored, but if currents and voltages are transferred from one side of the transformer bank to the other, these phase shifts must be taken into account. This appendix will document these relations. For this the standard ANSI connections are shown in Fig. A4.3-1.

From Fig. A4.3-1a, all quantities are phase-to-neutral values, and in amperes or volts; for per unit, $N = 1$, $n = 1/\sqrt{3}$.

$$I_A = n(I_a - I_c) \quad \text{and} \quad V_a = n(V_A - V_B)$$

For positive sequence [see Eq. (4.2)],

$$I_{A1} = n(I_{a1} - aI_{a1}) = n(1 - a)I_{a1} \tag{A4.3-1}$$
$$= \sqrt{3}nI_{a1}\angle{-30^\circ} = NI_{a1}\angle{-30^\circ}$$
$$V_{a1} = n(V_{A1} - a^2V_{A1}) = n(1 - a^2)V_{A1} \tag{A4.3-2}$$
$$= \sqrt{3}nV_{A1}\angle{+30^\circ} = NV_{A1}\angle{+30^\circ}$$

For negative sequence [see Eq. (4.3)],

$$I_{A2} = n(I_{a1} - a^2I_{a1}) = n(1 - a^2)I_{a2} \tag{A4.3-3}$$
$$= \sqrt{3}nI_{a2}\angle{+30^\circ} = NI_{a2}\angle{+30^\circ}$$
$$V_{a2} = n(V_{A2} - aV_{A2}) = n(1 - a)V_{A2} \tag{A4.3-4}$$
$$= \sqrt{3}nV_{A2}\angle{-30^\circ} = NV_{A2}\angle{-30^\circ} \tag{A4.3-5}$$

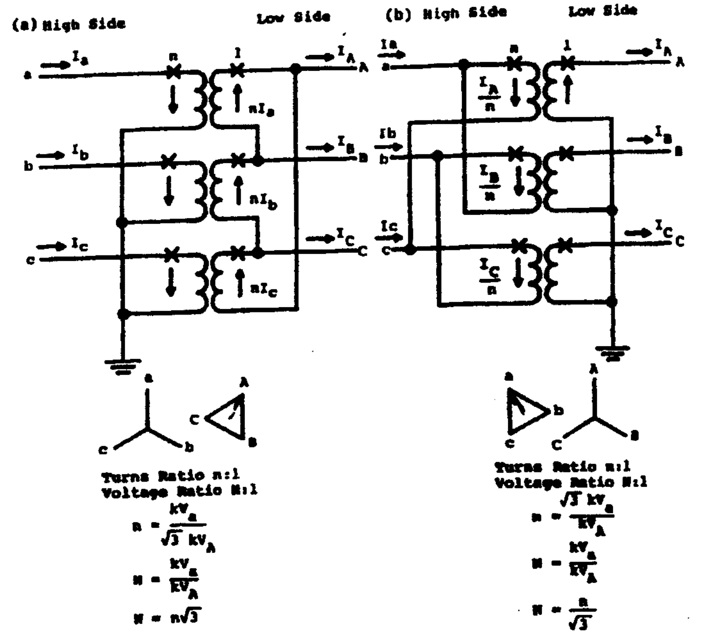


FIGURE A4.3-1 ANSI-connected wye–delta transformer banks: The high-voltage side phase a leads the low-voltage side phase a for both connections illustrated: (a) wye (star) on high side; (b) delta on high side.

Now consider the connections in Fig. A4.3-1b. Again all values are in phase-to-neutral amperes or volts; for per unit, $N = 1$, $n = \sqrt{3}$.

$$I_a = \frac{1}{n}(I_A - I_B) \quad \text{and} \quad V_A = \frac{1}{n}(V_a - V_c)$$

For positive sequence [see Eq. (4.2)],

$$I_{a1} = \frac{1}{n}(I_{A1} - a^2I_{A1}) = \frac{1}{n}(1 - a^2)I_{A1} \tag{A4.3-6}$$
$$= \frac{\sqrt{3}}{n}I_{A1}\angle{+30^\circ} = \frac{1}{N}I_{A1}\angle{+30^\circ}$$

$$V_{A1} = \frac{1}{n}(V_{a1} - aV_{a1}) = \frac{1}{n}(1 - a)V_{a1} \tag{A4.3-7}$$

$$= \frac{\sqrt{3}}{n} V_{a1}\angle{-30^\circ} = \frac{1}{N} V_{a1}\angle{-30^\circ}$$

For negative sequence [see Eq. (4.3)],

$$I_{a2} = \frac{1}{n}(I_{A2} - aI_{A2}) = \frac{1}{n}(1 - a)I_{A2} \tag{A4.3-8}$$

$$= \frac{\sqrt{3}}{n} I_{A2}\angle{-30^\circ} = \frac{1}{N} I_{A2}\angle{-30^\circ}$$

$$V_{A2} = \frac{1}{n}(V_{a2} - a^2V_{a2}) = \frac{1}{n}(1 - a^2)V_{a2} \tag{A4.3-9}$$

$$= \frac{\sqrt{3}}{n} V_{a2}\angle{+30^\circ} = \frac{1}{N} V_{a2}\angle{+30^\circ}$$

Summary

An examination of the foregoing equations shows that for ANSI standard connected wye–delta transformer banks: (1) if both the positive-sequence current and voltage on one side lead the positive-sequence current and voltage on the other side by 30°, the negative-sequence current and voltage correspondingly will both lag by 30°; and (2) similarly, if the positive-sequence quantities lag in passing through the bank, the negative-sequence quantities correspondingly will lead 30°. This fundamental is useful in transferring currents and voltages through these banks.

Zero sequence is not phase-shifted *if* it can pass through and flow in the transformer bank. The zero-sequence circuits for various transformer banks are shown in Figs. A4.2-1 and A4.2-3.

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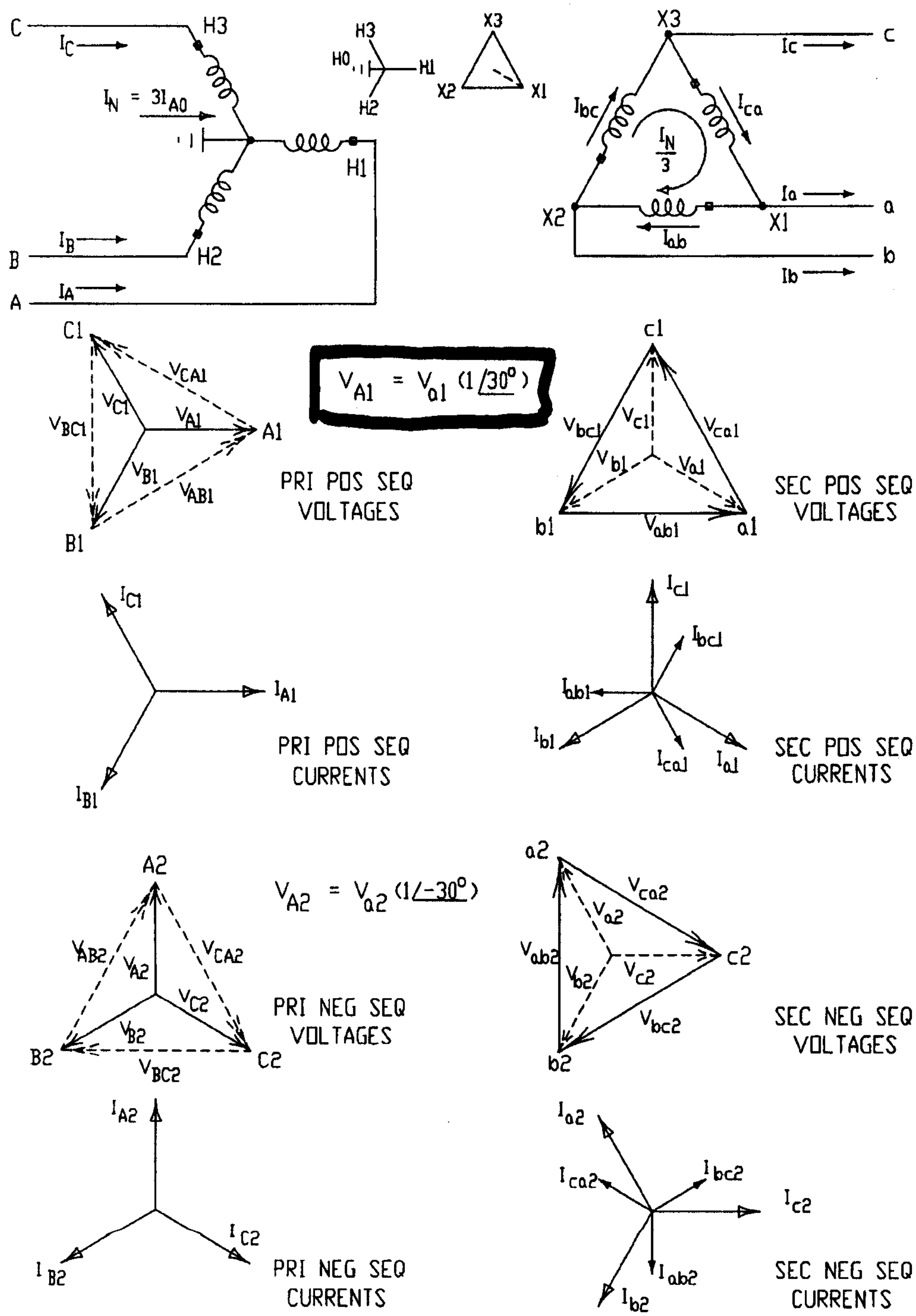

ANSI STANDARD 30-DEGREE SHIFT WYE-DELTA

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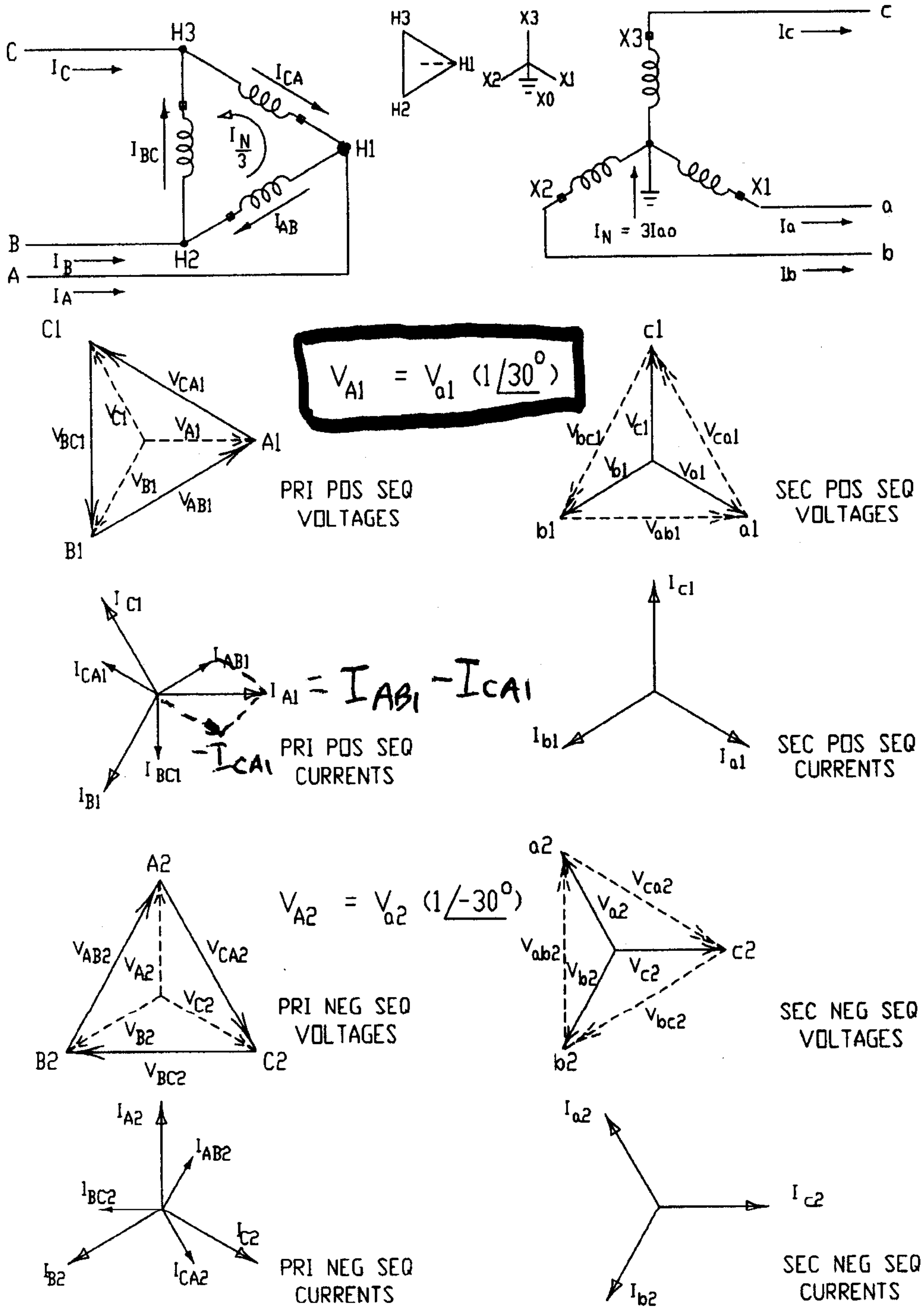

ANSI STANDARD 30-DEGREE SHIFT DELTA-WYE

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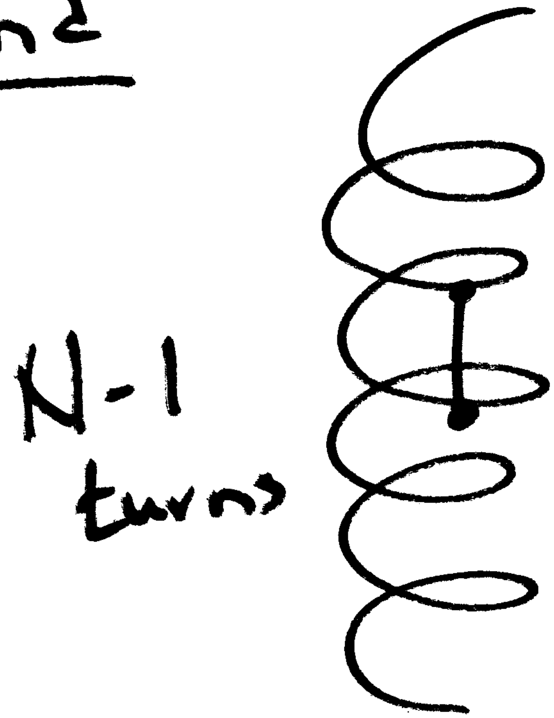

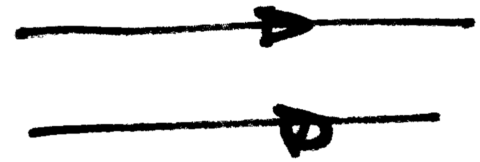

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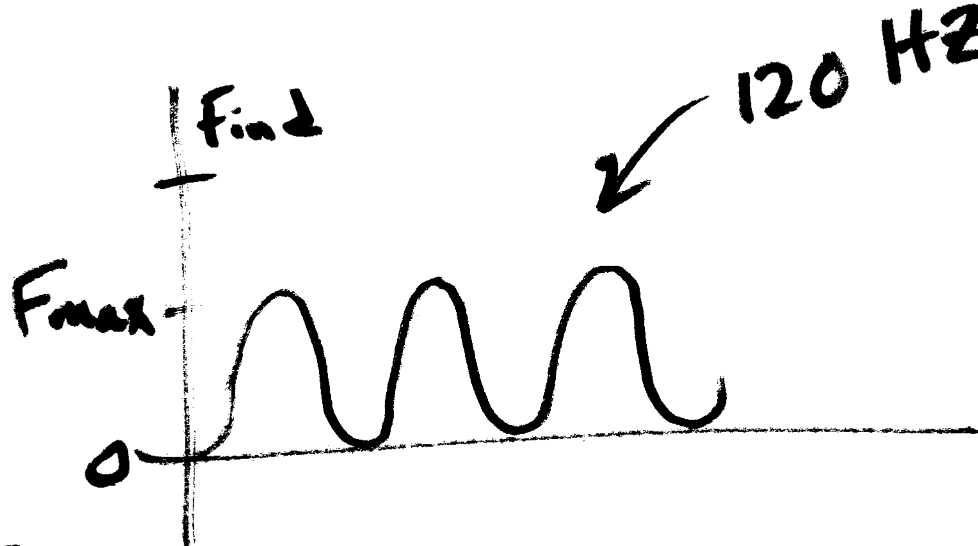

- turn-turn faults
- Layer-layer faults
- Coil-core faults
- Coil-tank faults