EE 5223 - Lecture 40 Monday April 17, 2023

Ongoing List of Topics:

- URL: https://pages.mtu.edu/~bamork/EE5223/index.htm
- Term Project - last few proj/teams need to submit draft report for comment.
    - Follow timeline, see posting on web page (posted in week 5)
    - Reports due Mon noon – get/keep cranking...
- Homework - example problem on Cap Bank configuration & protection
    - Spreadsheet capbank.xls should solve most all of it.
- Note on D/A inputs to relays - can use 87T relay for Cap Bank voltage diff
- Gen Protection - Ch. 8, Basic Protection issues
    - IEEE Publication 95TP102 - Prot of Synch Gens
    - IEEE C37.102 - Guide for AC Generator Protection
    - IEEE C37.101, C37.106 - Ground Protection, Abnormal Freq Protection
    - Grounding Issues
    - Notes from adjunct faculty, example
    - Out-of-step issues - see also Kundur's text
- Motor Protection
- SCADA, Event Recorders, transducers
- Real-time Communications for protection & control
- Smart Grid

Followup on Safety from last Friday's Lecture 39:

Here are photos of the CT "shorting blocks" that were discussed.

The brass screws in the corners are inserted in the shorting strip in the center. Then the downstream relays can be removed w/o interrupting current flow in the CT secondaries.

Safety Issues

EE 5223
Spring 2021

We informally discuss safety issues throughout this course, eg. with high-impedance ground faults (typical of downed lines) we can look analytically at the issue, in terms of a) voltage gradient along the surface of the ground you are standing on, b) step potential, and c) touch potential.

On the following page, find a scanned version of our local utility's safety warnings issued to customers. Periodically there have been public service messages on TV, warning people to stay away from downed power lines. Now we know why, from an engineer's point of view. Another useful reference, from IEEE, is:

- *Downed Power Lines: Why They Can't Always be Detected*, IEEE Power Engineering Society, © February 22, 1989.

There are many safety issues that can be mentioned here, that you as power systems engineers should be aware of. Utilities, consultants, and contractors will make sure their employees take safety training before going out in the field, and comply with OSHA and other safety stds. ***Pay attention.*** Safety is not just for linemen, and you may need to direct electricians and linemen. Even 120-V ac circuits and 125-V dc circuits can be dangerous, and there are many potentially dangerous situations that you might not have thought of. A few examples are provided here. Engineering knowledge, basic safety training, and common sense provide most of the needed understanding and confidence. Never get lax. A line-man told me that accidents tend to occur to rookies who don't know better and to veterans who get lax.

- If possible, always make wiring changes in CT secondary circuits when the circuit is de-energized. If you temporarily remove a hard-wired relay, meter, or transducer, you must first ALWAYS short out the upstream CT leads before re-energizing the circuit. If you must make a live change, ALWAYS place an upstream short on the CT before disconnecting/changing any downstream leads. NEVER open-circuit a CT secondary when making live changes in relay connections or CT ratio. If you do, a potentially fatal high voltage will be induced at the open-circuited connections.
- When designing CT secondary circuits, a) ALWAYS provide a set of "shorting blocks" (special terminal blocks that can be used to short out the CTs), and b) ground the CT secondary circuit at ONE point, typically the neutral. Note that multiple grounds cause circulating ground currents and may result in misoperation of relays.
- Beware of step and touch potential hazards. Be observant of frayed or corroded equipment grounds – these can result in unsafe touch potentials. Do not touch or lean against any metallic equipment, structures, fences, or surfaces unless you need to. Never lean against a bucket truck whose outriggers are up.
- ALWAYS practice the one-hand rule. When taking voltage measurements, a practical procedure is to use an alligator lead on one of the meter leads, so you never have to hold both leads. Know in advance what voltage magnitude you expect to measure. Pay attention to your multi-meter function settings. A meter set for AMPS will be a short circuit and will initiate a fault. A coworker of mine did that on a 480-volt circuit. He was flash-blinded (temporary blindness) and badly burned his hands. Note that above 240 volts there may be enough energy to ionize an arc path through air – if you initiate a fault it will not be self-extinguishing!

Customer connection

JANUARY 2003

ENERGY NEWS

from Upper Peninsula Power Company

UPPCO

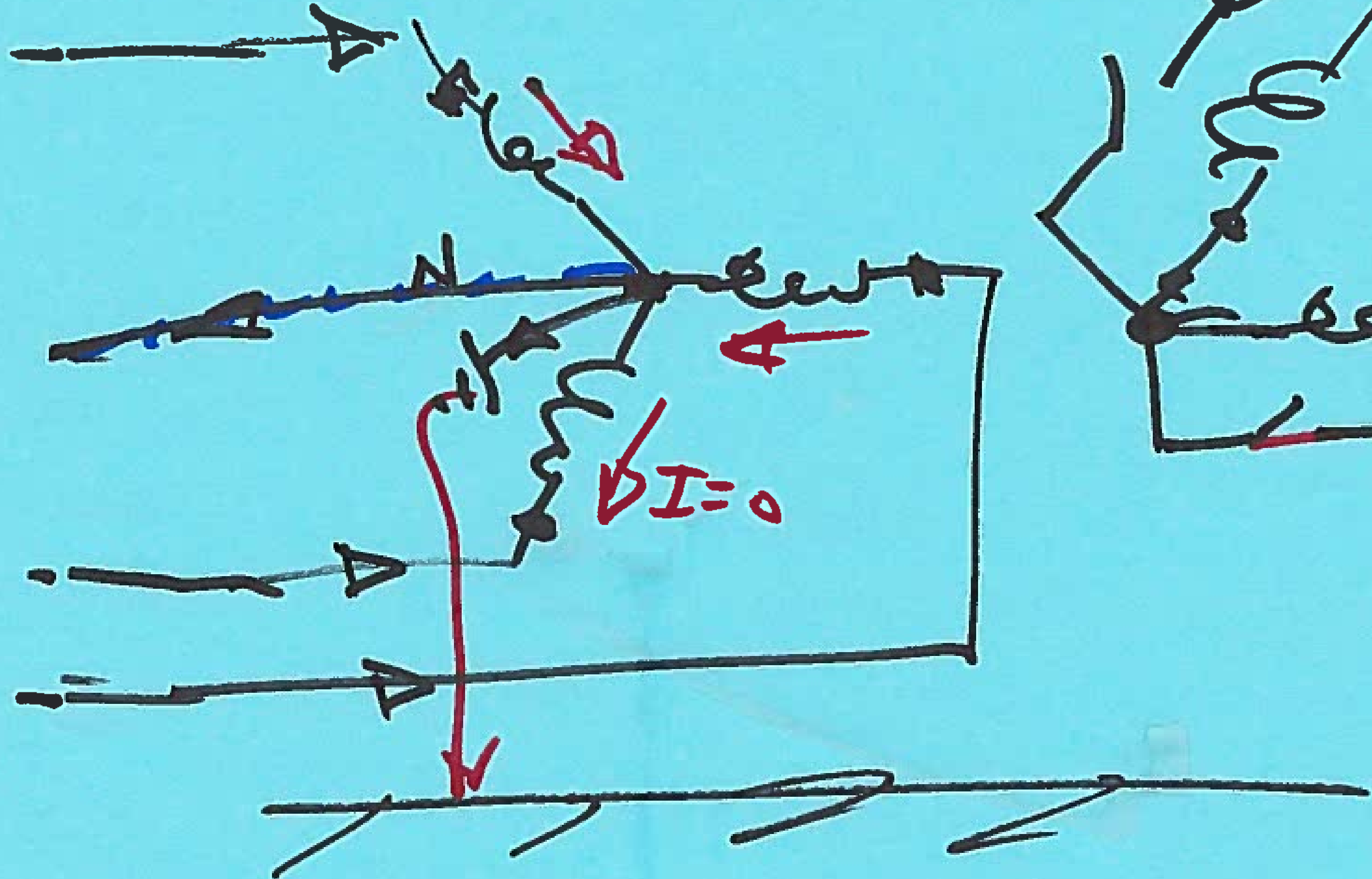
Winter 02/03

Downed Power Lines —

While they're normally a safe distance over our heads, power lines can be brought down by a variety of events. In the winter, heavy snow, ice or vehicles skidding into utility poles can bring high-voltage lines down to the ground where they can pose a threat. The one thing to remember about power lines, whether on the ground or high in the air, is that you should never make contact with a power line. It's too difficult to determine if power lines are energized just by looking at them.

Here are some things to keep in mind if you ever encounter a downed power line:

- **Never go near a downed power line!** It can still be energized, and making contact can cause severe injuries or even death.
- **Immediately report any fallen power line** by calling 911 (if your area has that service), your local law enforcement agency, or UPPCO's customer service at 1-800-562-7680 or electric emergency service at 1-800-562-7809. These numbers are in most Upper Michigan telephone directories.
- **Don't exit the vehicle if a power line should fall on it.** It's almost always safer to stay in the vehicle until the power company arrives and removes the wire. If you must abandon it because of fire or other life-threatening circumstances, jump out as far as possible without touching the car and the ground at the same time. Try to land with your feet together.
- **Warn others to stay away from the vehicle** if there's a downed line touching it. They could be electrocuted if they touch the vehicle, because they would create the path to ground the current is seeking.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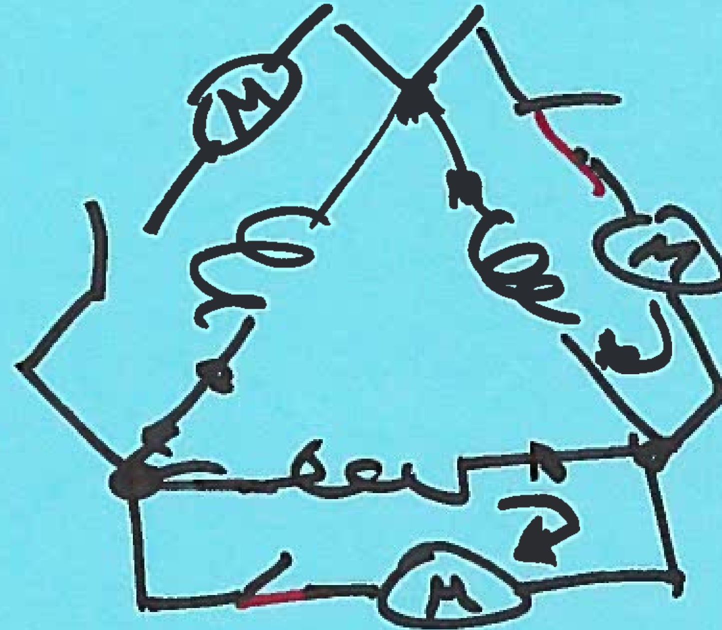
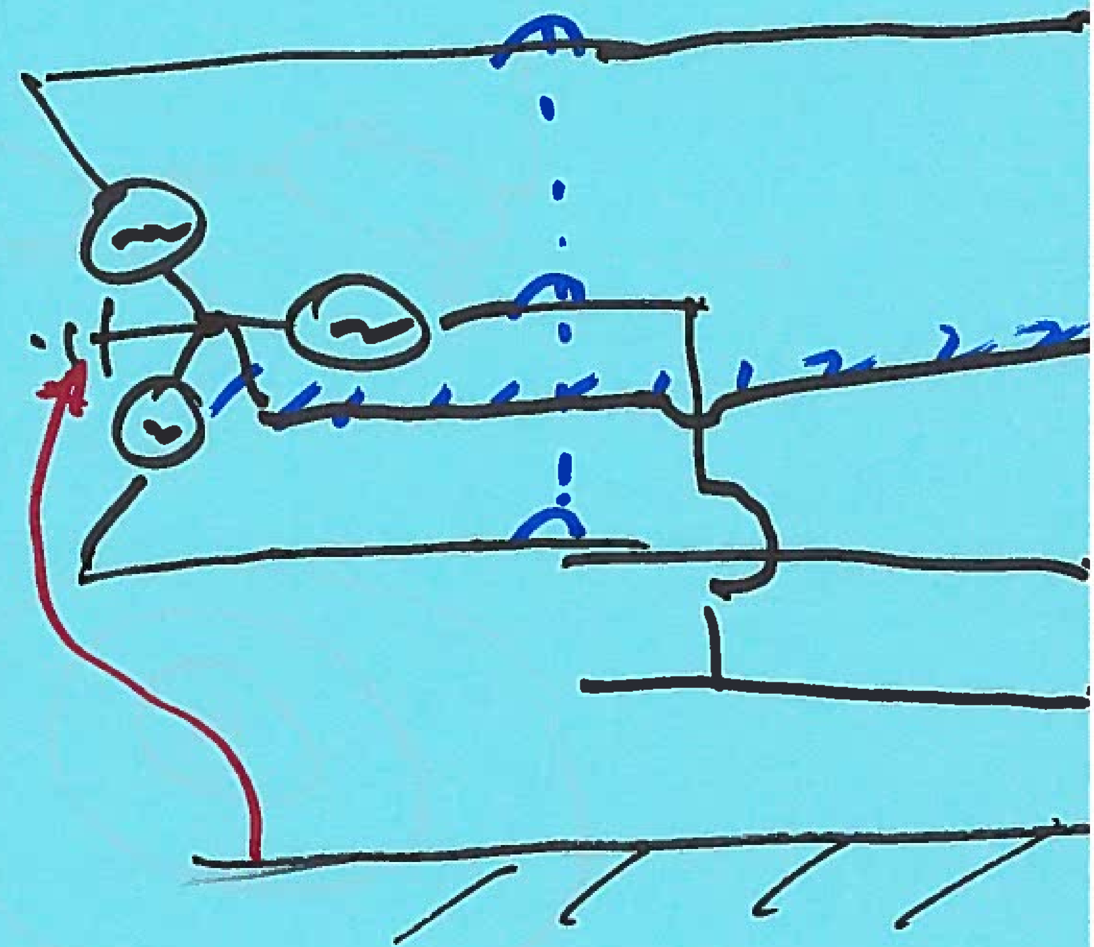
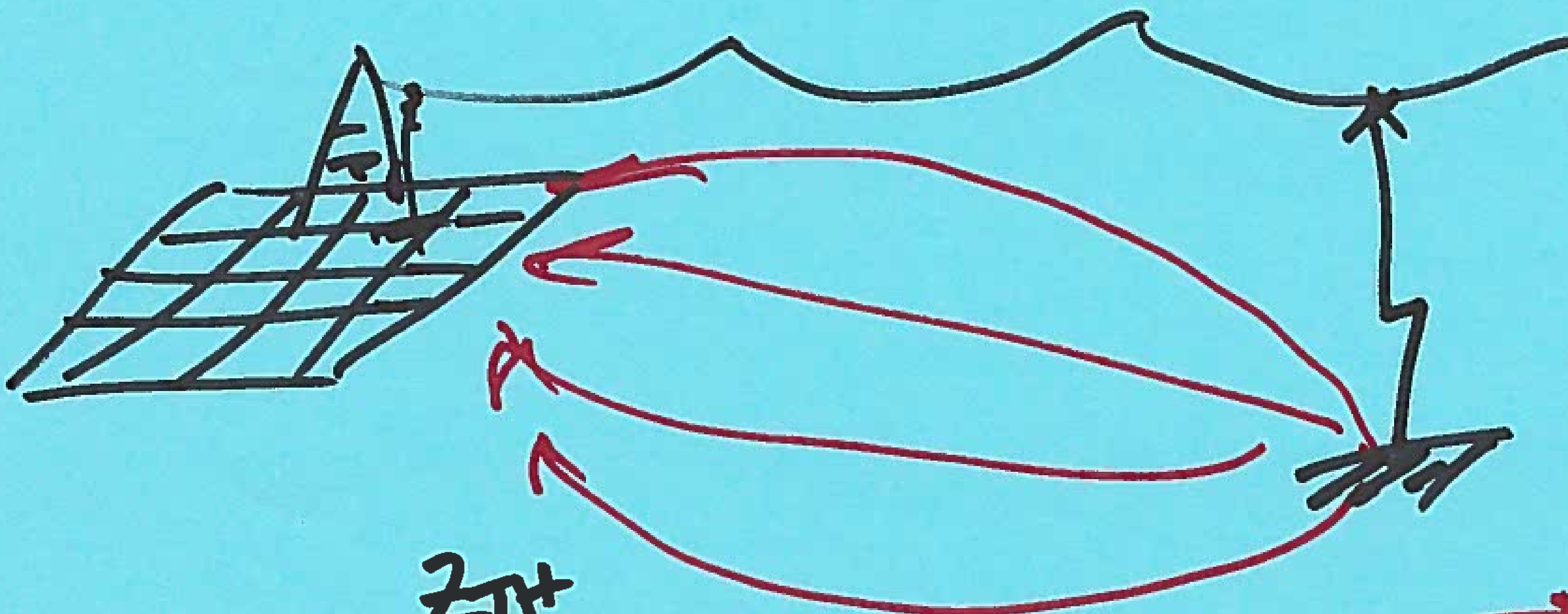
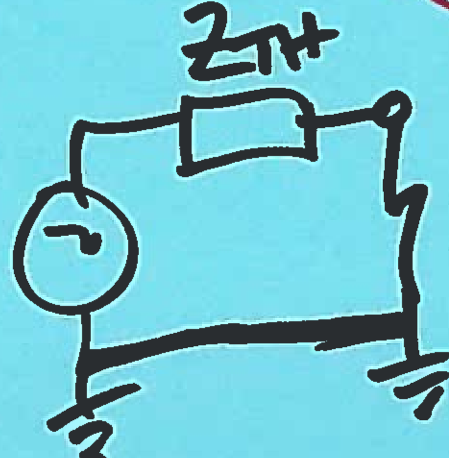
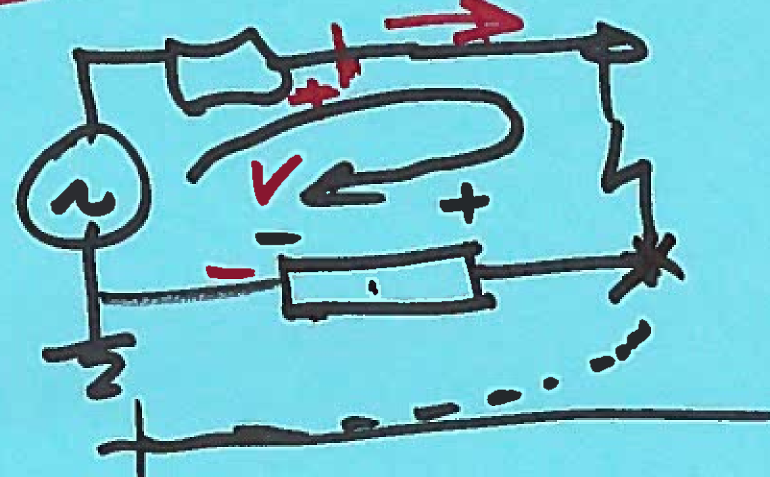


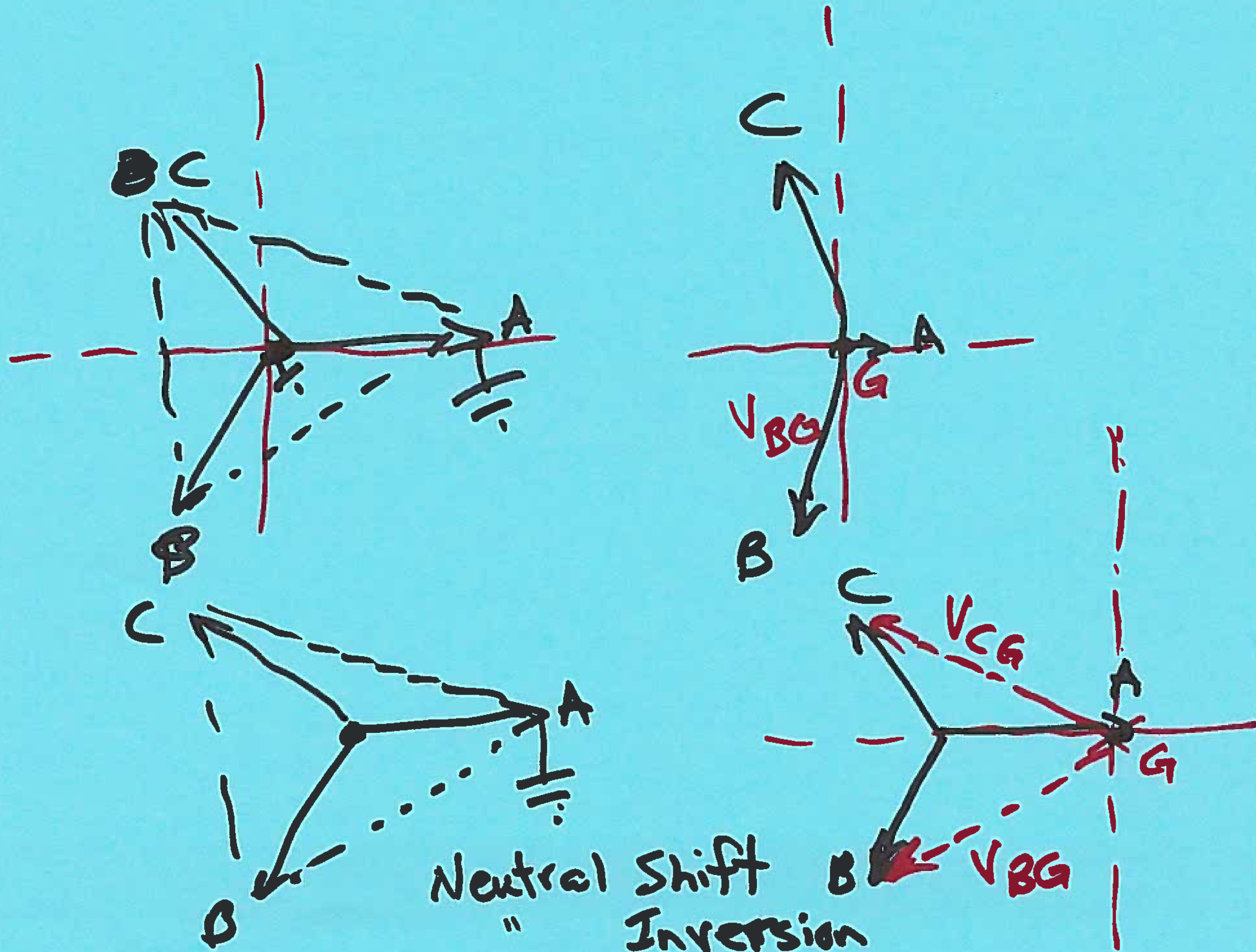


Ground Potential Rise









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V_{BG}
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C
V_{CG}
A
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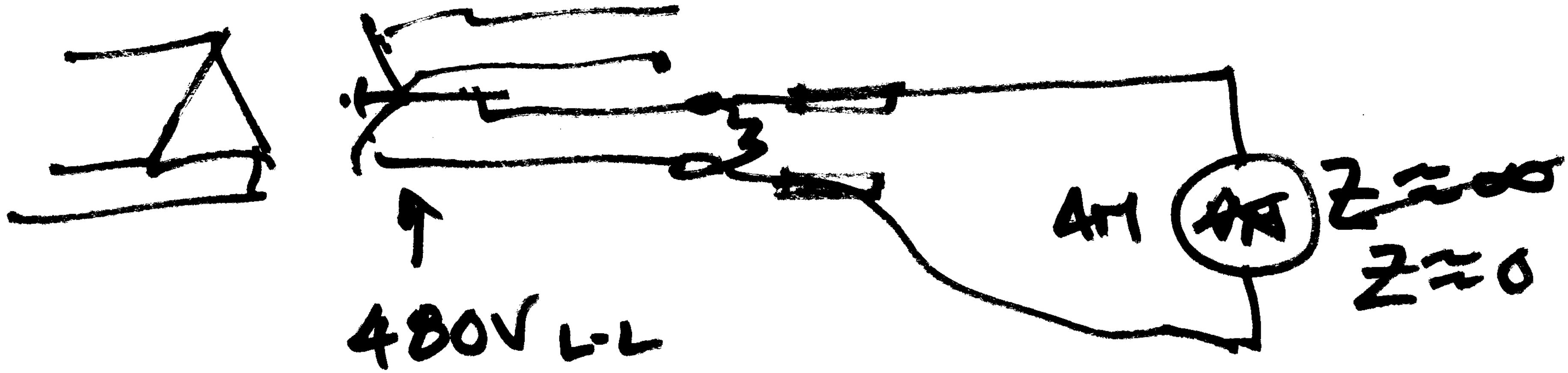
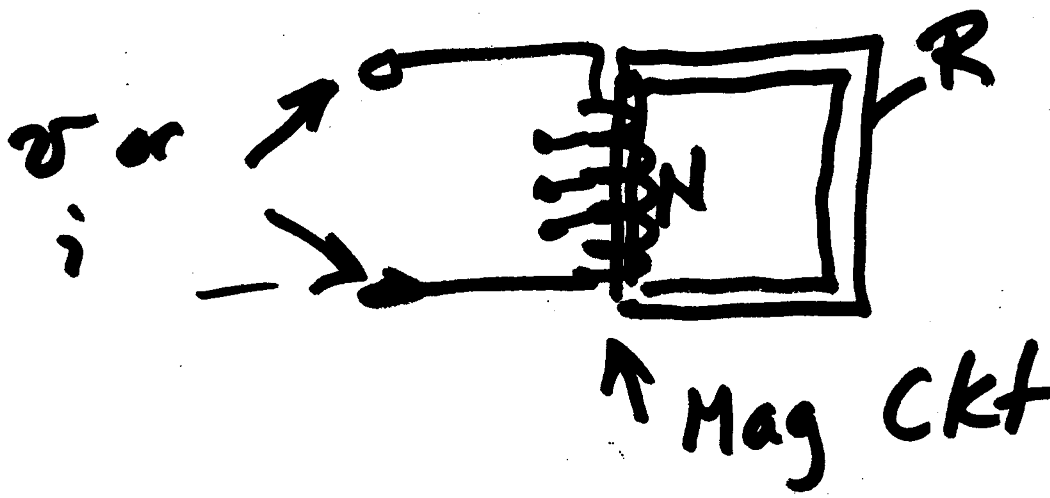
Neutral Shift
" Inversion



- Hurry
- Not using test techs/engrs
- Not paying attention
- Used both hands

Interface to uProc Relays

In old electro-mech relays



$$L = \frac{N^2}{R}$$

$$X = 2\pi L = 2\pi \frac{N^2}{R}$$

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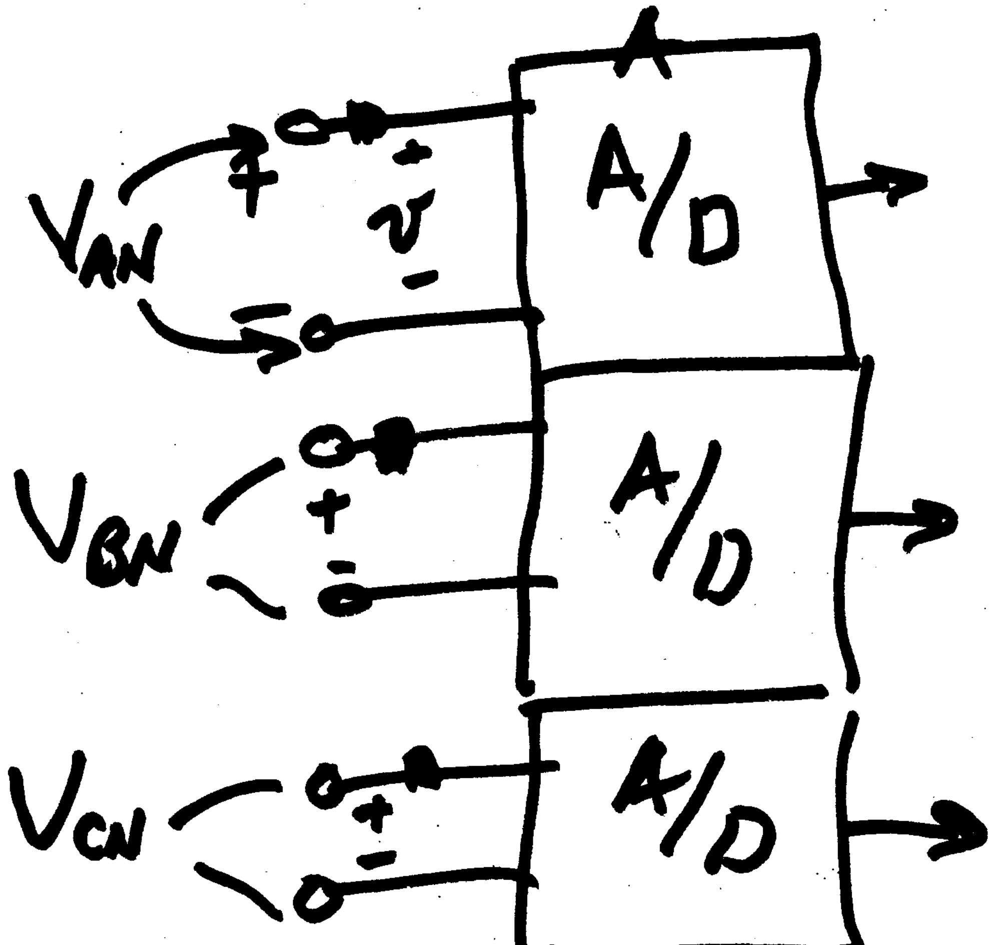
A/D Converters on input



Input: $v(t)$

Output: Binary nos, updated at each sample. (Typ: 4-8 times/cycle). (8-12 bits of resolution)

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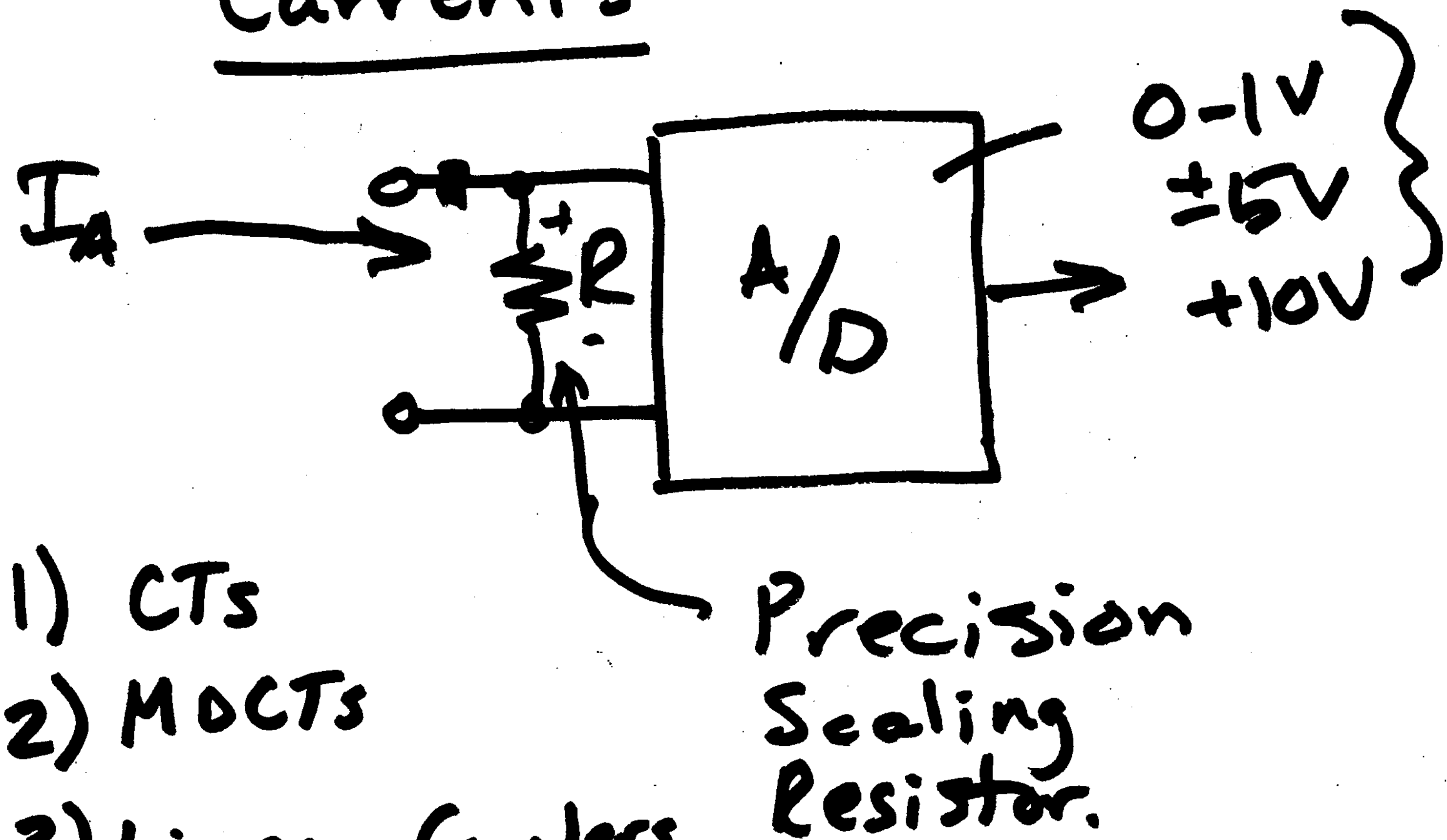
Currents:



1) CTs
2) MOCTs
3) Linear Couplers (Rogowski Coils)

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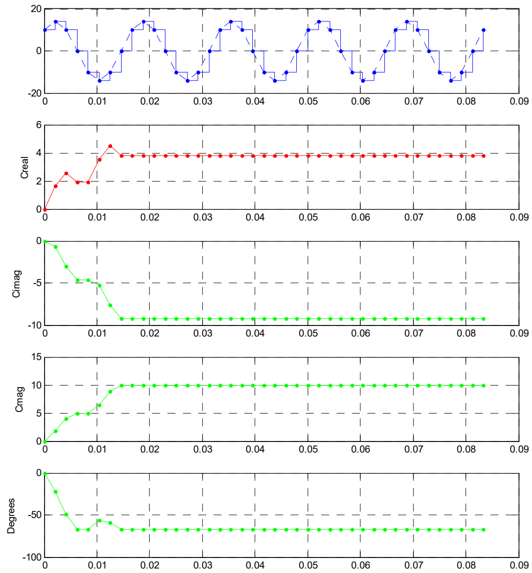
Moving Window DTFT



Fourier Transform

$$C_n = \frac{1}{T}\int_0^t f(t)e^{-j2\pi\frac{nt}{T}}dt$$

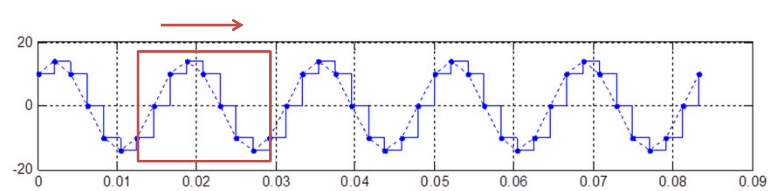
f(t) = waveform
n = harmonic (1 = fund)
T = period
C_n = Fourier coefficient

Numerical integration is done to solve for the desired C_n. Real-time performance is key.

Trapezoidal is accurate.
ZOH recursive is fastest.

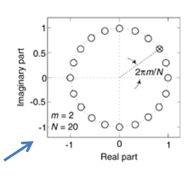
9

Implications of exponential term



$$C_n = \frac{1}{T}\int_0^t f(t)e^{-j2\pi\frac{nt}{T}}dt$$

"Multiplier"



As newest point enters window, oldest point drops out.
But the multiplier for each point changes as the window moves forward, so the entire window must be recalculated in the numerical integration.
A recursive method allows multiplier to be fixed to each point, making real-time performance much faster, i.e. use running summation.

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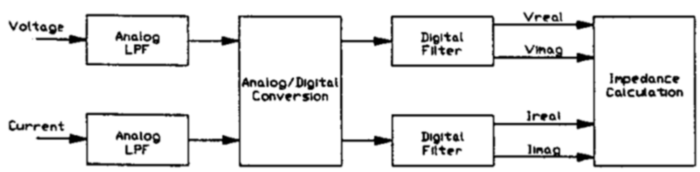
Examples of Usage

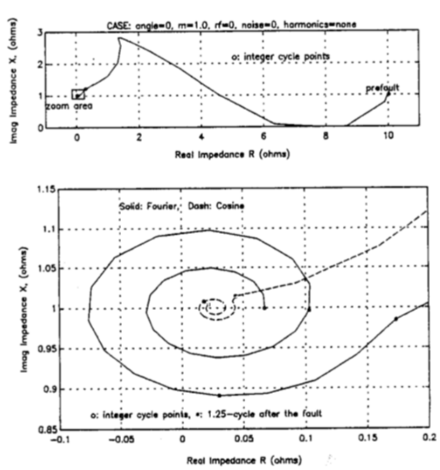
- **Impedance Relay**



- **Issues:**
  - **Sampling rate**
  - **A/D resolution and dynamic range**
  - **Real-time performance**

11

Filter response



Ref: Filtering Requirements for Distance Relays, 1993 APC.

- Pre-fault operating point on R-X plane is a very high impedance at near-unity PF (load current at rated voltage).
- Filter trajectory and response (settling time) are important.

12

Implications

- Fourier filter is most basic type of filter used. Others*:
  - Walsh CAL, SAL
  - Cosine, Sine
  - Half-cycle Cosine
  - Kalman
- Voltage and current waveforms can then be converted to their phasor values.

- PMU = Phasor Measurement Unit, a device that produces $\tilde{V}$(t) and $\tilde{I}$(t) and shares digitally.
- Sampling may be 8, 16, 48, 80 times per cycle.
- Merging unit includes PMU and also sampled values (SV).

- https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=515273
- https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=270548

The zero sequence network for this is also shown in Fig. 7.15.

When a delta-connected transformer exists, or a system-neutral is unavailable, this type of grounding can be accomplished either by a shunt connection of a wye-grounded–delta or by a zigzag transformer. The wye-grounded–delta transformer could be applied only for grounding purposes and not for transmitting power. The grounding would be as just indicated and shown in Fig. 7.15.

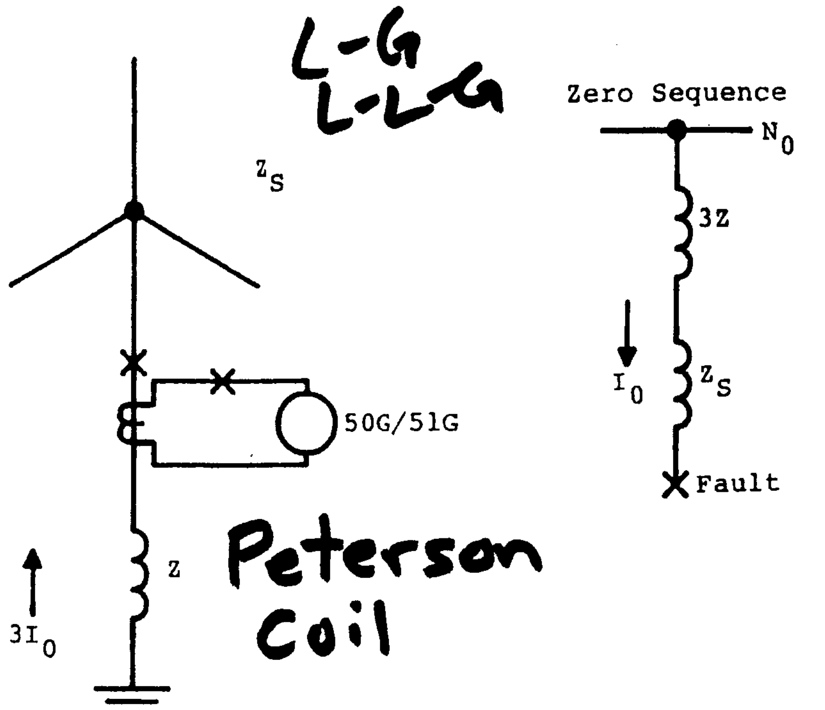


FIGURE 7.15 Low-impedance grounding with impedance in the system neutral.

FIGURE 7.16 Lc
transformer.

The zigzaş
consists of three
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$I_{c0} = I_0$, zero-sec
currents cannot
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With a line-to-r
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7.7.1 Exam React

The grounding
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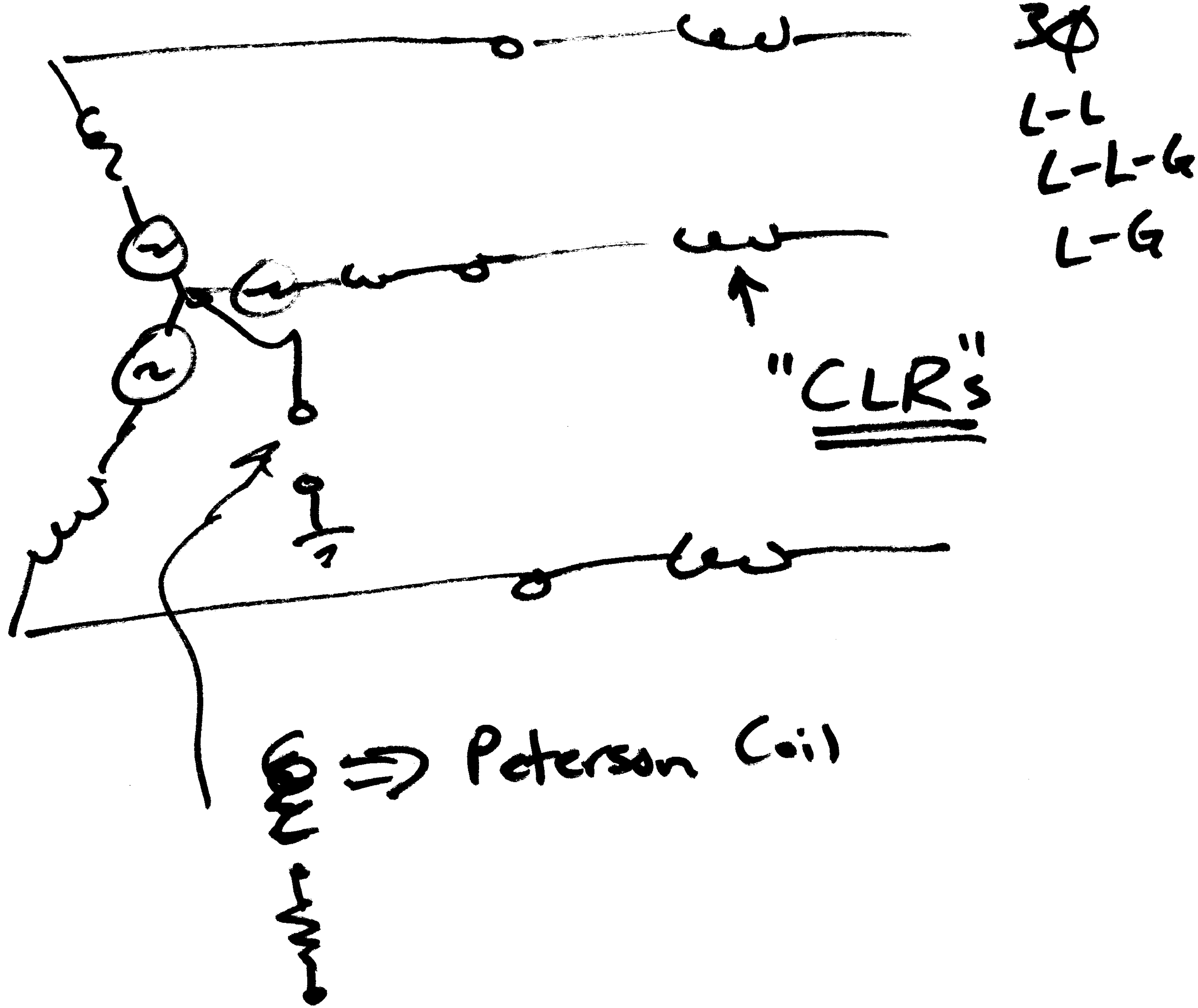
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L-L
L-L-G
L-G
"CLR's"
⇒ Peterson Coil

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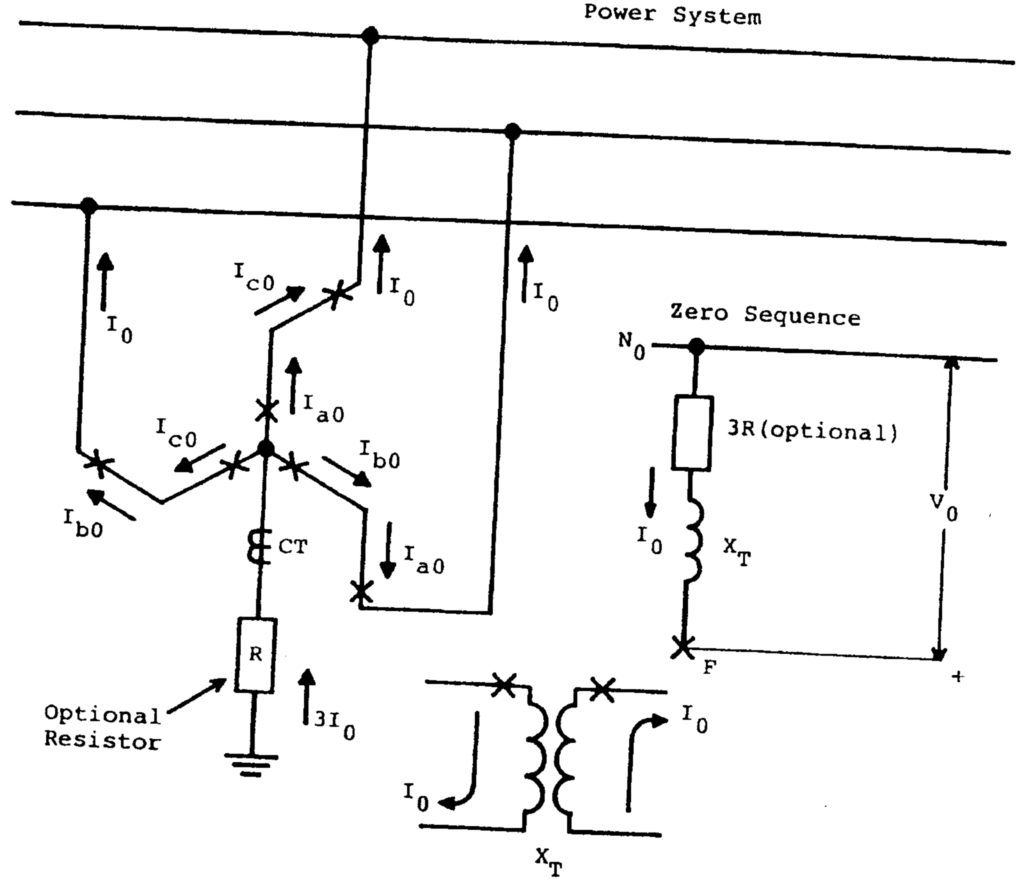
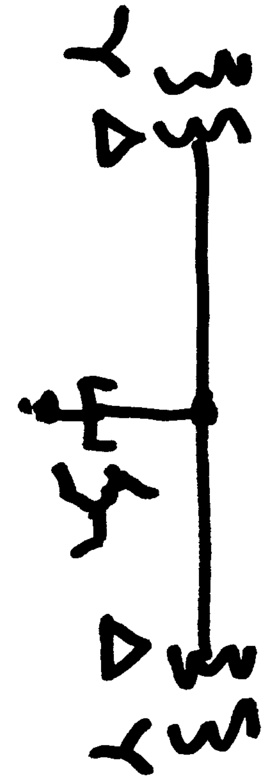
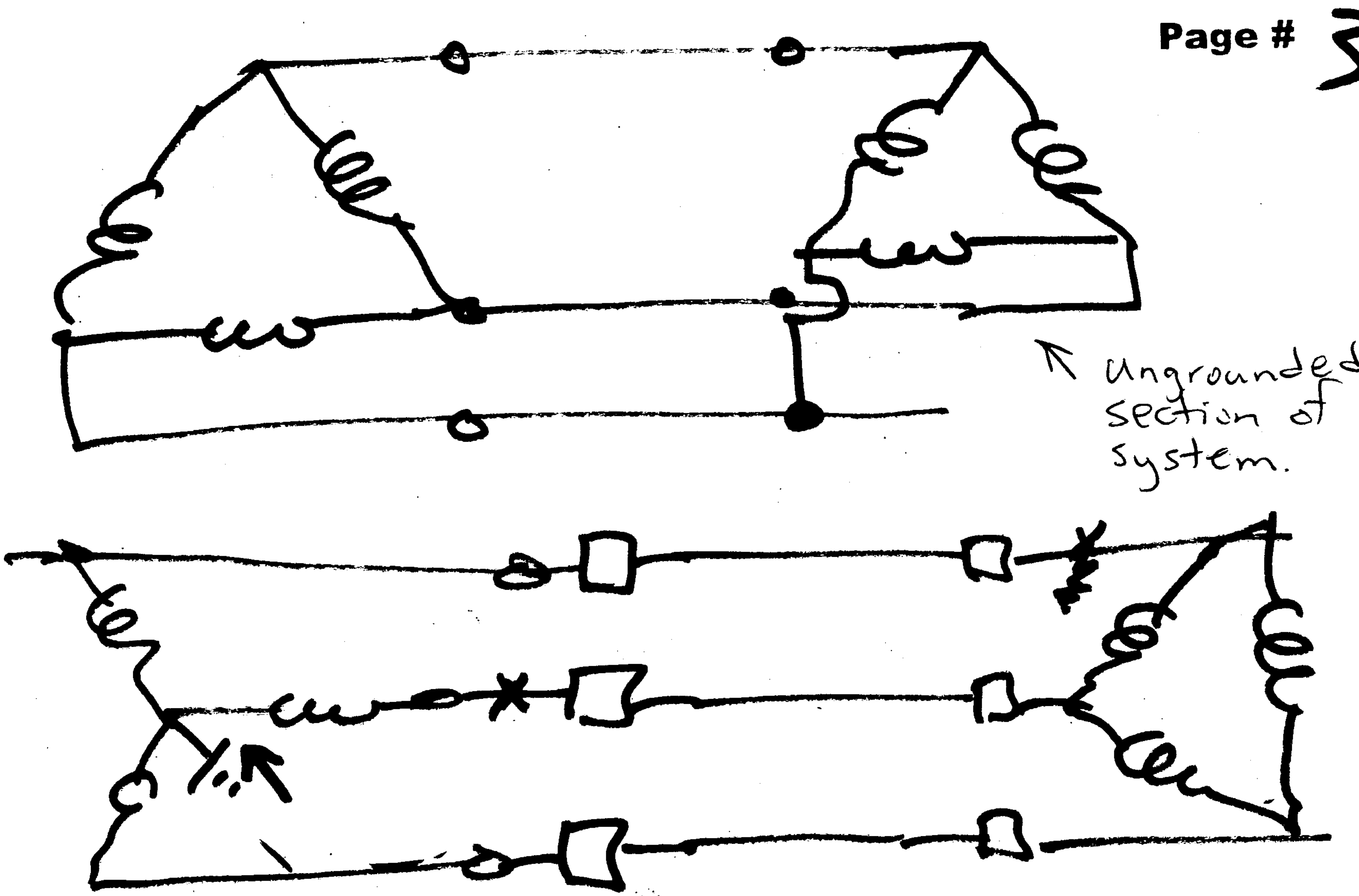


FIGURE 7.16 Low-impedance system grounding with a zigzag grounding transformer.



The zigzag transformer is illustrated in Fig. 7.16. Basically, this unit consists of three 1:1 ratio transformers interconnected to pass zero-sequence current only. With the transformer polarities shown and because $I_{a0} = I_{b0} = I_{c0} = I_0$, zero-sequence current can flow, but positive- and negative-



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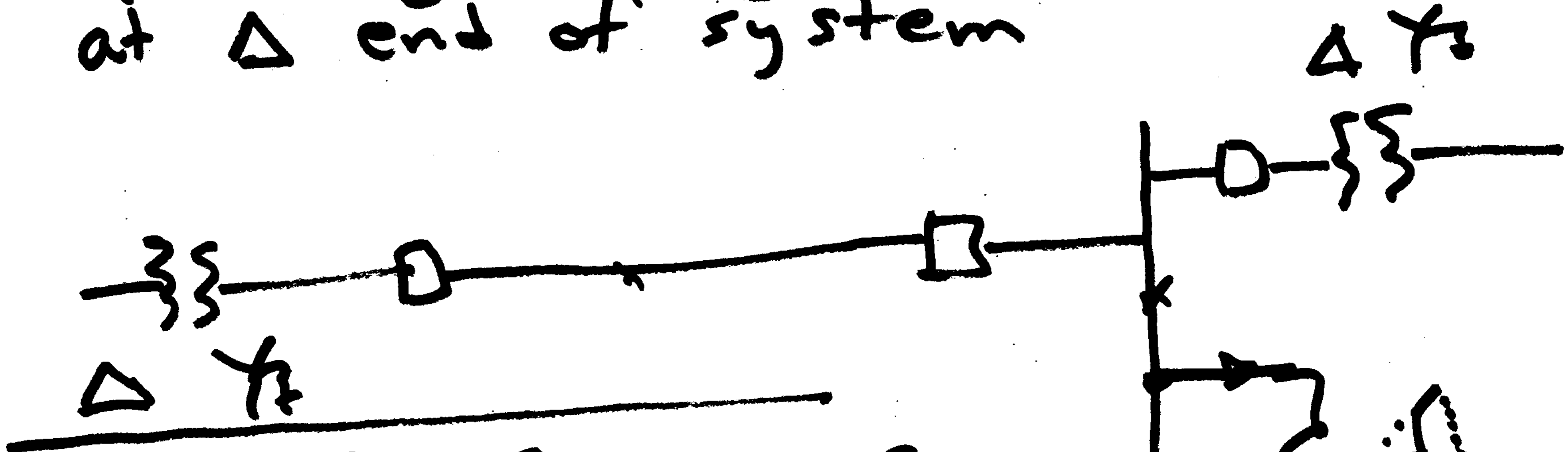
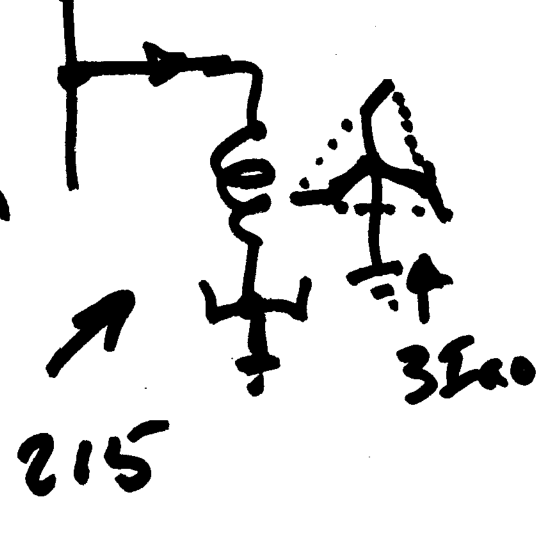
Spec a grounding xfmr at Δ end of system



$\tilde{I}_{a0} = \tilde{I}_{b0} = \tilde{I}_{c0}$: Low Z path

$\tilde{I}_{a1} \neq \tilde{I}_{b1} \neq \tilde{I}_{c1}$



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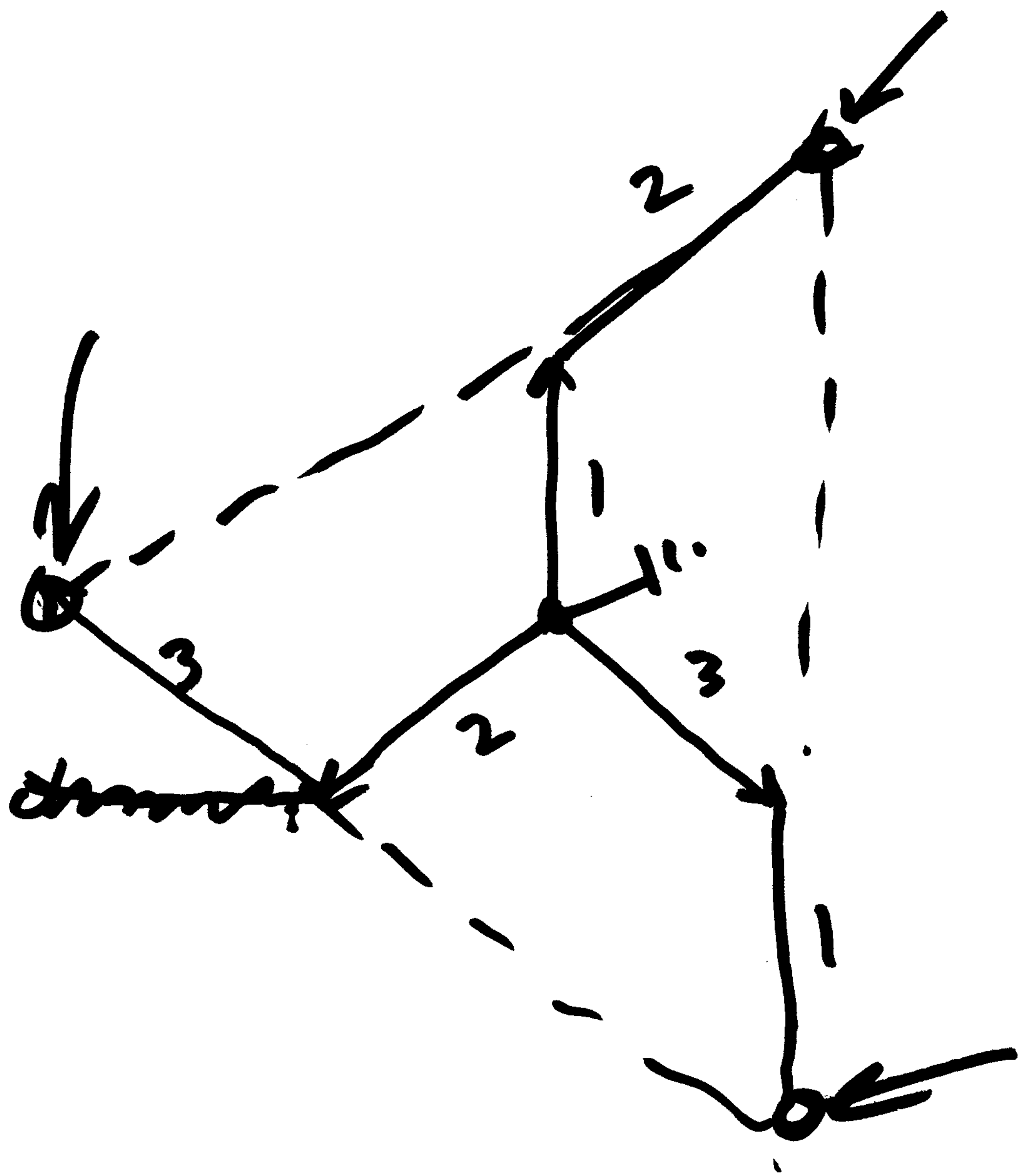
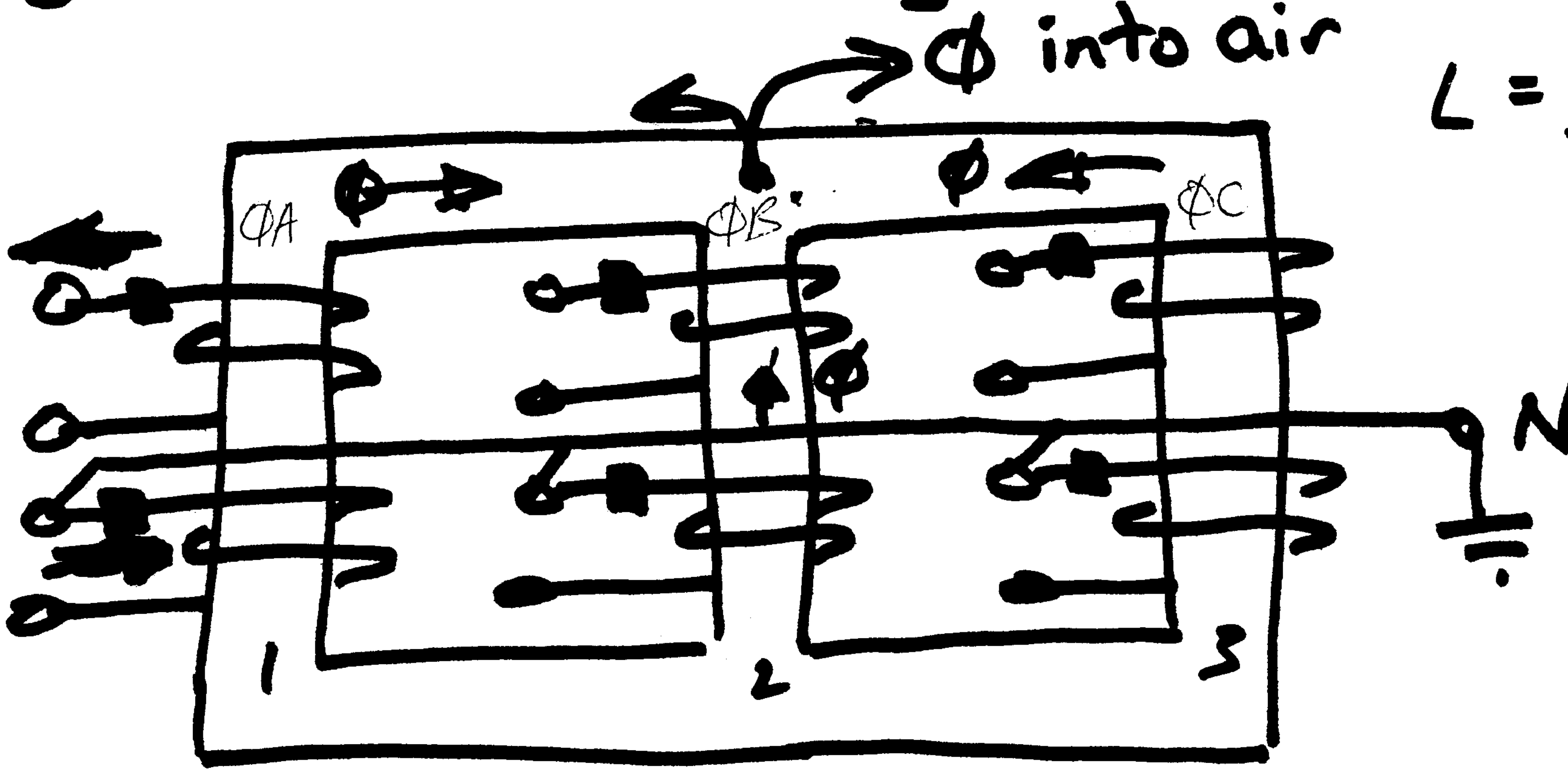


2
1
3
2
3
1

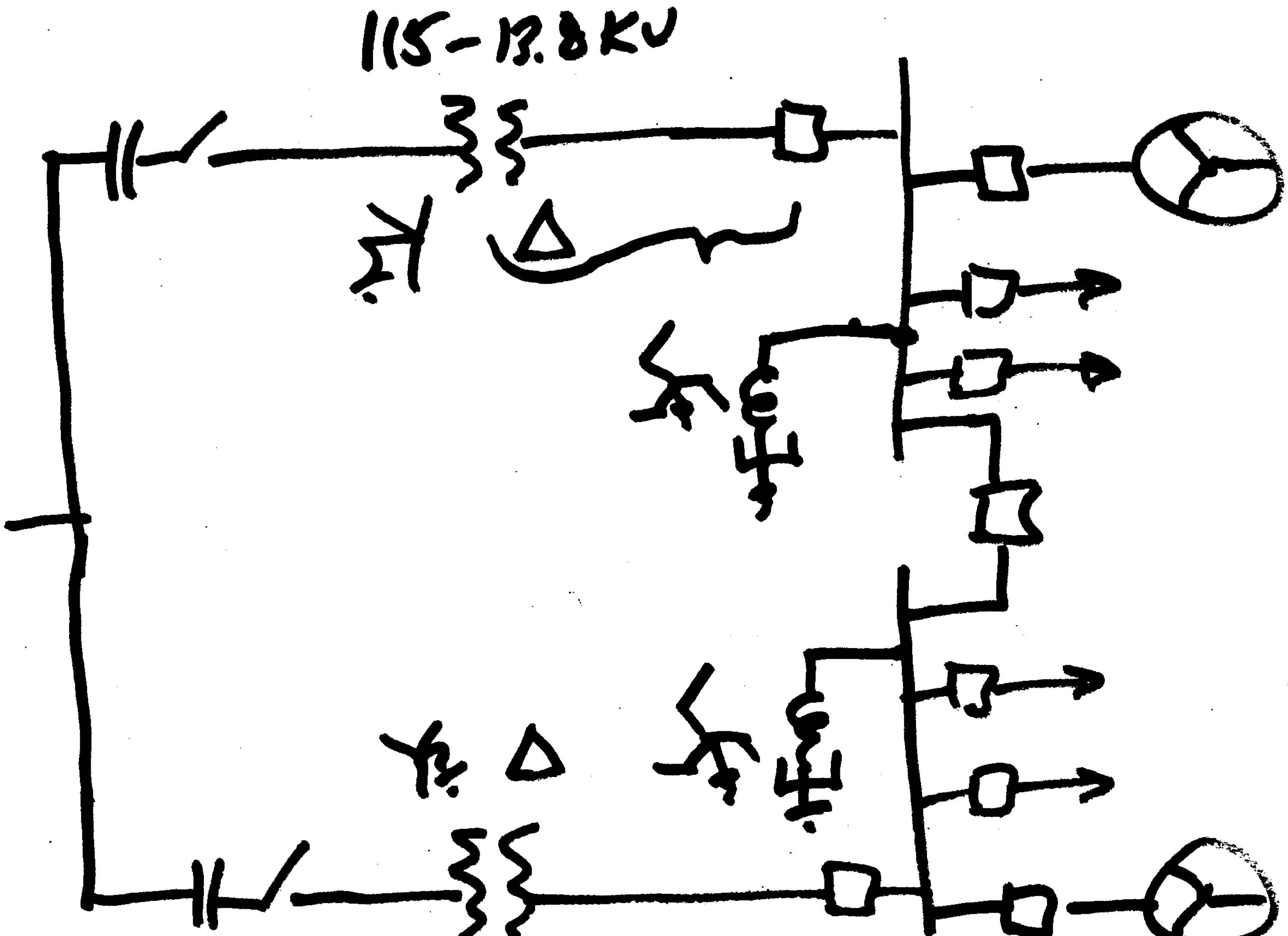
Zig-Zag Grounding (p. 215)

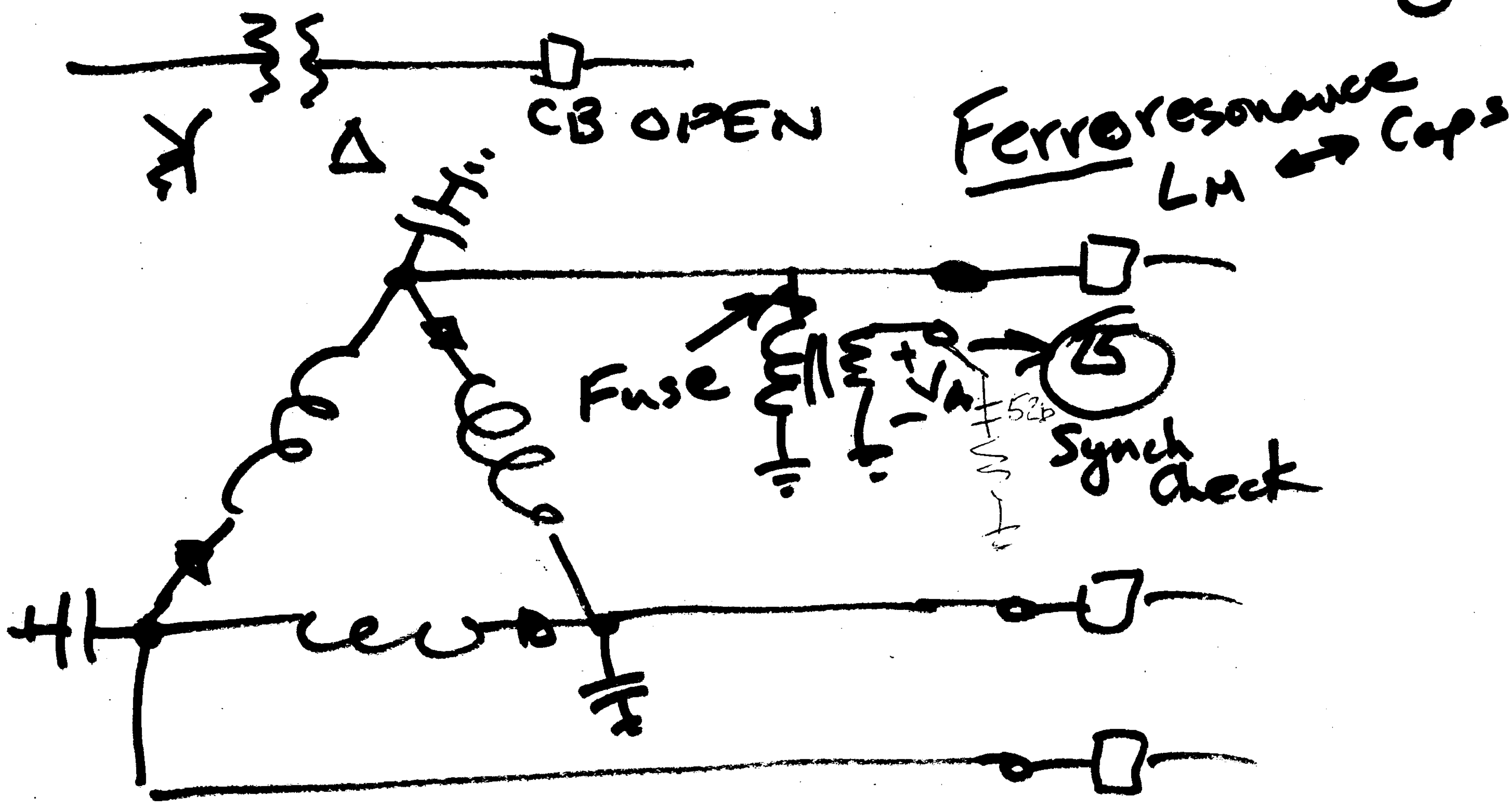
$$L = \frac{N^2}{R}$$



See total connections on p. 215

(Note: there is No page 6)





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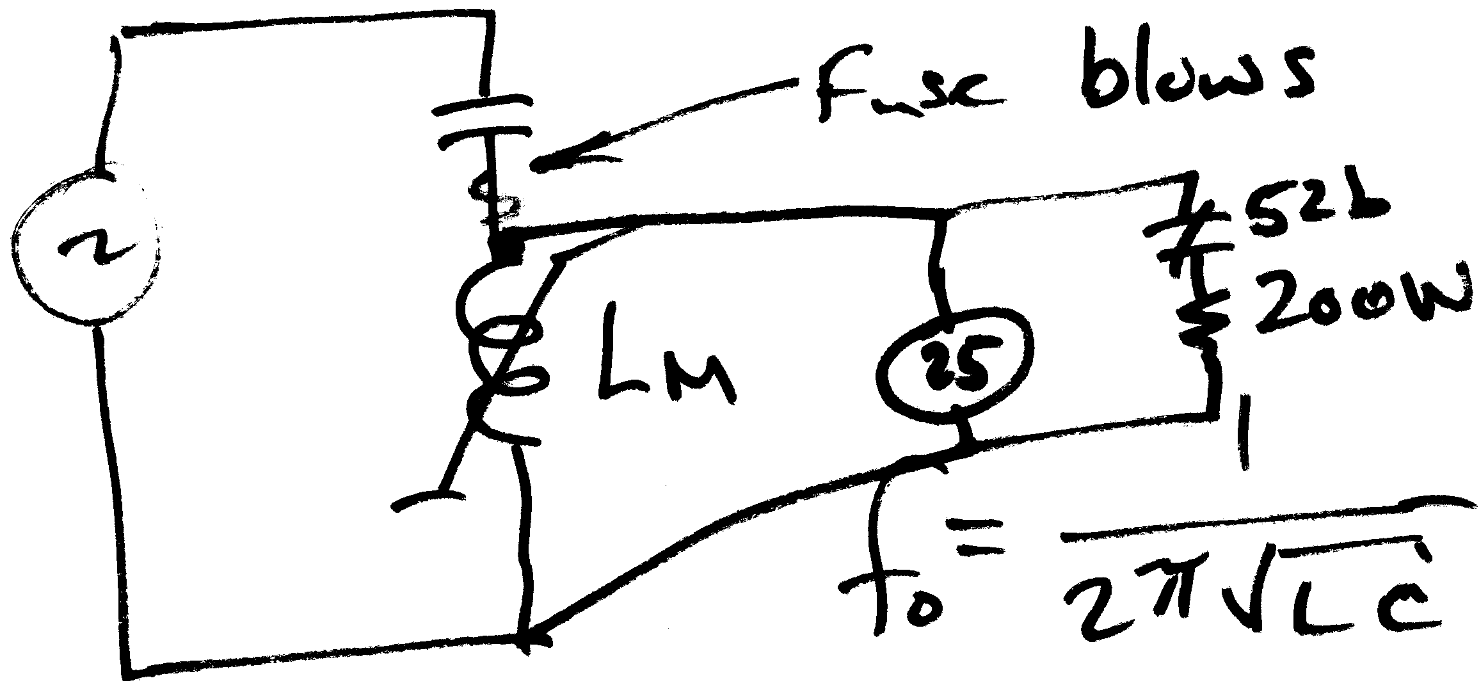
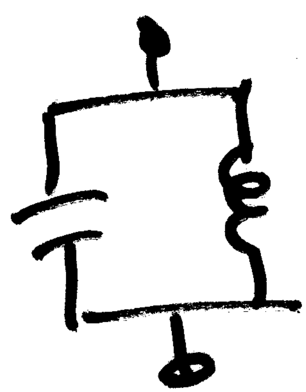


$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Series Resonance: $Z \to 0$

Parallel ": $Z \to \infty$



Zig-Zag Power Transformers

Δ-Y connections limited to
±30, ±90, ±150

Zero-degree phase shift

- Δ-Δ
- Y-Y : problem w/harmonics, i.e. triplen harmonics

Zig-Zag - Δ : · Zero degree shift
- Grounding
- Harmonic containment

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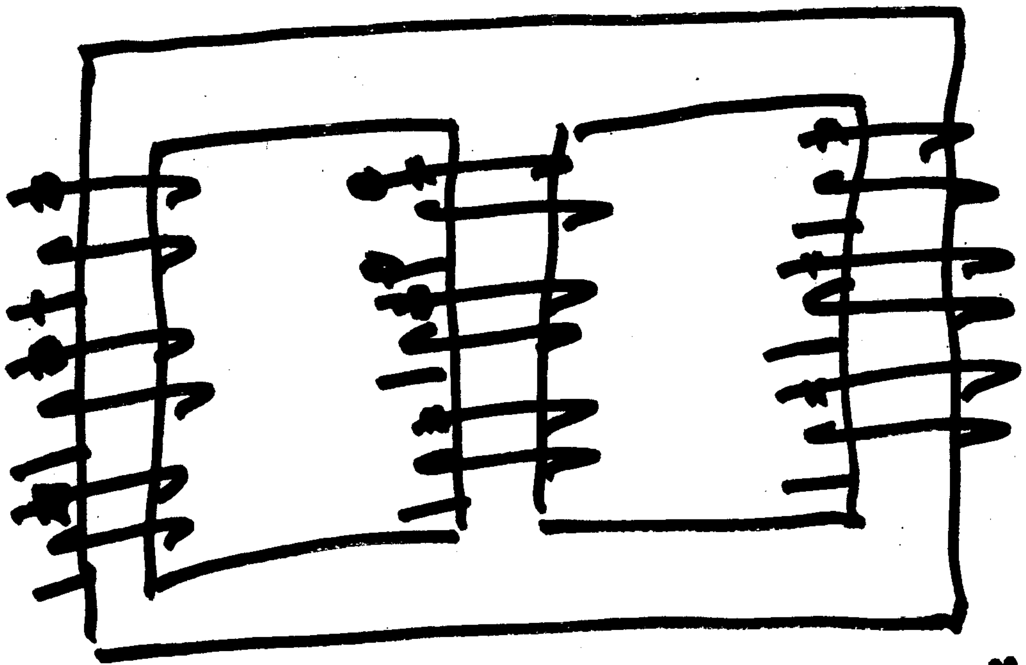

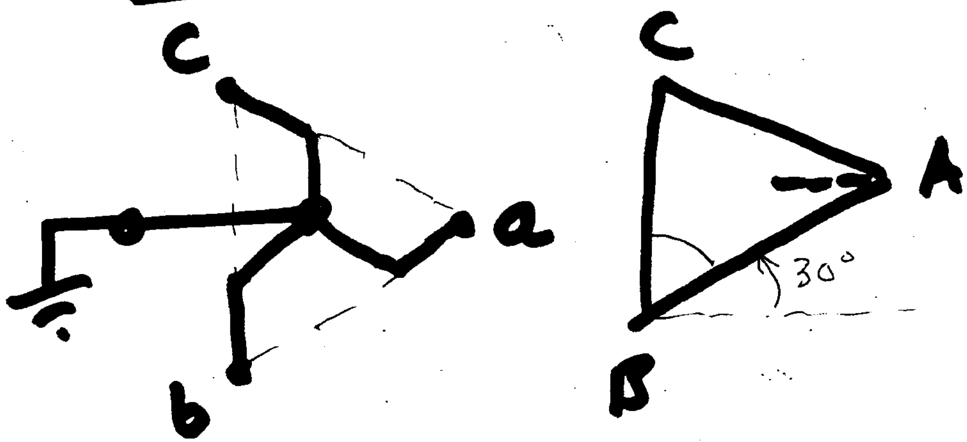

"Hoeppner" Transformer

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