Ongoing List of Topics:

- **URL:** [http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm](http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm)
- **Term Project** - last few proj/teams being firmed up.
  - E-mail me to discuss if questions.
- **Homework #8** - directional overcurrent protection
  - Phase impedances (a,b,c) vs. sequence impedances (0,1,2)
  - **Glover & Sarma gives good explanation, §8.2.**
- Next Homework - sequence networks, transformer phase shifts
- Symmetrical Components overview issues for today.
  - Protection fundamentals (cont’d):
    - Distance relaying fundamentals: §6.5.6, §6.5.7
    - Bus diff, xfmr diff, synch check, capacitor banks, generators, motors, etc. (take a quick run through Ch.6, also Glover & Sarma, Ch.10).
Bus Diff:

KCL: $\sum I_s = 0$

Trip if $I_s > I_{trip}$
CT Sec Currents

Trip CBI

Trip CBI

Trip CBI

Trip CBN

86B

Low Impedance

Moderate Impedance

High Impedance

"Lockout Relay"
Complications:
- Shunt Cap (Line-Charging Current)
- Phase imbalance
- Parallel Lines
- Failure of Comm
Complications/Details:
- Turns Ratio
- Phase Shift
- CT Ratios
- Avoid false trip due to thru-fault or to normal load current.
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, \( n = 1, \) \( n = \sqrt{3} \).

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

\[
I_A = n(I_a - I_d) \quad \text{and} \quad V_A = n(V_A - V_d)
\]

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

\[
I_A = n(I_a - aI_d) = n(1 - a)I_A
\]

\[
= \sqrt{3}nI_a/\angle -30^\circ = NI_a/\angle -30^\circ
\]

\[
V_A = n(V_A - aV_d) = n(1 - a)V_A
\]

\[
= \sqrt{3}nV_A/\angle 30^\circ = NV_A/\angle 30^\circ
\]

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

\[
I_A = n(I_a - aI_d) = n(1 - a)I_A
\]

\[
= \sqrt{3}nI_a/\angle 30^\circ = NI_a/\angle 30^\circ
\]

\[
V_A = n(V_A - aV_d) = n(1 - a)V_A
\]

\[
= \sqrt{3}nV_A/\angle -30^\circ = NV_A/\angle -30^\circ
\]

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

\[
I_e = \frac{1}{n} (I_a - I_d) \quad \text{and} \quad V_e = \frac{1}{n} (V_a - V_d)
\]

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

\[
I_A = \frac{1}{n} (I_a - aI_d) = \frac{1}{n} (1 - a)I_A
\]

\[
= \sqrt{3} / n I_A/\angle 30^\circ = \frac{1}{N} I_A/\angle 30^\circ
\]
\[ V_{a1} = \frac{1}{n} (V_{a1} - aV_{a1}) = \frac{1}{n} (1 - a)V_{a1} \]

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

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

\[ I_{a2} = \frac{1}{n} (I_{a2} - aI_{a2}) = \frac{1}{n} (1 - a)I_{a2} \]

\[ = \frac{\sqrt{3}}{n} I_{a2} \angle -30^\circ = \frac{1}{N} I_{a2} \angle -30^\circ \]

\[ V_{a2} = \frac{1}{n} (V_{a2} - aV_{a2}) = \frac{1}{n} (1 - a^2)V_{a2} \]

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

**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\(^\circ\), the negative-sequence current and voltage correspondingly will both lag by 30\(^\circ\); and (2) similarly, if the positive-sequence quantities lag in passing through the bank, the negative-sequence quantities correspondingly will lead 30\(^\circ\). 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.
Find

N-1 turns

Find is attraction

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

F_{max} \rightarrow 120 \text{ Hz}
The per-unit sequence network (8.19(b)), have the following features:

1. The per-unit impedances do not depend on the winding connections.
2. A phase shift is included in the sequence networks. For the negative sequence, voltages and currents on the transformer lead the corresponding positive sequence voltages by 30°. For the positive sequence, voltages and currents on the transformer lag the corresponding negative sequence voltages by 30°.
3. Zero-sequence currents cannot flow for the connection and correspond to the Δ winding. However, in the Y winding.

The phase shifts in the positive sequence networks (8.19(b)) are represented by the symbol 3.4. Also, the zero-sequence network is used for zero-sequence currents to flow or leave the Δ winding.

The per-unit sequence network (8.19(c)), have the following features:

1. The positive- and negative-sequence impedances are the same as those for the voltage sources labeled as impedances do not depend on the sequence of the voltages.
2. Zero-sequence currents cannot flow, though they can circulate within the network.

**EXAMPLE 8.7** Solving unbalanced three-phase network using per-unit sequence components

A 75-kVA, 480-volt Y/Δ208-volt Y transformer is connected to the source and leakage reactance is X_{leak} = 0.10 p.u. The per-unit sequence networks are used to analyze the network.

**SOLUTION** The base quantities are...
\[ V_{A1} = V_{a1} \left(1/\sqrt{3}\right) \]

**PRI POS SEQUENTIAL VOLTAGES**

**SEC POS SEQUENTIAL VOLTAGES**

**PRI POS SEQUENTIAL CURRENTS**

**SEC POS SEQUENTIAL CURRENTS**

\[ V_{A2} = V_{a2} \left(1/\sqrt{3}\right) \]

**PRI NEG SEQUENTIAL VOLTAGES**

**SEC NEG SEQUENTIAL VOLTAGES**

**PRI NEG SEQUENTIAL CURRENTS**

**SEC NEG SEQUENTIAL CURRENTS**

ANSI STANDARD 30-DEGREE SHIFT WYE-DELTA
$V_{A1} = V_{a1}(1/30^\circ)$

PRI POS SEQUENTIAL VOLTAGES

$V_{BC1} = V_{b1} - V_{c1}$

PRI POS SEQUENTIAL CURRENTS

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

PRI NEG SEQUENTIAL VOLTAGES

SEC POS SEQUENTIAL VOLTAGES

SEC POS SEQUENTIAL CURRENTS

SEC NEG SEQUENTIAL VOLTAGES

SEC NEG SEQUENTIAL CURRENTS

ANSI STANDARD 30-DEGREE SHIFT DELTA-WYE
Auto

Δelta Tertiary?
- Zero-seg Circ.
- Harmonic "Containment"
  "triplet" Harmonics
e.g. 3rd, 6th, 9th...
  ...like Z-seg, in phase.
- Relaying Conn.
- Station Service
- Local dist.