Ongoing List of Topics:

• URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
• Term Project - last few proj/teams/topics being firmed up. Be sure that work plan has all team members are contributing!
• 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, xfrm diff, synch check, capacitor banks, generators, motors, etc. (take a quick run through Ch.6, also Glover & Sarma, Ch.10).
Bus Diff:

\[ KCL: \quad \sum I_S = 0 \]

Trip if $\sum I_S > I_{\text{pickup}}$
CT Sec Currents

- Low Impedance
- Moderate Imp.
- 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.

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

\[
I_A = n(I_a - I_0) \quad \text{and} \quad V_A = n(V_A - V_0)
\]

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

\[
I_{A1} = n(I_{a1} - aI_{a0}) = n(1 - a)I_{a1} = \sqrt{3}nI_{a1}/\sqrt{30} = nI_{a1}/\sqrt{30} \tag{A4.3-1}
\]

\[
V_{A1} = n(V_{a1} - a^2V_{a0}) = n(1 - a^2)V_{a1} = \sqrt{3}nV_{a1}/\sqrt{30} = nV_{a1}/\sqrt{30} \tag{A4.3-2}
\]

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

\[
I_{A2} = n(I_{a1} - a^2I_{a0}) = n(1 - a^3)I_{a1} = \sqrt{3}nI_{a1}/\sqrt{30} = nI_{a1}/\sqrt{30} \tag{A4.3-3}
\]

\[
V_{A2} = n(V_{a0} - a^2V_{a1}) = n(1 - a)V_{a1} = \sqrt{3}nV_{a1}/\sqrt{30} = nV_{a1}/\sqrt{30} \tag{A4.3-4}
\]

For phase-to-neutral voltages for both connections illustrated: (a) wye (star) on high side; (b) delta on high side.

\[
L_e = \frac{1}{n} (I_a - I_0) \quad \text{and} \quad V_n = \frac{1}{n} (V_A - V_0)
\]

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

\[
L_e = \frac{1}{n} (I_a - aI_0) \quad \text{and} \quad V_n = \frac{1}{n} (V_A - aV_0) \tag{A4.3-6}
\]

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

\[
I_{A1} = \frac{1}{n} (I_{a1} - aI_{a0}) = \frac{1}{n} (1 - a^2)I_{a1} = \frac{\sqrt{3}}{n} I_{a1}/\sqrt{30} \tag{A4.3-6}
\]

\[
V_{A1} = \frac{1}{n} (V_{a1} - a^2V_{a0}) = \frac{V_A}{n} \tag{A4.3-6}
\]
$V_{A1} = V_{a1} (1/30^\circ)$

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

PRI POS SEQ VOLTAGES

PRI POS SEQ CURRENTS

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

PRI NEG SEQ VOLTAGES

PRI NEG SEQ CURRENTS

SEC POS SEQ VOLTAGES

SEC POS SEQ CURRENTS

SEC NEG SEQ VOLTAGES

SEC NEG SEQ CURRENTS

ANSI STANDARD 30-DEGREE SHIFT DELTA-WYE
\[ V_{n1} = \frac{1}{n} (V_{a1} - aV_{a2}) = \frac{1}{n} (1 - a)V_{a1} \]  
\[ = \frac{\sqrt{3}}{n} V_{a1} \angle -30^\circ = \frac{1}{N} V_{a1} \angle -30^\circ \]  

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

\[ I_{n2} = \frac{1}{n} (I_{a2} - aI_{a3}) = \frac{1}{n} (1 - a)I_{a2} \]  
\[ = \frac{\sqrt{3}}{n} I_{a2} \angle -30^\circ = \frac{1}{N} I_{a2} \angle -30^\circ \]  
\[ V_{n2} = \frac{1}{n} (V_{a2} - a^2V_{a3}) = \frac{1}{n} (1 - a^2)V_{a2} \]  
\[ = \frac{\sqrt{3}}{n} V_{a2} \angle +30^\circ = \frac{1}{N} V_{a2} \angle +30^\circ \]  

**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°, 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.
Find

N-1 turns

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

Find is attraction

120 Hz