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.
- Sequence networks and fault calcs for 2-winding transformers
- Symmetrical Components overview issues for today.
- 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).
Bus Diff:

\[ \sum I_s = 0 \]

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
Avoid false trip due to three-fault or to normal load current.
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 $Z_o$ and $3Z_o$ components shown are shorted-out in the system and sequence circuits.

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, $N = 1, n = \sqrt[3]{3}$.

$I_a = n(I_A - I_L)$ and $V_a = n(V_A - V_L)$

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

\[ I_A = n(I_{A1} - aI_{L1}) = n(1 - a)I_{A1} \]  \hspace{1cm} (A4.3-1)

\[ = \sqrt{3}nI_{A1}/\angle 30^\circ = NI_{A1}/\angle 30^\circ \]

\[ V_A = n(V_{A1} - a^2V_{L1}) = n(1 - a^2)V_{A1} \]  \hspace{1cm} (A4.3-2)

\[ = \sqrt{3}nV_{A1}/\angle 30^\circ = NV_{A1}/\angle 30^\circ \]

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

\[ I_A = n(I_{A1} - a^2I_{L1}) = n(1 - a^2)I_{A1} \]  \hspace{1cm} (A4.3-3)

\[ = \sqrt{3}nI_{A1}/\angle -30^\circ = NI_{A1}/\angle -30^\circ \]

\[ V_A = n(V_{A1} - a^2V_{L1}) = n(1 - a)I_{A1} \]  \hspace{1cm} (A4.3-4)

\[ = \sqrt{3}nV_{A1}/\angle -30^\circ = NV_{A1}/\angle -30^\circ \]  \hspace{1cm} (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, $N = 1, n = \sqrt[3]{3}$.

\[ I_a = \frac{1}{n} (I_A - I_L) \quad \text{and} \quad V_a = \frac{1}{n} (V_A - V_L) \]

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

\[ I_A = \frac{1}{n} (I_{A1} - aI_{L1}) = \frac{1}{n} (1 - a)I_{A1} \]  \hspace{1cm} (A4.3-6)

\[ = \frac{\sqrt{3}}{n} I_{A1}/\angle 30^\circ = \frac{1}{N} I_{A1}/\angle 30^\circ \]
\[ V_{A1} = V_{a1} \left(\frac{1}{\sqrt{3}}\right) \]

**PRI POS SEQ VOLTAGES**

**SEC POS SEQ VOLTAGES**

**PRI POS SEQ CURRENTS**

**SEC POS SEQ CURRENTS**

\[ V_{A2} = V_{a2} \left(1 - \frac{30}{60}\right) \]

**PRI NEG SEQ VOLTAGES**

**SEC NEG SEQ VOLTAGES**

**PRI NEG SEQ CURRENTS**

**SEC NEG SEQ CURRENTS**

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

PRI POS SEQ VOLTAGES

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

PRI NEG SEQ VOLTAGES

SEC POS SEQ VOLTAGES

SEC NEG SEQ VOLTAGES

PRI POS SEQ CURRENTS

PRI NEG SEQ CURRENTS

SEC POS SEQ CURRENTS

SEC NEG SEQ CURRENTS

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

For negative sequence [see Eq. (4.3)],
\[ I_{st} = \frac{1}{n} (I_{st} - aI_{st}) = \frac{1}{n} (1 - a)I_{st} \]
\[ = \frac{\sqrt{3}}{n} I_{st} \angle -30^\circ = \frac{1}{N} I_{st} \angle -30^\circ \]
\[ V_{st} = \frac{1}{n} (V_{st} - a^2V_{st}) = \frac{1}{n} (1 - a^2)V_{st} \]
\[ = \frac{\sqrt{3}}{n} V_{st} \angle +30^\circ = \frac{1}{N} V_{st} \angle +30^\circ \]

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