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 and getting moving.
  - Follow timeline, see posting on web page
  - Weeks 6 thru 9 - develop formal outline w/complete reference list

- Protection fundamentals (cont’d):
  - Distance relaying fundamentals: §6.5.6, §6.5.7
  - Observed vs actual Z: Three-terminal lines, series caps
  - Again — overview of bus diff, xfmr diff, synch check, capacitor banks, generators, motors, etc. (take a quick run through Ch.6, also Glover & Sarma, Ch.10).
Protection fundamentals in preparation for next EE5224 relaying lab:

- Gen diff 87G - quite simple, connect CTs so current flows in “do-nothing” loop through Restraint elements (resulting in near-zero current through Operate element). Use equal (preferably full) ratio with all CTs. Differential slope of trip characteristic is rather flat compared to 87T below. Example shown of how not to connect CT secondaries.

- Xfmr diff 87T - a) must connect CT secondaries to provide proper phase shift so that restraint currents flowing through restraint elements are in phase; b) relay settings are used to compensate for pri voltage ratio and CT ratios. CT accuracy problems can be a big concern due to having to use less than full CT ratio, and having Pri and Sec CTs with different accuracy levels. Differential slope of trip characteristic can be 10%, 15%, 25% to allow for mismatch (measurement error) due to CT accuracy problems.
A term project shall be done in lieu of a final exam. Teams shall be of 3. **Team requirement: no more than one BS student per team.** The objective is to actively figure out and explain the underlying concepts, key relationships and equations, design, develop, implement, test, and document the engineering details. Goal of report: a tutorial to document technical background, get another engineer up to speed on what you have done, explain the implementation, and present the results.

**The project you choose:**
- must be of topical interest,
- must relate to course material of EE5223.
- must demonstrate level of mastery and application of the related concepts and theories, at the level of the EE5223 course.
- includes a detailed literature search (applications magazines, standards, and journal papers) and Reference List, with salient concepts summarized in Background section of report. You'll also need to do a technical review of the journal paper that is most related to their project.
- length of body of report: approximately 10 pages of text (not including figures, tables, equations, or appendices).

Time line and required submissions are as follows. All deliverables contribute to the grade of your term project. Approximate schedule is:
- Week 6 (Friday): submit short e-mail with idea(s) requesting instructor feedback.
- Week 7 (Friday): submit formal outline of project and list of key references.
- Week 9: submit updated outline of project and complete reference list.
- Week 12: Submit rough draft of project report including a working initial model/system.
- Week 14: Submit final report/deliverable.
- Finals week: be prepared to present/demonstrate project.

**Report Outline/Table of Contents** (copy and paste this to start your Table of Contents):
- Title Page - Include project title, course name, authors' names, revision date
- Executive Summary (not needed for initial draft)
- Table of Contents (use as "working outline")
- Statement of contributions by each team member, signed in agreement by all.
- Introduction (brief overview of project: problem area, motivation, overview of project)
- Background
  - literature search, most important references
  - Presentation of key concepts connected with project
  - Identification of existing voids or weaknesses, and resulting opportunity
- Proposed Approach and Application
  - Overview of basic idea that you will develop and implement
  - Development and implementation details
- Implementation (may not be complete in draft versions)
- Results and Performance (in earlier draft reports, this can be the Expected Results)
- Conclusion
- Recommendations for Continued Work
- Reference List (IEEE format, numbered [1], [2], etc, in order of first author’s last name)
- Appendices as required to document details. Include journal paper & review as one appendix.

**Page layout:**
- Font: 11-pt CG Times w/1.25-1.5 line spacing; or 10-pt comic or ariel w/1.0-1.25 line space
- Page layout: 1" margins, include page numbering
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.

**APPENDIX 4.3 SEQUENCE PHASE SHIFTS THROUGH WYE–DELT A 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, \( N = 1, n = \sqrt{3} \).

\[
I_A = n(I_a - I_n) \quad \text{and} \quad V_a = n(V_A - V_n)
\]

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

\[
I_{A1} = n(I_{a1} - aI_{n1}) = n(1 - a)I_{a1} \quad (A4.3-1)
\]

\[
= \sqrt{3}nI_{a1} / A30^\circ = NI_{a1} / A30^\circ
\]

\[
V_{a1} = n(V_{A1} - a^2V_{n1}) = n(1 - a^2)V_{a1} \quad (A4.3-2)
\]

\[
= \sqrt{3}nV_{a1} / A30^\circ = NV_{a1} / A30^\circ
\]

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

\[
I_{A2} = n(I_{a2} - a^2I_{n2}) = n(1 - a^2)I_{a2} \quad (A4.3-3)
\]

\[
= \sqrt{3}nI_{a2} / A30^\circ = NI_{a2} / A30^\circ
\]

\[
V_{a2} = n(V_{A2} - a^2V_{n2}) = n(1 - a^2)V_{a2} \quad (A4.3-4)
\]

\[
= \sqrt{3}nV_{a2} / A30^\circ = NV_{a2} / A30^\circ \quad (A4.3-5)
\]

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

\[
I_e = \frac{1}{n} (I_e - I_n) \quad \text{and} \quad V_n = \frac{1}{n} (V_e - V_n)
\]

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

\[
I_{e1} = \frac{1}{n} (I_{e1} - aI_{n1}) = \frac{1}{n} (1 - a^2)I_{a1} \quad (A4.3-6)
\]

\[
= \sqrt{3} \frac{1}{N} I_{a1} / A30^\circ = \frac{1}{N} I_{a1} / A30^\circ
\]
\[ V_{a1} = \frac{1}{n} (V_{a1} - aV_{a2}) = \frac{1}{n} (1 - a)V_{a1} \]  
\[ = \frac{\sqrt{3}}{n} V_{a1} \angle -30^\circ = \frac{1}{N} V_{a1} \angle -30^\circ \]  

For negative sequence [see Eq. (4.3)],
\[ I_{a2} = \frac{1}{n} (I_{a2} - aI_{a3}) = \frac{1}{n} (1 - a)I_{a2} \]  
\[ = \frac{\sqrt{3}}{n} I_{a2} \angle -30^\circ = \frac{1}{N} I_{a2} \angle -30^\circ \]
\[ V_{a2} = \frac{1}{n} (V_{a2} - a^2 V_{a3}) = \frac{1}{n} (1 - a^2)V_{a2} \]  
\[ = \frac{\sqrt{3}}{n} V_{a2} \angle +30^\circ = \frac{1}{N} V_{a2} \angle +30^\circ \]  

**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

Find is attraction

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

Max

120 Hz
The per-unit sequence networks of Figure 8.19(b), have the following features:

1. The per-unit impedances do not depend on the winding connection.

2. A phase shift is included in the sequence networks. For the Y–Y, Y–Δ, and Δ–Δ networks, the phase shifts are 0°, 30°, and 30°, respectively.

3. Zero-sequence currents cannot flow in the Δ winding. However, they can flow in the Y winding.

The phase shifts in the positive-sequence network of Figure 8.19(b) are represented by the symbol (a). Also, the zero-sequence network of Figure 8.19(c) is used for zero-sequence currents to enter or leave the Δ winding.

The per-unit sequence networks of Figure 8.19(c), have the following features:

1. The positive- and negative-sequence impedances are the same as those for the Y–Y, Y–Δ, and Δ–Δ transformers, with the positive sequence being the same as the Y–Y transformer.

2. Zero-sequence currents can flow in the Δ winding, although they may circulate within the windings.

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

A 75-kVA, 480-volt Δ/208-volt Y transformer is connected to the source. The leakage reactance is \( X_{L} = 0.10 \) per unit. The positive-sequence network is used to connect the transformer to the source. The positive-sequence network is used to analyze the unbalanced load conditions.

The base quantities are

SOLUTION The base quantities are

\[ V_{b} = 480 \text{ volts} \]
\[ I_{b} = 125 \text{ amps} \]
\[ Z_{b} = 6 \text{ ohms} \]
$V_{A1} = V_{o1} (1/30^\circ)$

PRI POS SEQUENTIAL VOLTAGES

PRI POS SEQUENTIAL CURRENTS

$V_{A2} = V_{o2} (1/-30^\circ)$

PRI NEG SEQUENTIAL VOLTAGES

PRI NEG SEQUENTIAL CURRENTS

SEC POS SEQUENTIAL VOLTAGES

SEC POS SEQUENTIAL CURRENTS

SEC NEG SEQUENTIAL VOLTAGES

SEC NEG SEQUENTIAL CURRENTS

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

PRI POS SEQ VOLTAGES

PRI POS SEQ CURRENTS

\[ I_{A1} = I_{AB1} - I_{CA1} \]

SEC POS SEQ CURRENTS

SEC POS SEQ VOLTAGES

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

PRI NEG SEQ VOLTAGES

PRI NEG SEQ CURRENTS

SEC NEG SEQ CURRENTS

SEC NEG SEQ VOLTAGES

ANSI STANDARD 30-DEGREE SHIFT DELTA-WYE
Auto

\[ Y_3 \to Y_1 \]

Delta Tertiary?
- Zero-seg Circ.
- Harmonic "Containment"
  "Triplet" Harmonics
  eg. 3rd, 6th, 9th...
  ... like 2-seg, in phase.
- Relaying Conn.
- Station Service
- Local dist.
6) [30 pts] A simple 3φ power system consists of a generator, a transformer, a transmission line, and a large synchronous motor. Nameplate data for each piece of equipment is given below. The transformer has ANSI standard phase shift (high-voltage LN voltages lead the low-voltage LN voltages by 30°).

G1: 50MVA, 24kV, \( X_0 = 5\% \), \( X_t = 20\% \), \( X_g = 10\% \), \( X_n = 0.40 \)
T1: 100MVA, 24-13.8kV, \( X_0 = 5\% \), \( X_t = X_g = 10\% \)
M1: 50MVA, 13.2kV, \( X_0 = 5\% \), \( X_t = X_g = 20\% \)
T-Line: \( X_0 = 10\% \), \( X_1 = X_2 = 0.50 \)

\[
Z_{new} = Z_{old} \left( \frac{V_{new}}{V_{old}} \right)^2 \left( \frac{S_{new}}{S_{old}} \right)
\]

a) [15 pts] Using a system base of 100MVA and 24kV at bus 1, determine the base impedance for both sections of the system and convert all impedances to per unit values on the common system base.

b) [15 pts] Construct the zero, positive and negative sequence impedance diagrams. Label all impedances with their correct values in per unit. Include the effects of positive and negative sequence phase shift.
\( V_{DOP} = \frac{3I_{AO}Z^2}{I_{AO}} \)
\( z_0, z_1 = x_2 \)

\( z_0, z_1 = z_2 \)

\( z_1 = j \cdot 0.03 \text{ p.m.} \)

\( z_2 = j \cdot 0.03 \text{ p.m.} \)

\( z_0 = j \cdot 0.05 \text{ p.m.} \)

\( z_N = j \cdot 5z_2 \)

\( z_0 = 0.10 \text{ p.m.} \)

\( x_1 = z_2 = 0.05 \text{ p.m.} \)

\( x/R \approx 10 \)
- e-mail addresses:
  - Using MTU Address only!
  - add personal address?

- Wed office hr: 2-3 p.m.
- e-mail your questions!
For the general zero-sequence network, Figure 8.21(a), the connection between terminals H and H' depends on how the high-voltage windings are connected, as follows:

1. Solidly grounded Y—Short H to H'.
2. Grounded Y through Z_y—Connect (3Z_y) from H to H'.
3. Ungrounded Y—Leave H—H' open as shown.
4. Δ—Short H' to the reference bus.

Transformers X—X' and M—M' are connected in a similar manner.

The impedances of the per-unit negative-sequence network are the same as those of the per-unit positive-sequence network, which is always true for nonrotating equipment. Phase-shifting transformers, not shown in Figure 8.21(b), can be included to model phase shift between Δ and Y windings.

**Example 8.8** Three-winding three-phase transformer; per-unit sequence networks

Three transformers, each identical to that described in Example 3.9, are connected as a three-phase bank in order to feed power from a 900-MVA, 13.8-kV generator to a 345-kV transmission line and to a 34.5-kV distribution line. The transformer windings are connected as follows:

- 13.8-kV windings (X): Δ to generator
- 199.2-kV windings (H): solidly grounded Y, to 345-kV line
- 19.92-kV windings (M): grounded Y through Z_y = 0.10 Ω, to 34.5-kV line

The positive-sequence voltages and currents of the high- and medium-voltage Y windings lead the corresponding quantities of the low-voltage Δ winding by 30°. Draw the per-unit sequence networks, using a three-phase base of 900 MVA and 13.8 kV for terminal X.

**Solution** The per-unit sequence networks are shown in Figure 8.22. Since \( V_{lineX} = 13.8 \text{ kV} \) is the rated line-to-line voltage of terminal X, \( V_{lineX} = \)