Ongoing List of Topics:

- URL: 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):
  - 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).
  - Sequence networks, fault calcs
    - Transformers: Y-Δ, Δ-Y, Auto-Δ
    - Overall network calculations
• 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.
\[
\begin{bmatrix} \tilde{V}_{ao} \\ \tilde{V}_{av} \\ \tilde{V}_{av^2} \\ \tilde{V}_{aw} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}
\]

Sequence Networks

Per Phase, Y-N, P.U.

Pos

NEG

Zero 32

See details on next page.
\[ V_{A1L-30^\circ} \]

\[ V_{A2} = 0 \]

\[ I_{A2} + V_{A2} \]

\[ V_{A0} = 0 \]

\[ I_{A0} + V_{A0} \]
\[ \frac{1}{Z_1} V_{A1} = I_{E,A1} \]

\[ I_{a2} = \frac{V_{A2}}{Z_2} \]

\[ I_{a1} = \frac{V_{A1}}{Z_1} \]

\[ I_{a1} = -I_{a2} \]

\[ V_{A1} = V_{A2} \]

\[ I_{a1} Z_2 = -I_{a2} Z_2 \]
\[ I_{a1} = I_{a2} = I_{ao} \]

\[ \frac{I_{F}}{3} = I_{a1} = I_{a2} = I_{ao} \]

\[ Z = [V_p] = [A] [V_s] \]
L - L - G

L-L : Reduced case, \( Z_0 \approx 0 \)
Fault Impedance

ZF:
- LG
- LL
- LLG
- 3Φ
Pos:

Bus 1: \( V_{a1,1} = V_{a1,\text{fault}} + I_{1F} Z_L,1F \)

Bus 2: \( V_{a1,2} = V_{a1,\text{fault}} + I_{2F} Z_L,2F \)

NEG:

Bus 1: \( \tilde{V}_{a2,1} = \tilde{V}_{a2,\text{fault}} + I_{a2,2F} Z_L,1F \)

Bus 2: \( \tilde{V}_{a2,2} = \tilde{V}_{a2,\text{fault}} + I_{a2,2F} Z_L,2F \)

Zero:

\( \tilde{V}_{ao,1} = \tilde{V}_{ao,\text{fault}} + I_{ao,1F} Z_L,1F \)

\( \tilde{V}_{ao,2} = \tilde{V}_{ao,\text{fault}} + I_{ao,2F} Z_L,2F \)
Then you'll have $[I_s]$ at $[V_s]$ at each bus.

Then can "apply" relay.

i.e. do settings.

Phase $Q$ty's:

$$
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} V_{a0} \\
V_{a1} \\
V_{a2}
\end{bmatrix}
$$

67 relays: Phase $Q$ty's (i.e. A, B, C)

21 relays: Seg $Q$ty's (i.e. pos, neg, zer...
\[ Z(w) = \frac{V(w)}{I(w)} \]

For Relays:

\[ Z_0 = \frac{\sqrt{V_{ao}}}{I_{ao}} \]
\[ Z_1 = \frac{\sqrt{V_{AI}}}{I_{AI}} \]
\[ Z_A = \frac{\sqrt{V_{AN}}}{I_A} \]

Simplest case

If you use \( V_{111} \):

\[ Z_{AB} = \frac{\sqrt{V_{AB}}}{I_{AB}} = \frac{V_A - V_B}{I_A - I_B} \]

"delta currents"
3-Winding XFMR

- Auto W/Δ test.

Key: External fault: It's enough to know line currents and voltages at the bushings.
What about internal fault?
Also: How can we calculate $I_{ao}$ in new or inside Δ for ground polarization?

Thus: need to reconcile line currents into xfrm, with internal currents thru coils.

See last page of L21!

Objective: obtain CT currents of neutral and Δ for ground polarization.
1. In the 3-phase system below, the lines have the following values:

- Generator (G):
  - 315 MVA, 15.0 kV, X₀ = 20, X₁ = 20, X₂ = 20
- Transformer (T):
  - 250 MVA, 15.0 kV, X₀ = 30, X₁ = 20, X₂ = 20
  - Three single-phase units, high voltage side connected wye, low voltage side connected delta, each unit is 15 kV/220 kV, 50 MVA, with a reactance of 10.
  - A three-phase transformer, 500 kV side, 15 kV delta, 500 MVA, with a reactance of 10.
- Load (L):
  - Z₀ = 0 ohm/phase, Z₁ = Z₂ = 10 ohm/phase
  - Z₀ = 10 ohm/phase, Z₁ = Z₂ = 10 ohm/phase

Choose a base of 145 kV, 1.000 MVA at the load and draw the phasor diagram. Show the load impedance values on the diagram. Assume all pre-fault bus voltages are 1.0 per unit. Neglect the load.

2. Construct the three-phase equivalent zero, positive, and negative sequence networks for the system of problem 1 looking into the networks at bus 1.

3. For a 1-L-G fault with an impedance of 0.1 per unit on bus 3 in the problem above, find the a-b-c line currents flowing toward the fault:
   - A. Coming from line 1-2
   - B. Coming from generator G

4. Repeat problem 3 for a solid line 1-1 fault on bus 1.

5. Repeat problem 3 for a solid 2-L-G fault on bus 3.

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6. The 3-bus system shown below has the bus impedance matrices:

\[
\begin{bmatrix}
    Z_{11} & Z_{12} & Z_{13} \\
    Z_{21} & Z_{22} & Z_{23} \\
    Z_{31} & Z_{32} & Z_{33}
\end{bmatrix}
\]

\[
Z_{11} = \begin{bmatrix}
    1284 & 0.341 & 0.0197 & 12278 & 0.0000 \\
    0.341 & 0.0031 & 0.0044 & 0.0000 & 12728 \\
    0.0197 & 0.0044 & 0.0000 & 12278 & 0.0000 \\
    12278 & 0.0000 & 0.0000 & 0.0000 & 12278 \\
    0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000
\end{bmatrix}
\]

7. For a 1-L-G fault with a pre-fault voltage of 1.0. For a line-to-ground fault with an impedance of \(j0.0792\) on bus 3, find the a-b-c per unit line currents:
   - A. In the fault itself
   - B. From generator 2, which has \(X_0 = 0.2, X_1 = 1.5, X_2 = 0.5, X_3 = 0.5\)
   - C. In line 1-3, which has \(X_0 = X_1 = 3.5\)

8. Repeat problem 6 for a line-to-line fault on bus 3 with an impedance of \(j0.3222\).

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Please note that the diagrams and text are quite detailed and require careful reading for full comprehension. The solutions to the problems involve understanding of electrical networks, phasor analysis, and matrix operations.