Homework #5 Solution

Assignment: 13.1, 13.2, 13.3 ,13.4, and 13.5 Bergen & Vittal

Solutions:

13.1

Assuming a fault at bus 4….

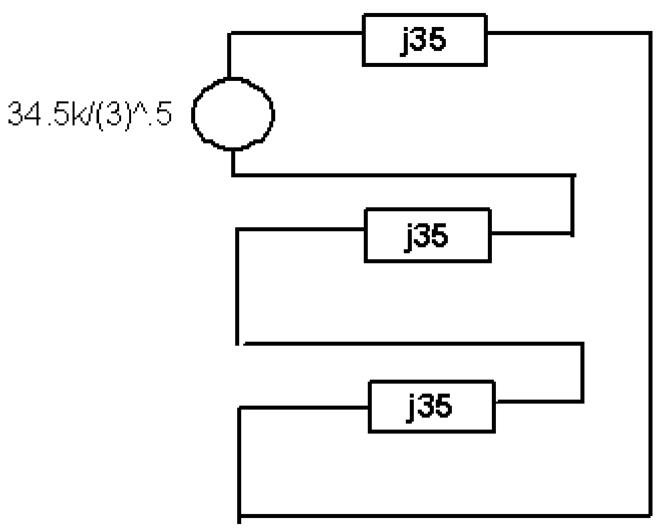
Deriving the Thevenin equivalent circuits:

$$Z_{a'g}^{+} = j5 + j10 + j10 + j10 = j35$$

$$Z_{a'g}^{-} = j5 + j10 + j10 + j10 = j35$$

$$Z_{a'g}^{0} = j5 + j10 + j10 + j10 = j35$$

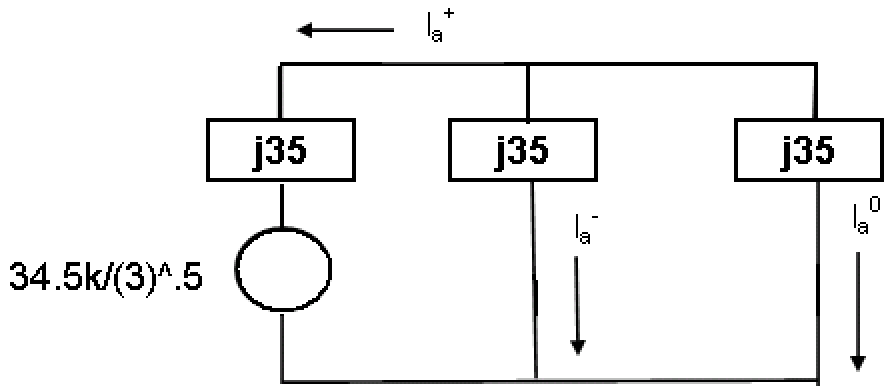
SLG Fault



$$\frac{I_f}{3} = \frac{\frac{34.5k}{\sqrt{3}}}{j35 + j35 + j35} = 189.7$$

$$\left|I_f\right| = 569 Amps$$

DLG Fault



$$I_a^+ = \frac{\frac{34.5k}{\sqrt{3}}}{(j35 \parallel j35) + j35} = 379.40\angle -90°$$

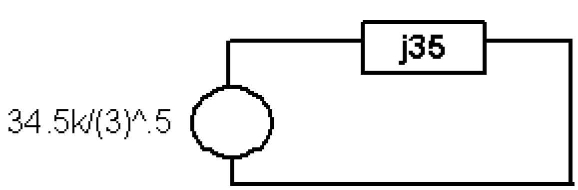
Current Divider

$$I_a^0 = I_a^- = \frac{379.4\angle -90°}{2} = 189.70\angle 90°$$

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} 189.70\angle 90° \\ 379.40\angle -90° \\ 189.70\angle 90° \end{bmatrix} = \begin{bmatrix} 0 \\ 569 \\ 569 \end{bmatrix}$$

$$\left| I_f \right| = 569 Amps$$

3-Phase



$$\left|I_f\right| = \frac{\frac{34.5k}{\sqrt{3}}}{j35} = 569$$

All of these currents are larger than the L-L current of 492.86 Amps (as found in Example 13.1 in the book).

13.2

Since the fault occurs at the midpoint of the line we can assume that the line impedance between bus 3 and 4 is halved (j5).

Deriving the new Thevenin equivalent circuits:

$$Z_{a'g}^{+} = j5 + j10 + j10 + j5 = j30$$

$$Z_{a'g}^{-} = j5 + j10 + j10 + j5 = j30$$

$$Z_{a'g}^{0} = j5 + j10 + j10 + j5 = j30$$

<u>SLG Fault</u>

Using the same network drawn in 13.1, but with updated Thevenin impedances

$$\frac{I_f}{3} = \frac{\frac{34.5k}{\sqrt{3}}}{j30 + j30 + j30} = 221.3$$

$$\left|I_f\right| = 664\,Amps$$

For a fault between buses 3 and 4, **Breaker 3 should operate**.

The setting for **R3** were already found in example 13.1. To Recap:

R3
CT Ratio: 150:5
Current Tap Setting: 5.0 Amps

TDS: ½
Therefore:

$$I_{RelayPickUp} = \frac{664}{(150/5)} = 22.133 Amps$$

Which is $\frac{22.133}{5.0} = 4.43$ times the tap setting

From the CO-7 curves (Figure 13.3) the trip should occur in approximately **.17 seconds.**

If B3 doesn't clear the fault, **the backup breaker is B2.** Using the same settings as example 13.1 for **R2:**

R2
CT Ratio: 150:5
Current Tap Setting: 5.0 Amps
TDS: 1.5

From the CO-7 curves (Figure 13.3) the trip should occur in approximately **.55 seconds.**

13.3

The smallest fault that will be picked up by B3 will occur at bus 4, we now need to figure out what type is the smallest.

Deriving the new Thevenin equivalent circuits:
Note: The book states that ONLY the zero-sequence LINE impedances are now 3 times the original (NOT X_t^0)

$$Z_{a'g}^{+} = j5 + j10 + j10 + j10 = j35$$

$$Z_{a'g}^{-} = j5 + j10 + j10 + j10 = j35$$

$$Z_{a'g}^{0} = j5 + j30 + j30 + j30 = j95$$

Using the same circuits as 13.1, just with new impedances

SLG Fault

$$\frac{I_f}{3} = \frac{\frac{34.5k}{\sqrt{3}}}{j35 + j35 + j95} = 120.72$$

$$\left| I_f \right| = 362 Amps$$

DLG Fault

$$I_a^+ = \frac{\frac{34.5k}{\sqrt{3}}}{(j35 \parallel j95) + j35} = 328.82\angle -90°$$

Current Divider

$$I_a^- = 328.82\angle -90°\left(\frac{j95}{j35 + j95} \right) = 240.288\angle 90°$$

$$I_a^0 = 328.82\angle -90°\left(\frac{j35}{j35 + j95} \right) = 88.527\angle 90°$$

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} 88.527\angle 90° \\ 328.82\angle -90° \\ 240.288\angle 90° \end{bmatrix} = \begin{bmatrix} 0 \\ 510 \\ 510 \end{bmatrix}$$

$$\left| I_f \right| = 510 Amps$$

3-Phase

$$\left|I_f\right| = \frac{\frac{34.5k}{\sqrt{3}}}{j35} = 569$$

<u>Line to Line</u>
Is the same as in the example

$$\left|I_f\right| = 493Amps$$

The smallest current is the SLG; 362 Amps.

Setting R3 with a safety factor of 3

Breaker Pick Up is… $\frac{362}{3} = 120Amps$

Pick a **CT Ratio of 100:5**

Relay Pick Up is… $\frac{120}{(100/5)} = 6$

Current Tap Setting = 6.0
We want the breaker to act as quick as possible therefore choose the **TDS=1/2**

B2 is the backup breaker
As stated in Example 13.1 it is always convenient to choose the same CT and Current Tap Settings for backup breakers. Therefore:

R2
CT Ratio: 100:5
Current Tap Setting: 6.0 Amps
TDS: ????? this is what we need to find!

We first need to find the maximum fault at bus 3 or seen by B2. You can perform all the same fault analyses as done above to determine the max. The maximum fault on bus 3 is a 3-Phase.

$$\left|I_f\right| = \frac{\frac{34.5k}{\sqrt{3}}}{j5 + j10 + j10} = 797$$

Relay Pick Up is… $\frac{797}{(100/5)} = 39.85$

Which is $\frac{39.85}{6.0} = 6.64$ times the tap setting

Looking at Figure 13.3 we can determine that **R3's operating time is approximately .14**. To find the lower limit for R2's operating time we must add in the synchronizing time.

$$OperatingTime_{R2} = .14 + .3 = .44$$

This gives us a **TDS of 1.5**

13.4

Deriving the new Thevenin equivalent circuits:

$$Z_{a'g}^{+} = j5 + j2 + j2 + j2 = j11$$

$$Z_{a'g}^{-} = j5 + j2 + j2 + j2 = j11$$

$$Z_{a'g}^{0} = j5 + j6 + j6 + j6 = j23$$

Using the same circuits as 13.1, just with new impedances

SLG Fault

$$\frac{I_f}{3} = \frac{\frac{34.5k}{\sqrt{3}}}{j11 + j11 + j23} = 443$$

$$\left|I_f\right| = 1328 Amps$$

DLG Fault

$$I_a^+ = \frac{\frac{34.5k}{\sqrt{3}}}{(j11 \| j23) + j11} = 1080.11\angle -90°$$

Current Divider

$$I_a^- = 1080.11\angle -90° \left(\frac{j23}{j11 + j23}\right) = 730.67\angle 90°$$

$$I_a^0 = 1080.11\angle -90° \left(\frac{j11}{j11 + j23}\right) = 349.449\angle 90°$$

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} 349.449\angle 90° \\ 1080.11\angle -90° \\ 730.67\angle 90° \end{bmatrix} = \begin{bmatrix} 0 \\ 1653 \\ 1653 \end{bmatrix}$$

$$\left|I_f\right| = 1653 Amps$$

3-Phase

$$\left|I_f\right| = \frac{\frac{34.5k}{\sqrt{3}}}{j11} = 1811 Amps$$

<u>Line to Line</u>

$$I_b^{34} = -j\sqrt{3}\left(\frac{\frac{34.5k}{\sqrt{3}}}{j11 + j11}\right) = -1568.18$$

$$I_{34}^{c} = -I_{34}^{b} = 1568.18$$

$$\left|I_f\right| = 1568 Amps$$

The smallest current is the SLG; 1328 Amps.

Setting R3 with a safety factor of 3

Breaker Pick Up is… $\frac{1328}{3} = 443 Amps$

Pick a **CT Ratio of 450:5**

Relay Pick Up is… $\frac{443}{(450/5)} = 4.92$

Current Tap Setting = 5.0
We want the breaker to act as quick as possible therefore choose the **TDS=1/2**

B2 is the backup breaker

As stated in Example 13.1 it is always convenient to choose the same CT and Current Tap Settings for backup breakers. Therefore:

R2
CT Ratio: 450:5
Current Tap Setting: 5.0 Amps
TDS: ????? this is what we need to find!

We first need to find the maximum fault at bus 3 or seen by B2. You can perform all the same fault analyses as done above to determine the max. The maximum fault on bus 3 is a 3-Phase.

$$\left|I_f\right| = \frac{\frac{34.5k}{\sqrt{3}}}{j5 + j2 + j2} = 2213$$

Relay Pick Up is… $\frac{2213}{(450/5)} = 24.59$

Which is $\frac{24.59}{5.0} = 4.9$ times the tap setting

Looking at Figure 13.3 we can determine that **R3's operating time is approximately .15**. To find the lower limit for R2's operating time we must add in the synchronizing time.

$$OperatingTime_{R2} = .15 + .3 = .45$$

This gives us a **TDS of 1.3**

13.5

For a fault between buses 2 and 3 we once again assume that the line impedance between the buses is halved

Deriving the new positive sequence Thevenin equivalent circuit:

$$Z_{a'g}^{+} = j5 + j2 + j1 = j8$$

<u>3-Phase</u>

$$\left|I_f\right| = \frac{\frac{34.5k}{\sqrt{3}}}{j8} = 2490\,Amps$$

R2 Settings from 13.4
CT Ratio: 450:5
Current Tap Setting: 5.0 Amps
TDS: 1.3

Relay Pick Up is… $\frac{2490}{(450/5)} = 27.6667$

Which is $\frac{27.6667}{5.0} = 5.53$ times the tap setting

With the TDS set at 1.3 from the Figure 13.3 curves we get an **operation time of approximately .4 seconds.**