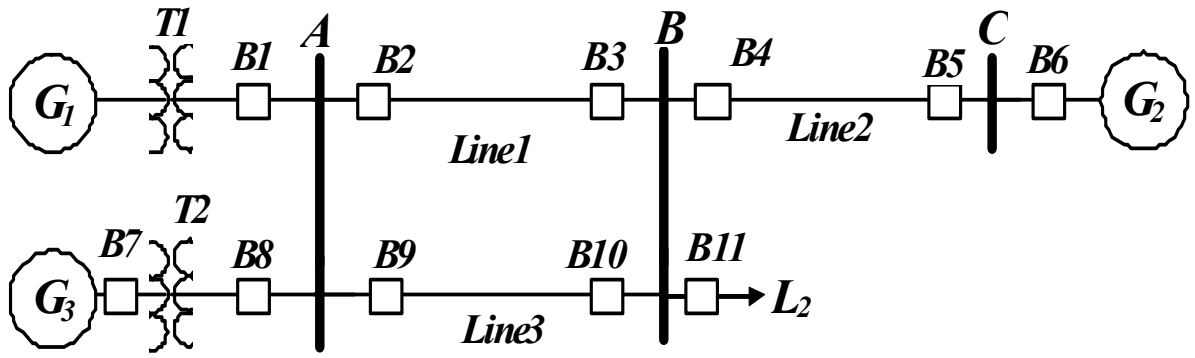
Tutorial 10: Protection Zone and Overcurrent Protection

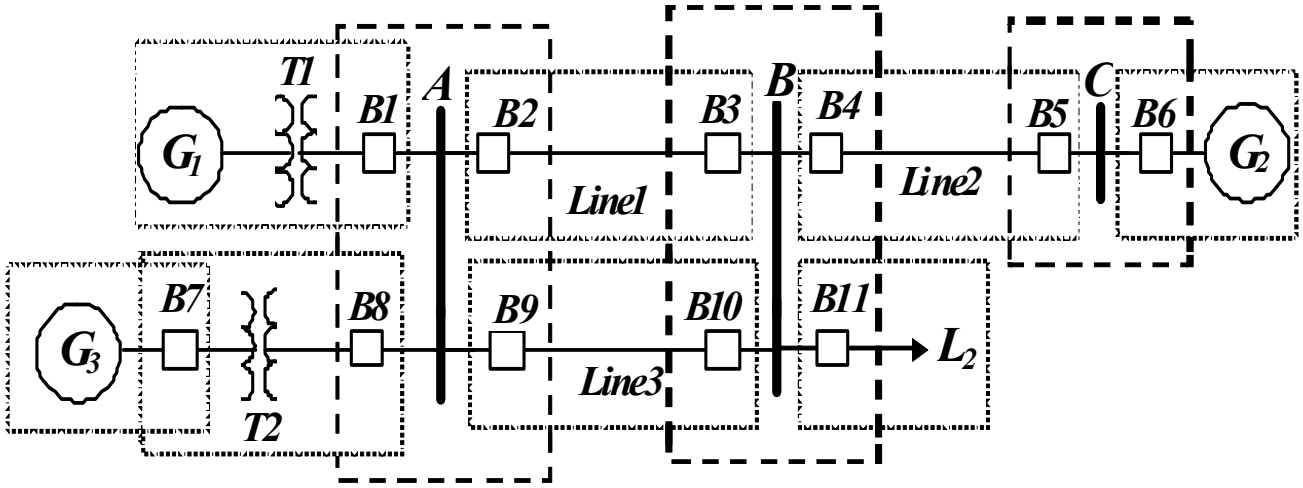
10.1: The system is shown in the following figure. Assuming that all the circuit breakers operated correctly, determine the fault locations for each of the following cases.

Case 1: B2 and B3
Case 2: B7, B8, B1, B2 and B9
Case 3: B6
Case 4: B11
Case 5: B2, B3, B4, B10and B11
Case 6: B3, B4, B10and B11



Solution:

The main protection zones based on the locations of the breakers are shown in the following figure.



The fault locations are as follows:

Case 1 (B2 and B3): The zone of Line1 excluding overlapping areas with the zones of buses A and B

Case 2 (B7, B8, B1, B2 and B9): The overlapping area of the zones of transformer T2 and bus A.

Case 3 (B6): The zone of G2 excluding overlapping area with the zone of bus C.

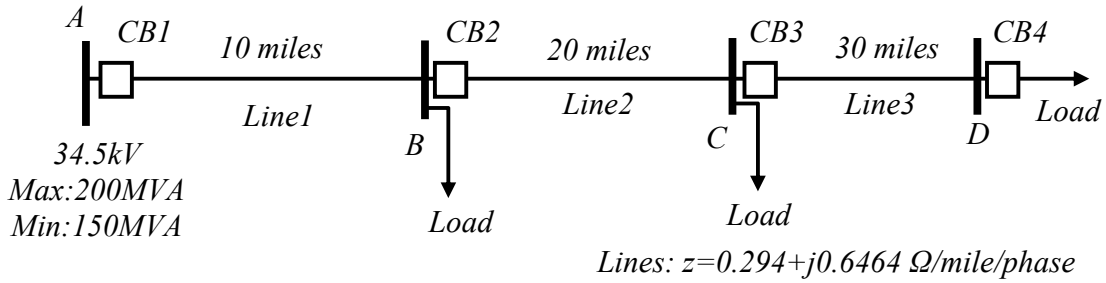
Case 4 (B11): The zone of L2 excluding overlapping area with the zone of bus B.

Case 5 (B2, B3, B4, B10 and B11): The overlapping area of the zones of Line1 and bus B.

Case 6 (B3, B4, B10and B11): The zone of bus B excluding overlapping areas with the zones of Line1, Line2 and Line 3.

10.2: A 50-Hz radial distribution system and the data are shown in the figure. The maximum and minimum fault levels at bus A are 200 MVA and 150 MVA, respectively. The maximum and minimum loads for each of the three load points are 5 MVA and 3MVA, respectively. The power factors of the loads are the same. The CO-8 relays are selected to protect load and lines. The coordination time interval (CTI) for two adjacent relays is 0.3s. Ignore transmission losses when calculate the maximum load current. Ignore the operating time of the breakers.

1) **Select the CT ratio for the related relay at each bus.**
2) **Select current plug settings (PSs) for all the relays.**
3) **Select time dial settings (TDSs) for the phase relays R2 at bus B and R3 at bus C.**
4) **Calculate the operating time of R2 and R3 if a three phase to ground fault occurs at 10 miles to Bus C on line3 for the minimum system capacity.**



Solutions:

System impedances:

At maximum system capacity (200MVA):

$$Z_{s\,min} = j\frac{|V_{l-l}|^2}{|S|_{max}} = j\frac{34.5^2}{200} = j5.95125\Omega$$

Line impedances:

Line1: $Z_{l1} = z \times 10 = 2.94 + j6.464\Omega$

Line2: $Z_{l2} = z \times 20 = 5.88 + j12.928\Omega$

Line3: $Z_{l3} = z \times 30 = 8.82 + j19.392\Omega$

Maximum fault currents (for TDS settings):

At Bus D: $I_{FD\,max} = \dfrac{|V_p|\angle 0^0}{Z_{s\,min} + Z_{l1} + Z_{l2} + Z_{l3}} = 414.21\angle\left(-68.48^o\right)A$

At Bus C: $I_{FC\,max} = \dfrac{|V_p|\angle 0^0}{Z_{s\,min} + Z_{l1} + Z_{l2}} = 742.2\angle\left(-70.81^o\right)A$

At Bus B: $I_{FB\,max} = \dfrac{|V_p|\angle 0^0}{Z_{s\,min} + Z_{l1}} = 1561\angle\left(-76.68^o\right)A$

1) Determine the CT ratios (Maximum load):

CT3 and CT4: $I_{max} = \dfrac{|S|_{max\,load}}{|V_{l-l}|\sqrt{3}} = \dfrac{5}{34.5\times\sqrt{3}} = 84A$

Select Ratio$_{CT3}$= Ratio$_{CT4}$=100:5

CT2: $I_{max} = \dfrac{2\times|S|_{max\,load}}{|V_{l-l}|\sqrt{3}} = \dfrac{10}{34.5\times\sqrt{3}} = 168A$

Select Ratio$_{CT2}$= 200:5

CT1: $I_{max} = \dfrac{3\times|S|_{max\,load}}{|V_{l-l}|\sqrt{3}} = \dfrac{15}{34.5\times\sqrt{3}} = 252A$

Select Ratio$_{CT2}$= 300:5

2) Determine the PSs of the relays (200% Maximum load current):

R3 and R4: $I_{\max} = 84A$, **MOC$_{R3}$=2×84=168A**

$I'_{R3\,max} = \dfrac{MOC_{R3}}{CTratio} = \dfrac{168}{100/5} = 8.4A$. **Select PS$_{R3}$=10A**

R2: $I_{\max} = 168A$, **MOC$_{R2}$=2×168=336A**

$I'_{R2\,max} = \dfrac{MOC_{R2}}{CTratio} = \dfrac{336}{200/5} = 8.4A$. **Select PS$_{R2}$=10A**

R1: $I_{\max} = 252A$, **MOC$_{R1}$=2×252=504A**

$I'_{R1\,max} = \dfrac{MOC_{R1}}{CTratio} = \dfrac{504}{300/5} = 8.4A$. **Select PS$_{R1}$=10A**

3) Determine time dial settings of the relays

R4 relay: **(PS_4=10A) as the main protection for the load at Bus D, B4 should trip as fast as possible.**

Select TDS_{R4}=1/2 (the fastest setting)

The max fault current at bus D (414.12A):

$$MPC_{R4} = \frac{414.21/(100/5)}{10} = 2.07$$

The minimum trip time: T_{R4trip}= 0.6s

R3 relay as back up of R4: **(PS_3=10A)**

For the same fault current 414.12A, if R4 cannot operate, R3 should operate as the back up for R4.

Required fault clearing time for R3:

$T_{R3trip} = T_{R4trip}$ +CTI=0.6+0.3=0.9s.

For the same max fault current (414.12A):

$$MPC_{R3} = \frac{414.21/(100/5)}{10} = 2.07$$

Select TDS_{R3}=1

R3 trip time as the main protection for the fault at Bus C (742 A):

$$MPC_{R3} = \frac{742/(100/5)}{10} = 3.71$$

The minimum trip time of R3: T_{R3trip}=0.53s

R2 relay as back up of R3: **(PS_2=10A)**

For the same fault current 742A, if R3 cannot operate as the main protection, R2 should operate as the back-up for R3.

Required fault clearing time for R2:

$T_{R2trip} = T_{R3trip}$ +CTI=0.53+0.3=0.83s.

Using the same fault current (742 A) at Bus C:

$$MPC_{R2} = \frac{742/(200/5)}{10} = 1.855$$

From the curve, select TDS_{R2}=1

4) Calculate the operating time of R2 and R3

At minimum system capacity (100MVA):

$$Z_{s\max} = j\frac{|V_{l-l}|^2}{|S|_{\min}} = j\frac{34.5^2}{150} = j7.935\Omega$$

For the fault at 10 miles to Bus D, the impedance of line3:

$$Z_{l3} = z \times 10 = 2.94 + j6.464\Omega$$

The minimum fault current:

$$I_{F\min} = \frac{|V_p|\angle 0^0}{Z_{s\max} + Z_{l1} + Z_{l2} + Z_{l3}} = 556.68\angle\left(-70.8^o\right) A$$

Operating times:

R3: $MPC = \dfrac{556.68/(100/5)}{10} = 2.78$

From curve, T_{R3}=0.87s

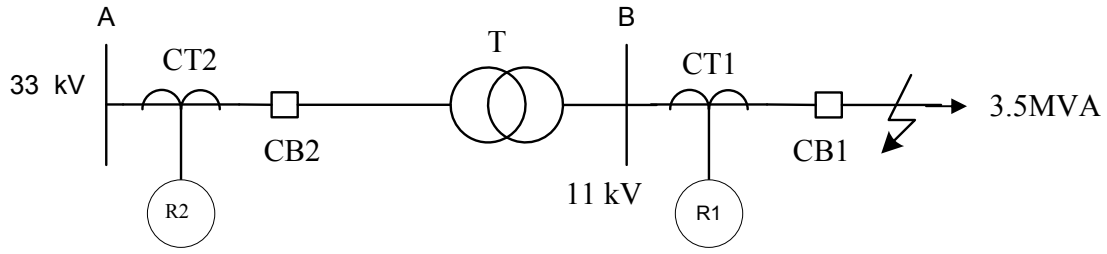
R2: $MPC = \dfrac{556.68/(200/5)}{10} = 1.39$

From curve, T_{R2}=5s

10.3: A 3.5 MVA rated load is supplied from 33 kV system bus through a 40MVA and 33Δ/11Y kV transformer with a leakage reactance of 15%. The fault level (or short circuit MVA) at 33 kV is 2000MVA. The relays R1 and R2 are IDMT relays with 5A rating. The time-current curve of the relay is represented by $t = \frac{0.14}{M^{0.02} - 1} TDS$. The TDSs are from 0.1 to 1 in the step of 0.1. The plug settings are from 50% to 200% of the relay rating in the step of 25%. The CT ratios for CT1 and CT2 are 400:5 and 300:5 respectively.

a. Determine the PSs and the TDSs of the phase relays if the required discrimination time or CTI between R2 and R1 is 0.4s.

b. Find the fault location and the minimum operating time of R2 based on the relay settings from part a.



Solutions:

a. Plug settings of the relays:

R1: $I_{max} = \frac{|S|_{max\ load}}{\sqrt{3}|V_{l-l}|} = \frac{3.5}{\sqrt{3} \times 11} = 184A$; **$MOC_{R1}$=2×184=368$A$**

$$I'_{R1\,max} = \frac{MOC_{R1}}{CTratio} = \frac{368}{400/5} = 4.6A$$; **I_{pickup}=5A (100%)**

R2: $I_{max} = \frac{|S|_{max\ load}}{\sqrt{3}|V_{l-l}|} = \frac{3.5}{\sqrt{3} \times 33} = 61A$; **$MOC_{R2}$=2×61=122**

$$I'_{R2\,max} = \frac{MOC_{R2}}{CTratio} = \frac{122}{300/5} = 2.03A$$; **I_{pickup}=2.5A (50%)**

Determine component *pu* impedances and *pu* currents:

Select S_{base}=2000MVA

V_{base}=33 kV (at Bus A); V_{base}=11 kV (at Bus B)

Base current at bus B: $I_{Bbase} = \frac{|S_{base}|}{\sqrt{3}|V_{l-l}|} = \frac{2000}{\sqrt{3} \times 11} = 104.97kA$

Base current at bus A: $I_{Abase} = \frac{|S_{base}|}{\sqrt{3}|V_{l-l}|} = \frac{2000}{\sqrt{3} \times 33} = 34.99kA$

Source reactance: $Z_{spu} = j\frac{|V|^2_{pu}}{|S_{pu}|} = j\frac{1}{2000/2000} = j1.0$

Transformer reactance: Z_{tpu}=2000/40×j0.15=j7.5

Determine the fault currents for the fault at bus B:

$$I_{pu} = \frac{V_{pu}}{Z_{Tpu}} = \frac{1}{j1 + j7.5} = -j0.1176$$

Fault current through CT1: $I = I_{pu} \times I_{Bbase} = 12.35kA$

Fault current through CT2: $I = I_{pu} \times I_{Abase} = 4.12kA$

Determine TDS of R1:

Select *TDS*=0.1 because it is the last relay of the system

CT1 secondary fault current: $I = \frac{12.35kA}{400/5} = 154.375A$

Multiples of pickup current: $M = 154.375/5A = 30.875$

The minimum operating time of R1: $t = \frac{0.14}{M^{0.02} - 1}TDS = 0.197s$

Step 5: TDS of R2 (as back up) for the same fault:

CT2 secondary current at Bus A: $I = \frac{4.12kA}{300/5} = 68.6A$

Multiples of pickup current: $M = 68.6 / 2.5A = 27.4$

Require operating time of R2: $t \geq 0.197s + 0.4s = 0.597s$

$$t = \frac{0.14}{M^{0.02} - 1} TDS \geq 0.197s + 0.4s = 0.597s$$

$$TDS \geq 0.597 \frac{M^{0.02} - 1}{0.14} = 0.291$$ **Select TDS=0.3**

b. R2 has the minimum operating time when the fault occurs at bus A (the maximum fault current)

Fault level at 33 kV bus A: $S = 2000MVA$

Fault current through CT2: $I = \frac{|S|}{\sqrt{3}|V_{l-l}|} = \frac{2000}{\sqrt{3} \times 33} = 34.99kA$

CT secondary current: $I = \frac{34.99kA}{300/5} = 583.18A$

$M = 583.18 / 2.5A = 233.26$

Operating time of R2:

$$t = \frac{0.14}{M^{0.02} - 1} = \frac{0.14}{233.26^{0.02} - 1} = 0.364s$$