Calculate the phase voltages and currents for the ABC fault using symmetrical components (assuming RL in ground path):

\[ V \] 

Define a vector of RL values to use for part C:

\[ Z_{\text{Theo}0} = 2.973 + 13.642 \] 
\[ Z_{\text{Theo}2} = 0.626 + 5.961 \] 
\[ Z_{\text{Theo}1} = 0.626 + 5.961 \]


Sequence Impedances to leg of fault:

- \( Z_{L1} = Z_{L2} + Z_{L3} \)
- \( Z_{L0} = Z_{S0} + m \cdot Z_{L0} \)
- \( Z_{L1} = Z_{S1} + m \cdot Z_{L1} \)
- \( Z_{L2} = Z_{S2} + m \cdot Z_{L2} \)
- \( Z_{L3} = Z_{S3} + m \cdot Z_{L3} \)

Pre-fault voltage:

- \( \Delta V \) = \( E_f \) - \( E_s \)

All in secondary ohms:

- \( Z_L = 1.2 \text{ohms} \)
- \( Z_S = 2 \text{ohms} \)
- \( Z_{L0} = 1.2 \text{ohms} \)
- \( Z_{S0} = 2 \text{ohms} \)

Impact of Fault Resistance
Impedance to the fault point.

Notice that all three apparent impedances are at the same point (the fault location) for $R_f = 0$ and that this is the line.

\[
\text{Re}(\text{linear}), \text{Re}(\text{zone 1}), \text{Re}(\text{zone 2}), \text{Re}(\text{zone 3})
\]
We see here that MFB falls below Z1 IMG, as was also illustrated with the inho circles.

Note that MFB is always equal to Z1 IMG (so it does not vary with RL).

\[
\text{MFB} = \text{Re} \left[ \frac{\text{Im} \left( \frac{1}{1 - \lambda \text{abc}(R_f)} \right) \text{Z1 IMG}}{\text{Im} \left( \frac{1}{1 - \lambda \text{abc}(R_f)} \right) \text{abc}(R_f)} \right] 
\]

\[
\text{MFB} = \text{Re} \left[ \frac{\text{Im} \left( \frac{1}{1 - \lambda \text{abc}(R_f)} \right) \text{Z1 IMG}}{\text{Im} \left( \frac{1}{1 - \lambda \text{abc}(R_f)} \right) \text{abc}(R_f)} \right] 
\]

Not required for the problem, but we could also look at these using the M-estimations (self-polynized for now).
Under reach - fail to trip the zone

Over reach - trip for a fault beyond the zone
This result is unchanged.
Since there is no fault resistance,
Notice that ZBC and ZCG now vary more as straight lines, and ZBC varies in a straight line.
\[
\begin{align*}
\left( R_f + I V_{ABCA} R_f \right) & \cdot \left( R_f + I V_{ABCA} R_f \right) \cdot \left( V_{ABCA} R_f \right) \\
\left( R_f + I V_{ABCA} R_f \right) & \cdot \left( R_f + I V_{ABCA} R_f \right) \\
\left( R_f + I V_{ABCA} R_f \right) & \cdot \left( R_f + I V_{ABCA} R_f \right)
\end{align*}
\]
Note from the figure

\[ \theta_{0,2} := \arg(I_{A0}) - \arg(I_{A2}) \quad \theta_{0,2} = -240.14 \, \text{deg} \]

\[ I_{0,2 \text{ang}} := \begin{cases} 
(\theta_{0,2} + 360 \, \text{deg}) & \text{if } \theta_{0,2} < -180 \, \text{deg} \\
(\theta_{0,2} - 360 \, \text{deg}) & \text{if } \theta_{0,2} > 180 \, \text{deg} \\
\theta_{0,2} & \text{otherwise}
\end{cases} \]

\[ I_{0,2 \text{ang}} = 119.86 \, \text{deg} \]

\[ FSA := \begin{cases} 
1 & \text{if } (-30 \, \text{deg} \leq I_{0,2 \text{ang}} \leq 30 \, \text{deg}) \\
0 & \text{otherwise}
\end{cases} \]

\[ FSA = 0 \quad \text{Since } FSA=0, \text{ the fault is NOT AG or BCG} \]

\[ FSB := \begin{cases} 
1 & \text{if } (90 \, \text{deg} \leq I_{0,2 \text{ang}} \leq 150 \, \text{deg}) \\
0 & \text{otherwise}
\end{cases} \]

\[ FSB = 1 \quad \text{Since } FSB=1, \text{ the fault is either BG or CAG} \]

\[ FSC := \begin{cases} 
1 & \text{if } (-150 \, \text{deg} \leq I_{0,2 \text{ang}} \leq -90 \, \text{deg}) \\
0 & \text{otherwise}
\end{cases} \]

\[ FSC = 0 \quad \text{Since } FSC=0, \text{ the fault is NOT CG or ABG} \]