ECE 526

PROTECTION OF POWER SYSTEMS II

SESSION no. 6

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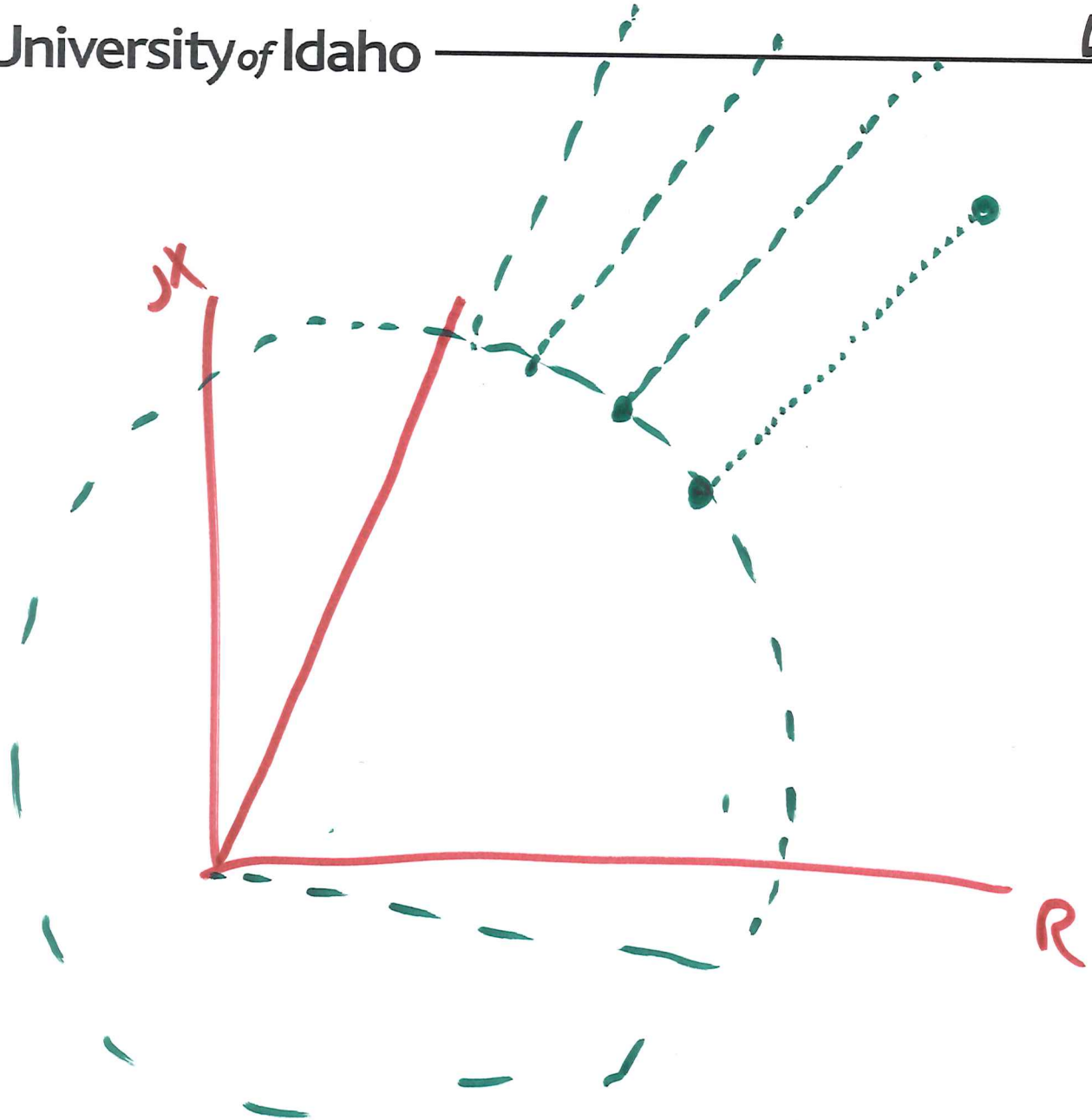

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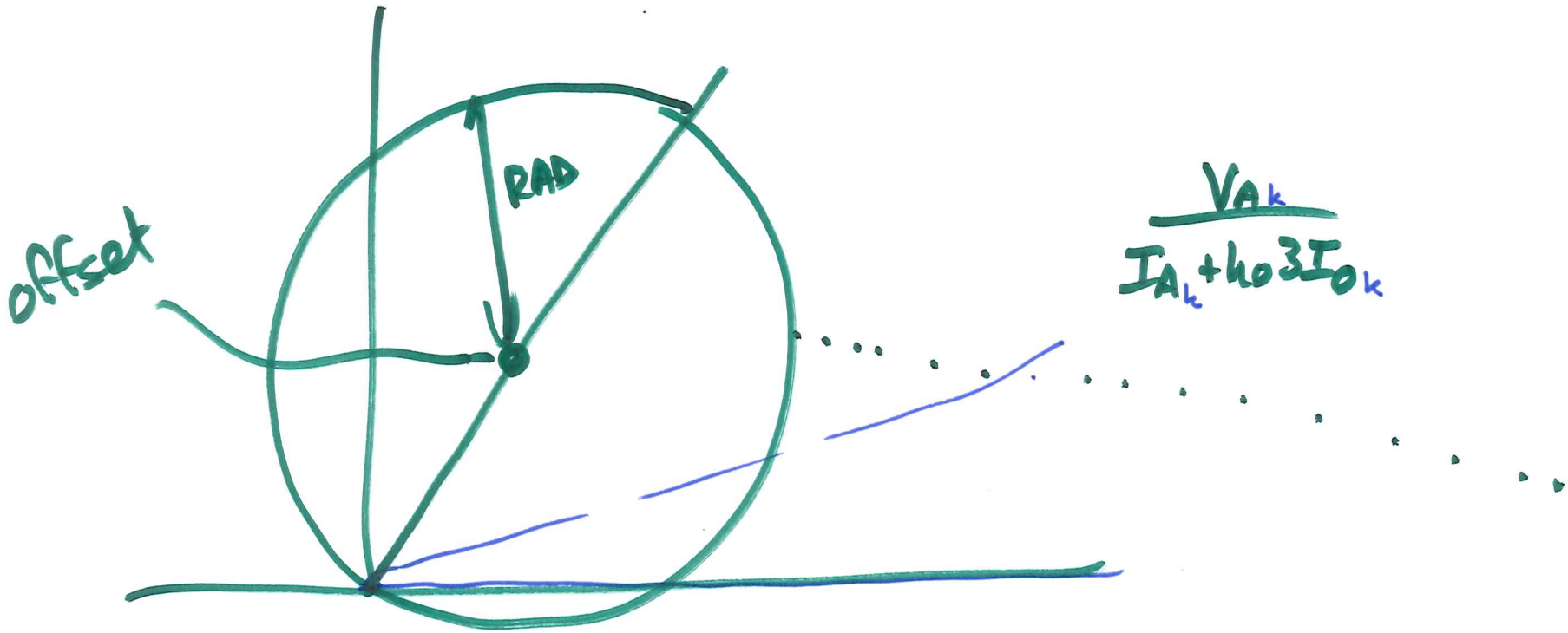


$$\left| \bar{Z}_{AG_k} - \bar{Z}_{center} \right| < \text{Radius}$$

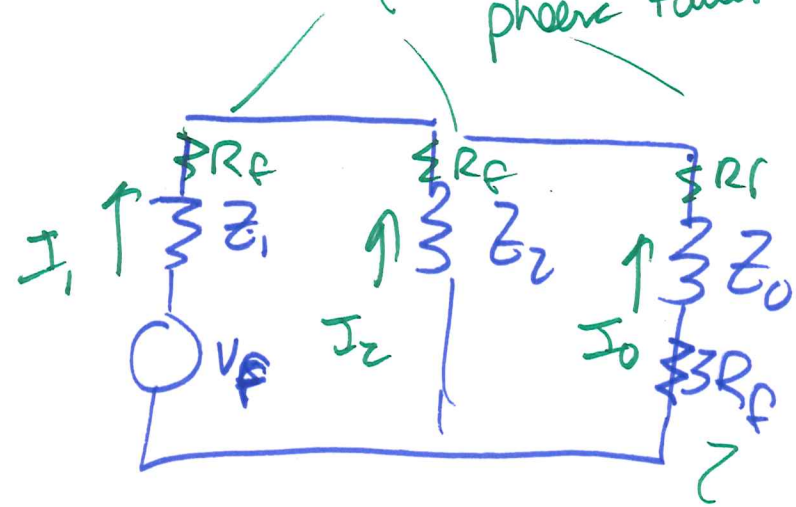
Thevenin equivalent (not counting fault resistance)

$$Z_{Thev1} := \left(\frac{1}{Z_{Left1}}\right)^{-1} \qquad Z_{Thev1} = (0.626 + 5.96i)\,\Omega$$

$$Z_{Thev2} := \left(\frac{1}{Z_{Left2}}\right)^{-1} \qquad Z_{Thev2} = (0.626 + 5.96i)\,\Omega$$

$$Z_{Thev0} := \left(\frac{1}{Z_{Left0}}\right)^{-1} \qquad Z_{Thev0} = (2.973 + 13.642i)\,\Omega$$

phase to phase fault R



Define a vector of R_f values to use for part C

$$R_f := 0ohm, 1.0ohm .. 10.0ohm$$

Calculate the phase voltages and currents for a BCG fault using symmetrical componenets (assume Rf in ground path): In N-G

$$V_f := E_s \qquad V_f = 70\,V$$

$$I_{1F}(R_f) := \frac{V_f}{Z_{Thev1} + \left(\frac{1}{Z_{Thev2}} + \frac{1}{Z_{Thev0} + 3\cdot R_f}\right)^{-1}}$$

$$I_{0F}(R_f) := -I_{1F}(R_f)\cdot\left[\frac{Z_{Thev2}}{Z_{Thev2} + (Z_{Thev0} + 3\cdot R_f)}\right]$$

$$I_{2F}(R_f) := -I_{1F}(R_f)\cdot\left[\frac{Z_{Thev0} + 3\cdot R_f}{Z_{Thev2} + (Z_{Thev0} + 3\cdot R_f)}\right]$$

$$V_1(R_f) := V_f - I_{1F}(R_f)\cdot Z_{S1}$$

$$V_2(R_f) := 0 - I_{2F}(R_f)\cdot Z_{S2}$$

$$V_0(R_f) := 0 - I_{0F}(R_f)\cdot Z_{S0}$$

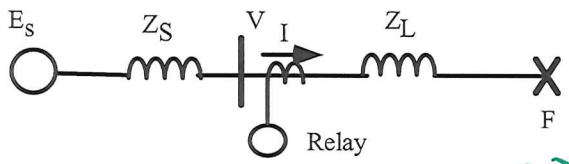
at relay location

Impact of Fault Resistance

$a := 1 \cdot e^{j \cdot 120deg}$ $\qquad A_{012} := \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}$

1. The system below has a BCG fault at location "F". Calculate the following:

A. The angle between I_0 and I_2 (the result should be ang(I_0) - ang(I_2)).



$Z_{S1} := 2ohm \cdot e^{j \cdot 88deg}$ $\qquad Z_{L1} := 4ohm \cdot e^{j \cdot 82deg}$ $\qquad E_s := 70V \cdot e^{j \cdot 0deg}$

$Z_{S2} := Z_{S1}$ $\qquad Z_{L2} := Z_{L1}$

$Z_{S0} := 2ohm \cdot e^{j \cdot 88deg}$ $\qquad Z_{L0} := 12ohm \cdot e^{j \cdot 76deg}$

All in secondary ohms

- Prefault voltage. $\qquad V_{pre} := E_s \qquad V_{pre} = 70\,V$

Sequence impedances to left of fault:

$m := 1$ $\qquad Z_{Left1} := Z_{S1} + m \cdot Z_{L1} \qquad Z_{Left1} = (0.626 + 5.96i)\,\Omega$

$Z_{Left2} := Z_{S1} + m \cdot Z_{L1} \qquad Z_{Left2} = (0.626 + 5.96i)\,\Omega$

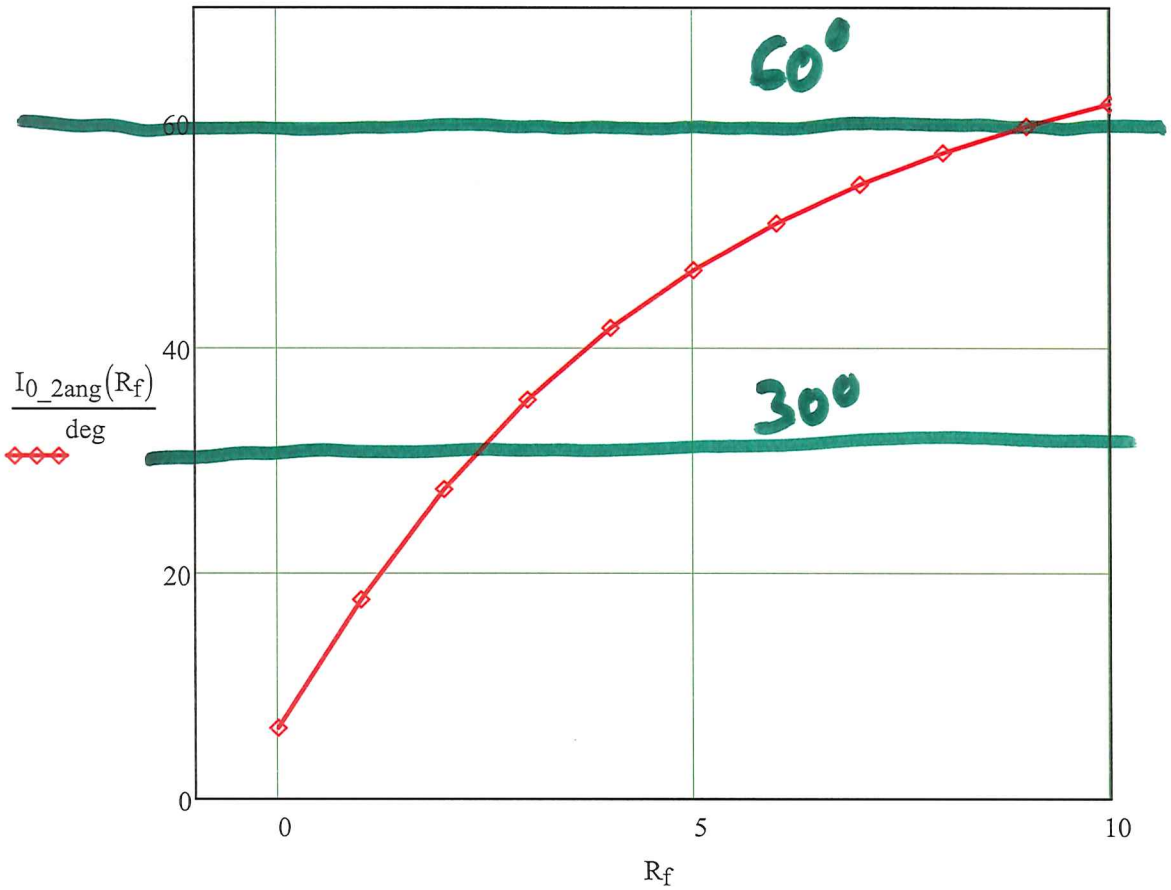
$Z_{Left0} := Z_{S0} + m \cdot Z_{L0} \qquad Z_{Left0} = (2.973 + 13.642i)\,\Omega$

$$I_{ABC}(R_f) := A_{012}\cdot\begin{pmatrix} I_{0F}(R_f) \\ I_{1F}(R_f) \\ I_{2F}(R_f) \end{pmatrix} \qquad V_{ABC}(R_f) := A_{012}\cdot\begin{pmatrix} V_0(R_f) \\ V_1(R_f) \\ V_2(R_f) \end{pmatrix}$$

- ***Part A (and C) plot the angle of (I0) minus the angle of (I2) for Rf=0 to Rf=10:***

$$I_{0\_2ang}(R_f) := \arg(I_{0F}(R_f)) - \arg(I_{2F}(R_f))$$

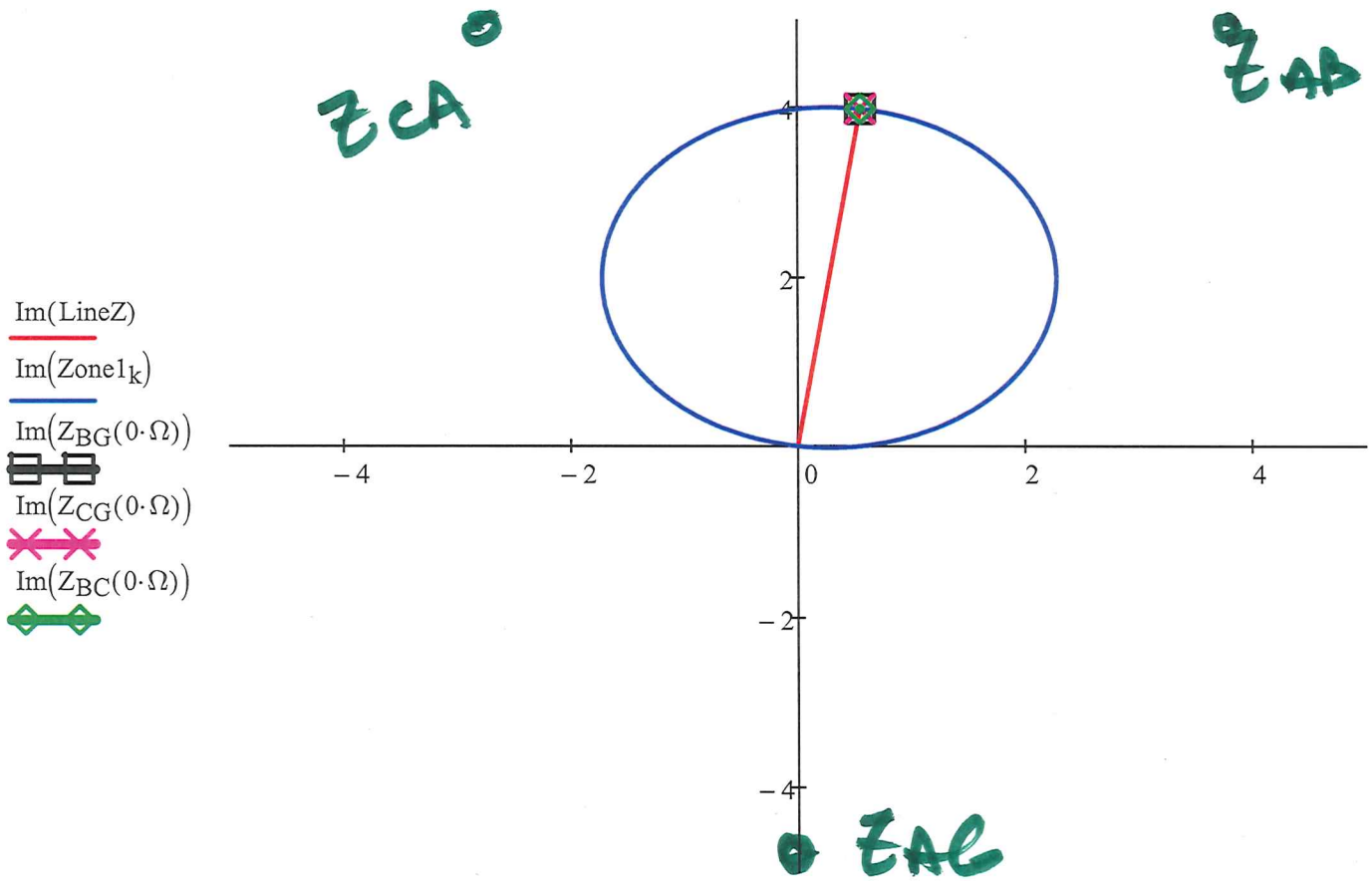
$I_{0\_2ang}(0ohm) = 6.293\cdot deg$



In tabular form:

R_f =	
0	Ω
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

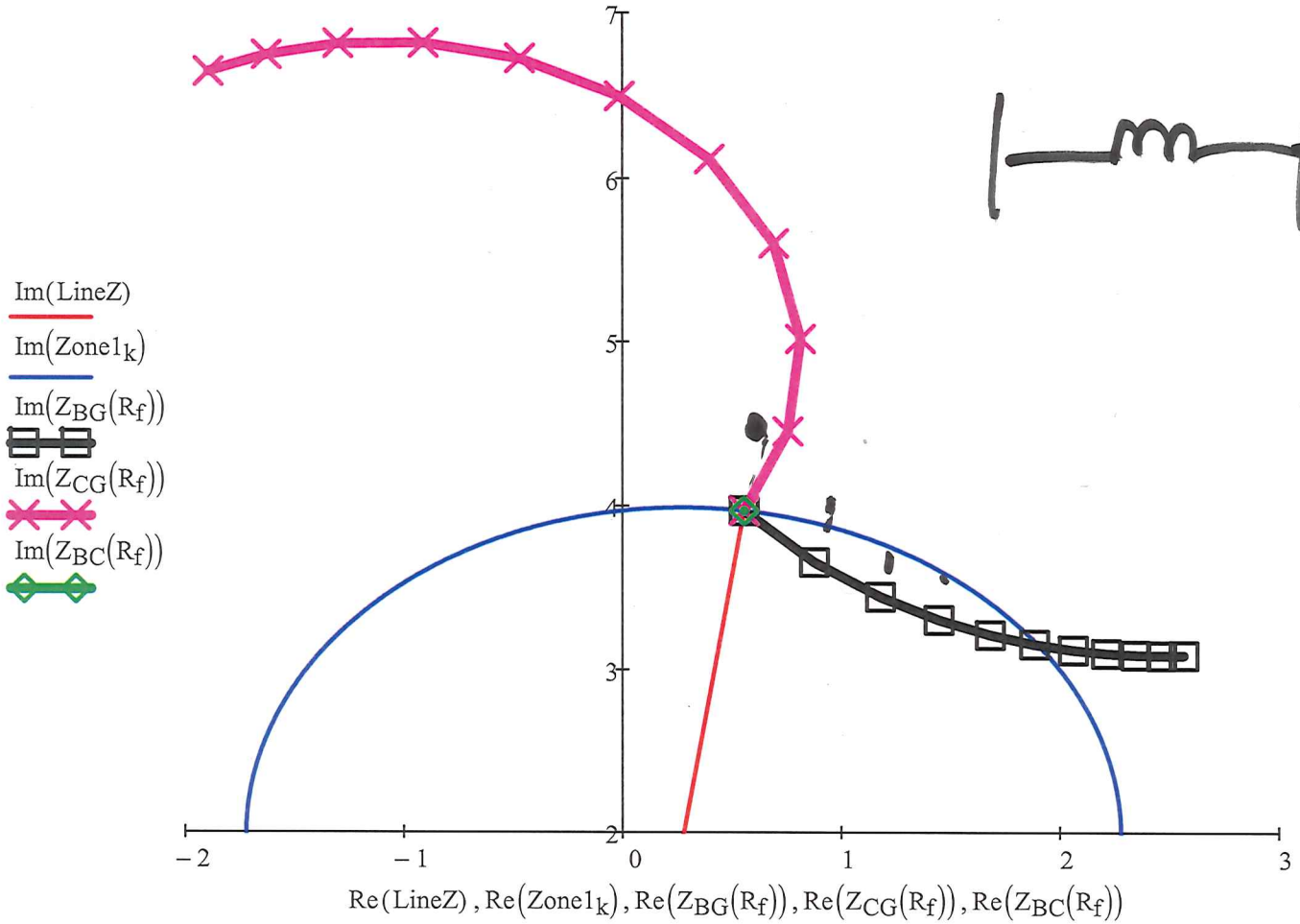
$I_{0\_2ang}(R_f)$ =	
6.293	·deg
17.644	
27.333	
35.27	
41.661	
46.799	
50.956	
54.356	
57.17	
59.526	
61.522	



$\mathrm{Re}(\mathrm{LineZ}), \mathrm{Re}(\mathrm{Zone1}_k), \mathrm{Re}(Z_{BG}(0\cdot\Omega)), \mathrm{Re}(Z_{CG}(0\cdot\Omega)), \mathrm{Re}(Z_{BC}(0\cdot\Omega))$

- Notice that all three apparent imepdances are at the same point (the fault location) for Rf = 0 and that this is the line impedance to the fault point.

- Repeat the plot, zooming in a bit
- ZBC does not move (there is not fault resistance phase to phase, only phase to ground)



$|Z|\angle\theta_Z$

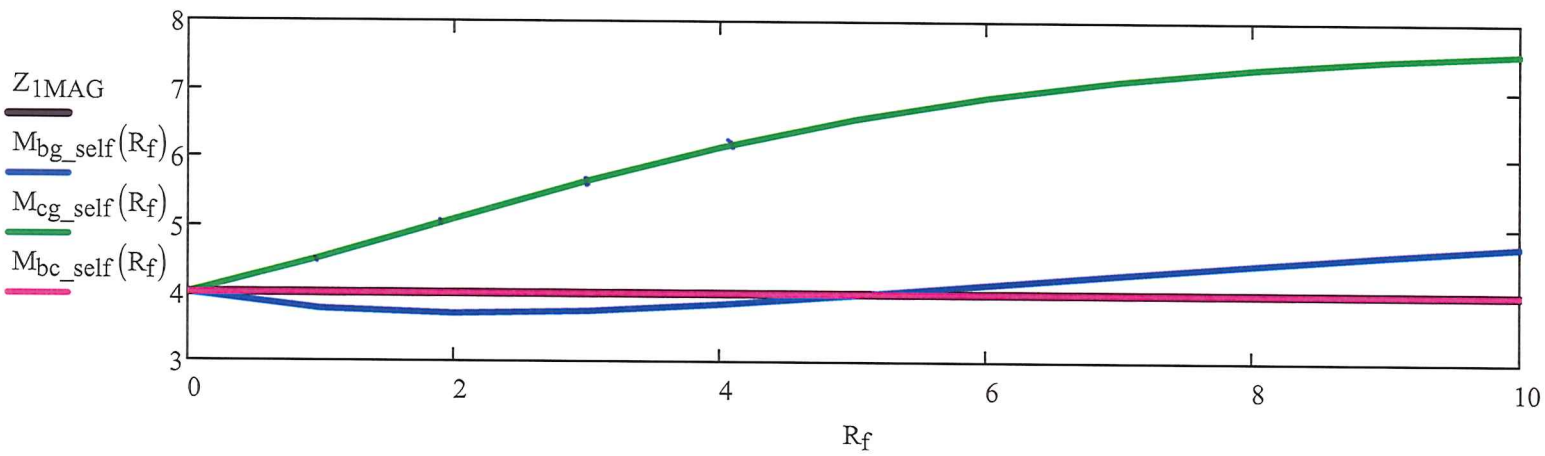
- Not required for the problem, but we could also look at these using the M-equations (self polarized for now):

$$M_{bg\_self}(R_f) := \frac{\mathrm{Re}\left(V_{ABC}(R_f)_1 \cdot \overline{V_{ABC}(R_f)_1}\right)}{\mathrm{Re}\left[\left(1 \cdot e^{j \cdot Z_{1ANG}}\right) \cdot \left(I_{ABC}(R_f)_1 + k_0 \cdot 3\, I_{0F}(R_f)\right) \cdot \left(\overline{V_{ABC}(R_f)_1}\right)\right]}$$

V_{pol}^* $\quad$ V_{pol}^* $\quad$ $M_b|Z_1|\angle$

$$M_{cg\_self}(R_f) := \frac{\mathrm{Re}\left(V_{ABC}(R_f)_2 \cdot \overline{V_{ABC}(R_f)_2}\right)}{\mathrm{Re}\left[\left(1 \cdot e^{j \cdot Z_{1ANG}}\right) \cdot \left(I_{ABC}(R_f)_2 + k_0 \cdot 3\, I_{0F}(R_f)\right) \cdot \left(\overline{V_{ABC}(R_f)_2}\right)\right]}$$

$$M_{bc\_self}(R_f) := \frac{\mathrm{Re}\left[\left(V_{ABC}(R_f)_1 - V_{ABC}(R_f)_2\right) \cdot \overline{\left(V_{ABC}(R_f)_1 - V_{ABC}(R_f)_2\right)}\right]}{\mathrm{Re}\left[\left(1 \cdot e^{j \cdot Z_{1ANG}}\right) \cdot \left(I_{ABC}(R_f)_1 - I_{ABC}(R_f)_2\right) \cdot \left[\overline{\left(V_{ABC}(R_f)_1 - V_{ABC}(R_f)_2\right)}\right]\right]}$$



- Note that: Mbc is always equal to Z1mag (so it does not vary with Rf).
- We see here that Mbg falls below Z1mag, as was also illustrated with the mho circles.

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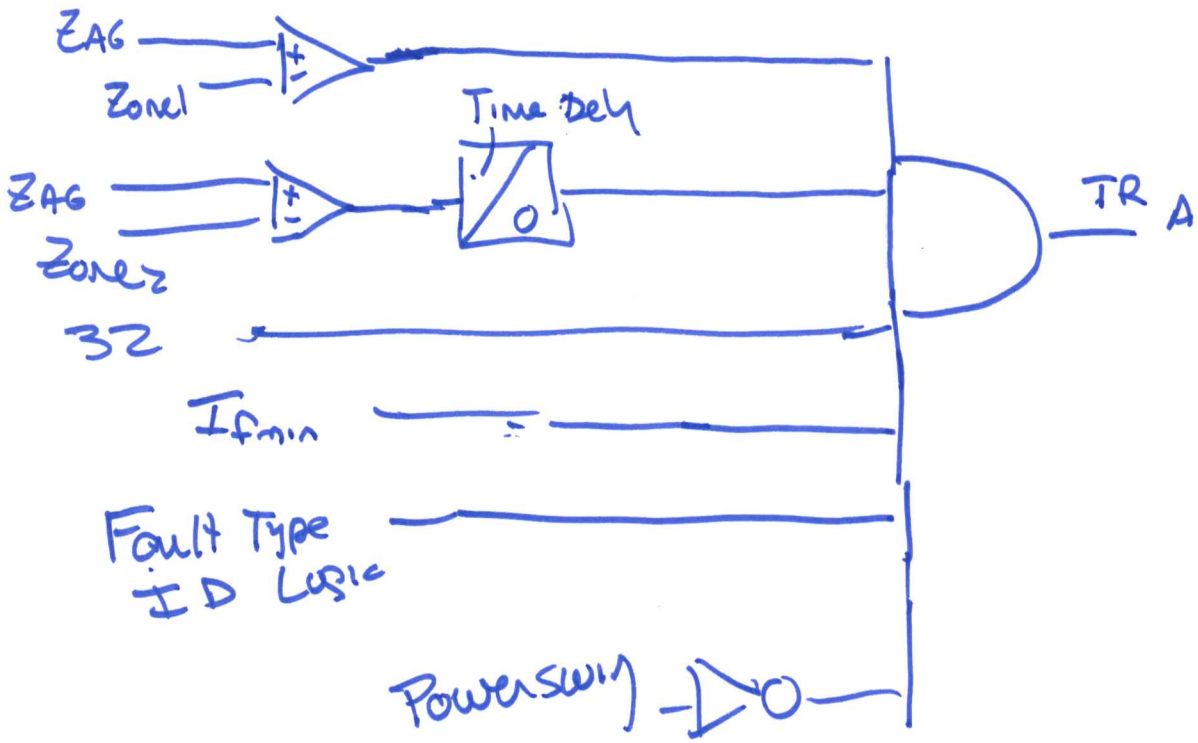
ZAG
Zone1
Time Dely
ZAG
Zone2
TR
A
32
Ifmin
Fault Type
ID Logic
Powerswing

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Overreach - Trip for a fault beyond the zone

Underreach - fail to trip for a fault in the zone

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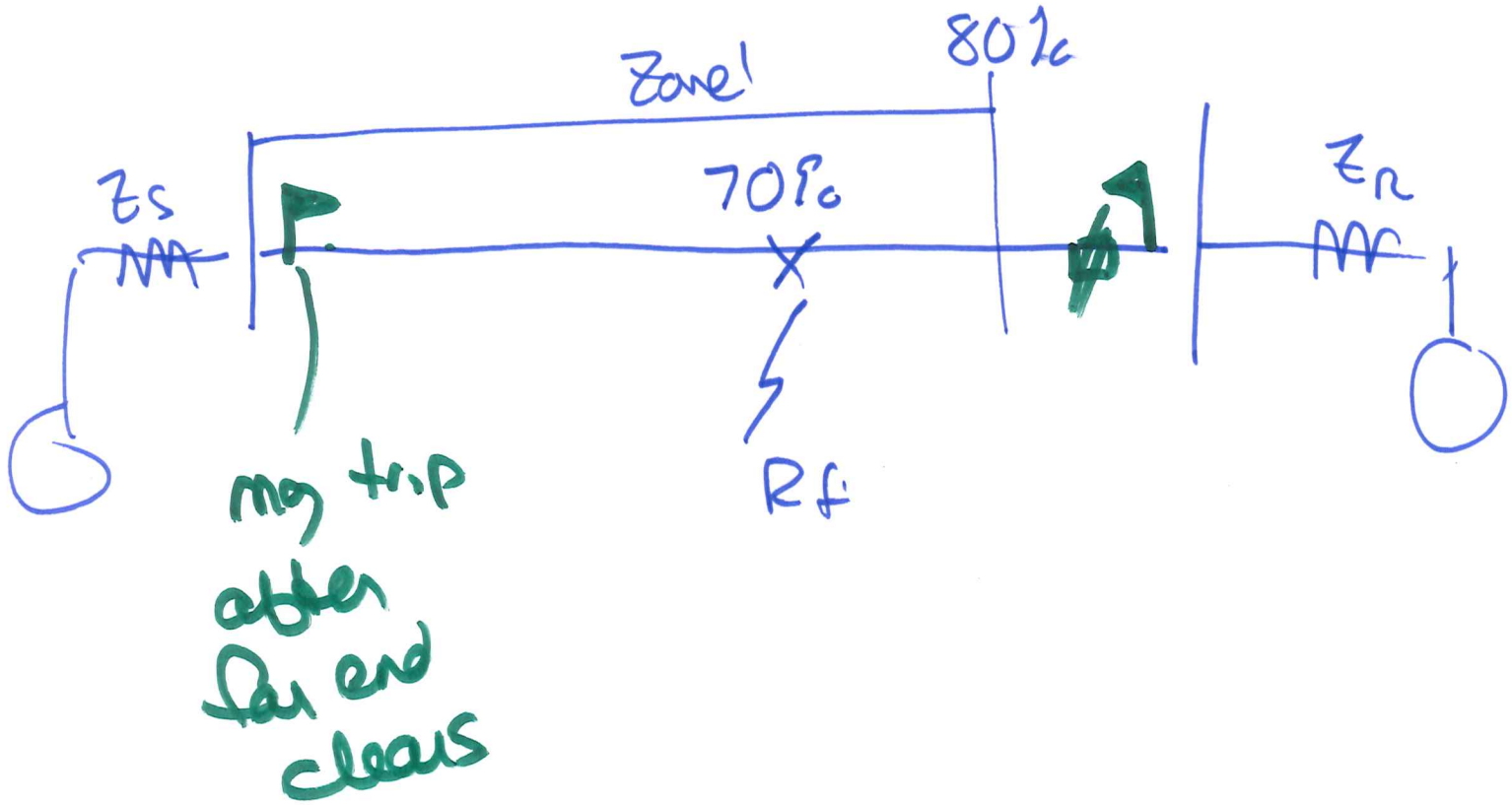

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Tabular format of the results (not required):

$R_f =$

0	Ω
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

$Z_{BCa}(R_f) =$ Ω

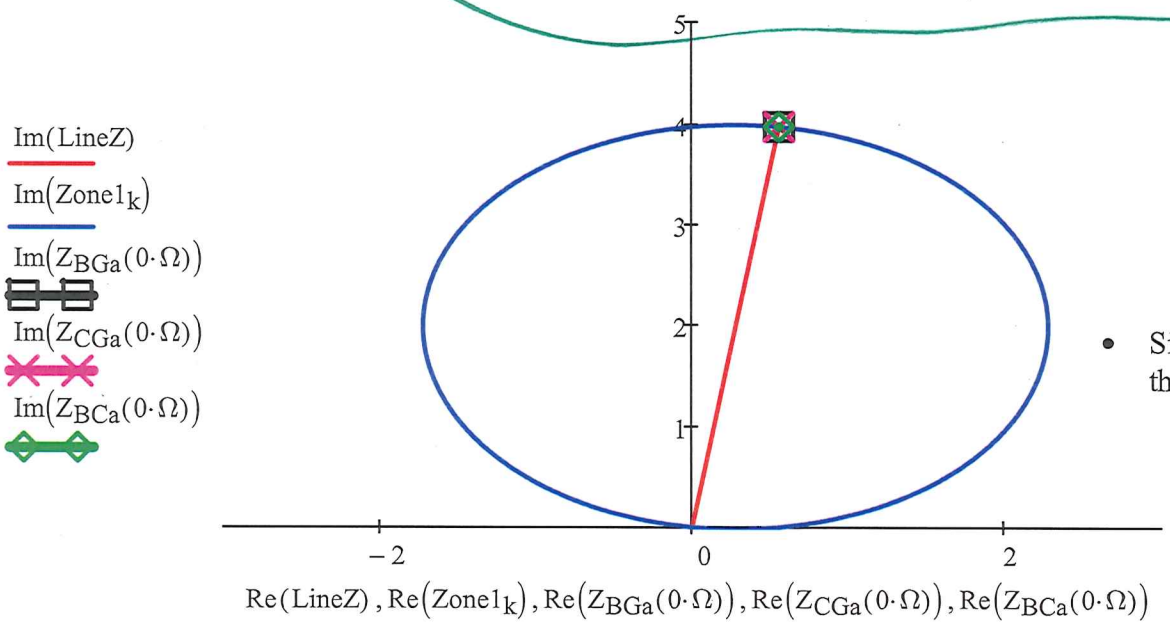
	0
0	0.557+3.961i
1	1.557+3.961i
2	2.557+3.961i
3	3.557+3.961i
4	4.557+3.961i
5	5.557+3.961i
6	6.557+3.961i
7	7.557+3.961i
8	8.557+3.961i
9	9.557+3.961i
10	10.558+3.96i

$Z_{BGa}(R_f) =$ Ω

	0
0	0.557+3.961i
1	1.387+4.266i
2	2.22+4.615i
3	3.039+5.005i
4	3.833+5.43i
5	4.594+5.877i
6	5.322+6.334i
7	6.018+6.79i
8	6.689+7.239i
9	7.339+7.678i
10	7.976+8.104i

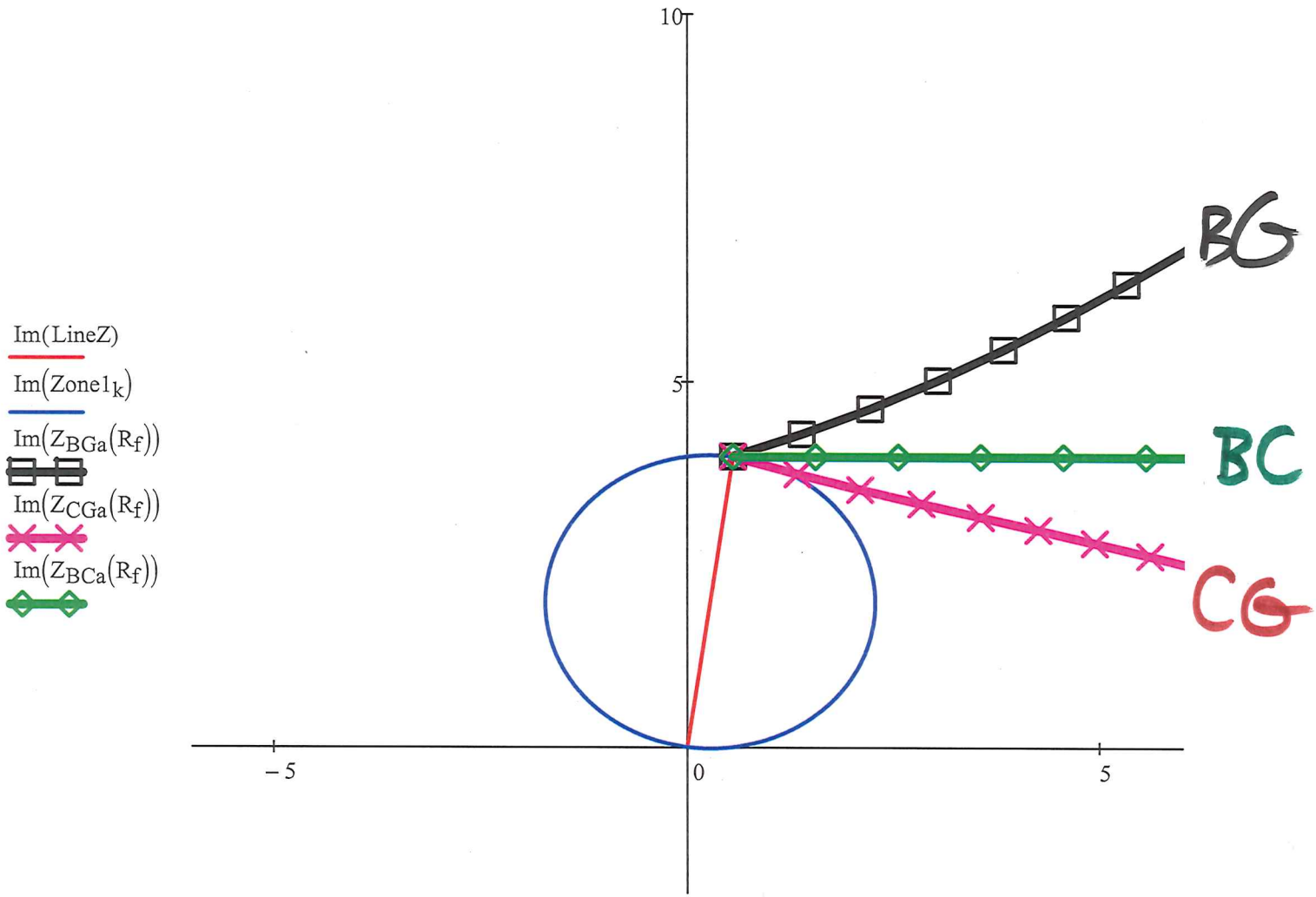
$Z_{CGa}(R_f) =$ Ω

	0
0	0.557+3.961i
1	1.338+3.722i
2	2.099+3.513i
3	2.838+3.323i
4	3.556+3.143i
5	4.254+2.969i
6	4.937+2.795i
7	5.607+2.62i
8	6.266+2.442i
9	6.918+2.261i
10	7.563+2.077i



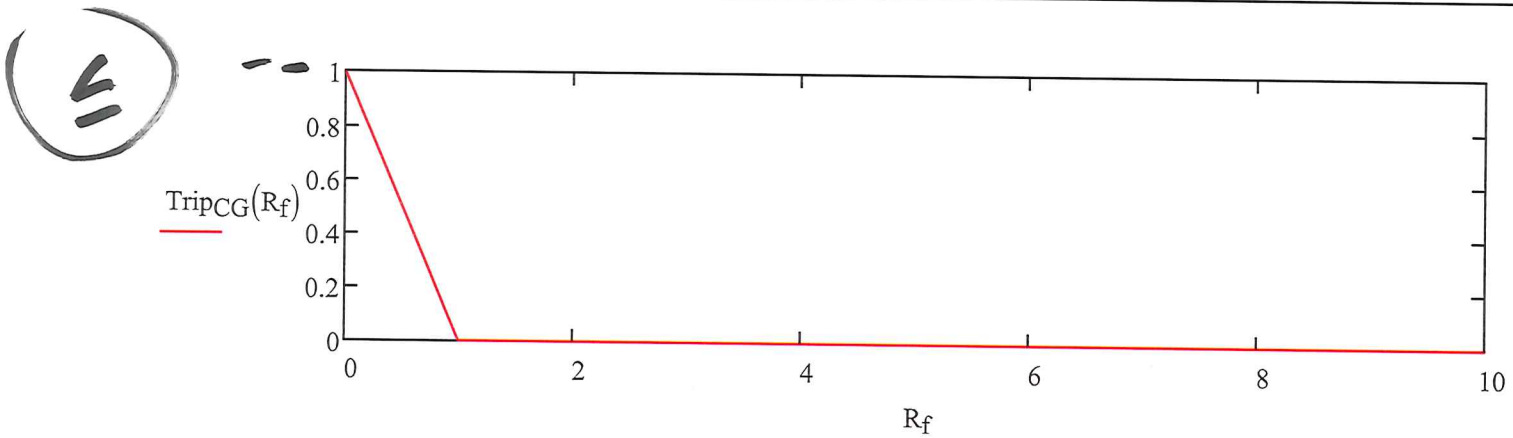
- Since there is no fault resistance, this result is unchanged

- ***Part C, with resistance varying from 0 to 10 ohm.***



$\mathrm{Re}(\mathrm{LineZ}), \mathrm{Re}(\mathrm{Zone1}_k), \mathrm{Re}(Z_{BGa}(R_f)), \mathrm{Re}(Z_{CGa}(R_f)), \mathrm{Re}(Z_{BCa}(R_f))$

- Notice that ZBG and ZCG now vary more as straight lines, and ZBC varies in a straight line.



- Zcg only intersects the Mho circle when the fault resistance is 0 and the fault is at the zone 1 boundary.

- Not required for the problem, but we could also look at these using the M-equations (self polarized for now):

$$M_{bg\_selfa}(R_f) := \frac{\mathrm{Re}\left(V_{ABCa}(R_f)_1 \cdot \overline{V_{ABCa}(R_f)_1}\right)}{\mathrm{Re}\left[\left(1 \cdot e^{j \cdot Z_{1ANG}}\right) \cdot \left(I_{ABCa}(R_f)_1 + k_0 \cdot 3\, I_{0Fa}(R_f)\right) \cdot \left(\overline{V_{ABCa}(R_f)_1}\right)\right]}$$

$$M_{cg\_selfa}(R_f) := \frac{\mathrm{Re}\left(V_{ABCa}(R_f)_2 \cdot \overline{V_{ABCa}(R_f)_2}\right)}{\mathrm{Re}\left[\left(1 \cdot e^{j \cdot Z_{1ANG}}\right) \cdot \left(I_{ABCa}(R_f)_2 + k_0 \cdot 3\, I_{0Fa}(R_f)\right) \cdot \left(\overline{V_{ABCa}(R_f)_2}\right)\right]}$$

$$M_{bc\_selfa}(R_f) := \frac{\mathrm{Re}\left[\left(V_{ABCa}(R_f)_1 - V_{ABCa}(R_f)_2\right) \cdot \overline{\left(V_{ABCa}(R_f)_1 - V_{ABCa}(R_f)_2\right)}\right]}{\mathrm{Re}\left[\left(1 \cdot e^{j \cdot Z_{1ANG}}\right) \cdot \left(I_{ABCa}(R_f)_1 - I_{ABCa}(R_f)_2\right) \cdot \left[\overline{\left(V_{ABCa}(R_f)_1 - V_{ABCa}(R_f)_2\right)}\right]\right]}$$

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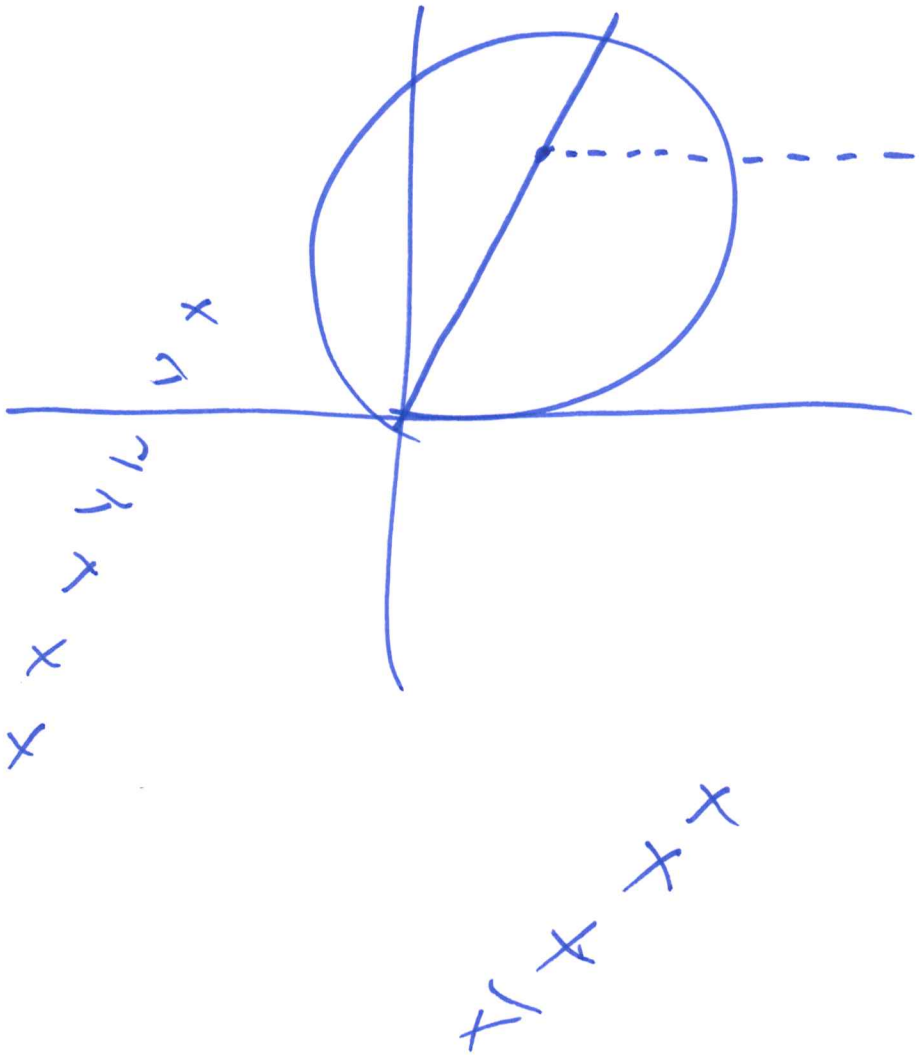
AG



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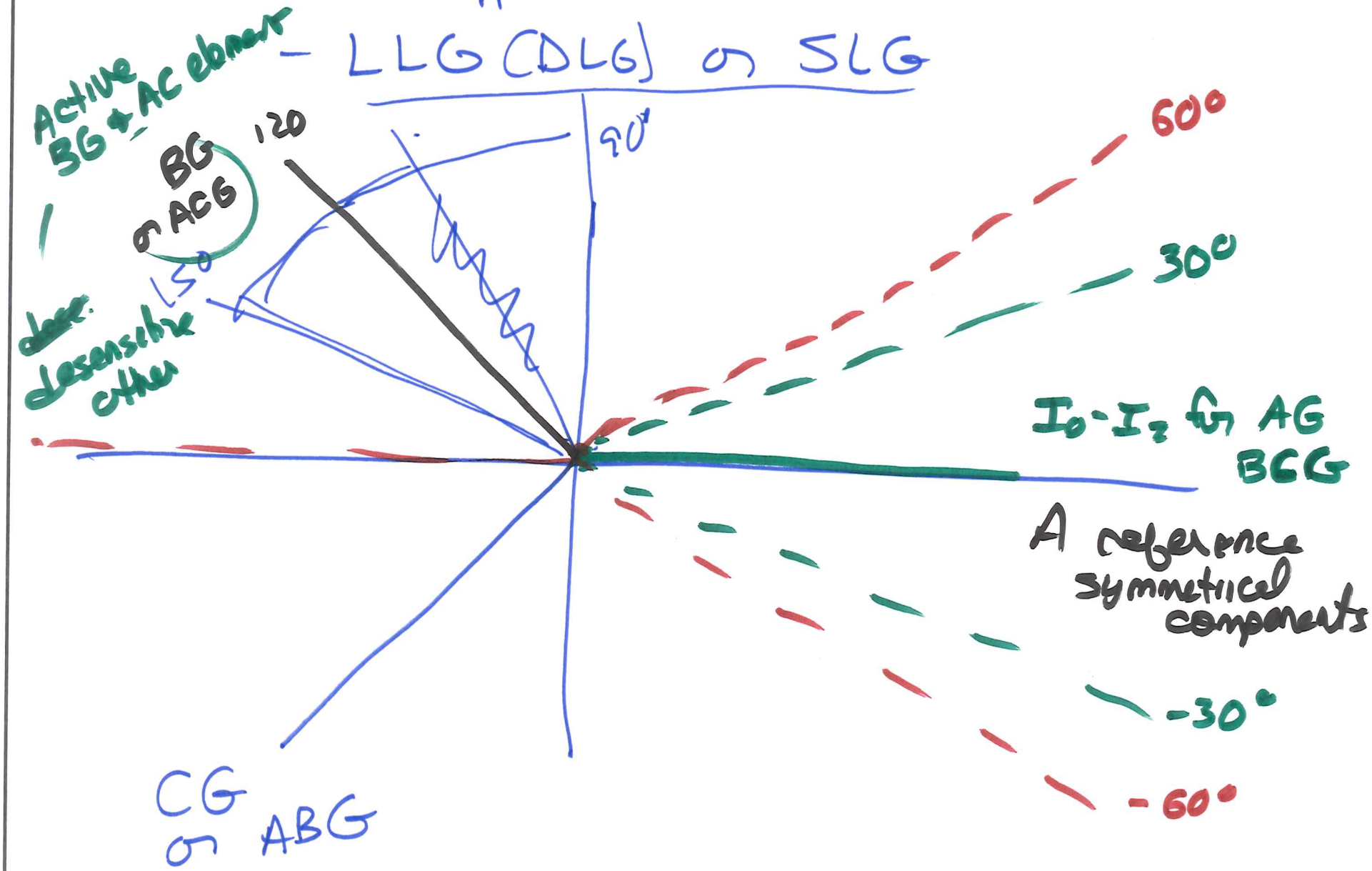
Fault type Identification

– LLG (DLG) or SLG



Note from the figure

$$\theta_{0\_2} := \arg(I_{A0}) - \arg(I_{A2}) \qquad \theta_{0\_2} = -240.14 \cdot deg$$

$$I0\_I2ang := \begin{cases} (\theta_{0\_2} + 360deg) & \text{if } \theta_{0\_2} < -180deg \\ (\theta_{0\_2} - 360deg) & \text{if } \theta_{0\_2} > 180deg \\ \theta_{0\_2} & \text{otherwise} \end{cases}$$

$$I0\_I2ang = 119.86 \cdot deg$$

$$FSA := \begin{cases} 1 & \text{if } (-30deg \le I0\_I2ang \le 30deg) \\ 0 & \text{otherwise} \end{cases}$$

$FSA = 0$ Since FSA=0, the fault is NOT AG or BCG

$$FSB := \begin{cases} 1 & \text{if } (90deg \le I0\_I2ang \le 150deg) \\ 0 & \text{otherwise} \end{cases}$$

$FSB = 1$ Since FSB=1, the fault is either BG or CAG

$$FSC := \begin{cases} 1 & \text{if } (-150deg \le I0\_I2ang \le -90deg) \\ 0 & \text{otherwise} \end{cases}$$

$FSC = 0$ Since FSC=0, the fault is NOT CG or ABG

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