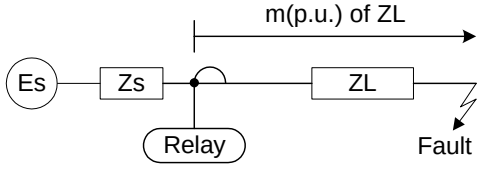
Fault Type Selection

- Protective relaying schemes using distance elements to detect faults along the protected line must have logic that dependably distinguishes fault type for both simple and complex faults.
- Using memory polarization expands the mho circle characteristics that allow the relays to operate correctly for higher resistive faults.
- Also more likely to operate for unintended fault types as compared to self-polarized mho elements

Fault Type Selection

- Detection is set to 300%.

$$Zapt_{\ fault\ type} = V/I$$



ZS1 = 1 Ω ∠ 80° ZL1 = 8 Ω ∠ 80°
ZS0 = 3 Ω ∠ 80° ZL0 = 24 Ω ∠ 80°

Torque - Fault Type Selection

$$T = \mathrm{Re}\left[\left(m \cdot ZL \cdot I - V\right) \cdot \overline{Vpol}\right]$$ where

$\overline{Vpol}$ = *Vpol complex conjugate*

$$T = \left|m \cdot ZL \cdot I - V\right| \left|Vpol\right| \cos\left(\angle\left(m \cdot ZL \cdot I - V\right) \angle Vpol\right)$$

$$Va1 = \left[Va + aVb - (1-a)Vc\right] / 3$$

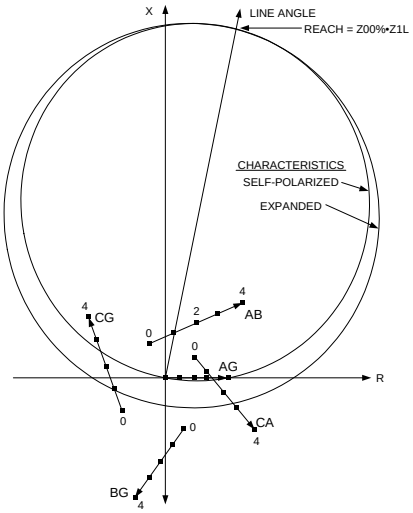
$$Vb1 = \left[Vb + aVc - (1-a)Va\right] / 3$$

$$Vc1 = \left[Vc + aVa - (1-a)Vb\right] / 3$$

Torque - Fault Type Selection

Multiple distance elements detect the AG fault when $R_F = 0$.

- The A, AB, and CA elements all detect the fault.
- All of the noted elements use phase A voltage and current quantities.
- This also emphasizes the need to block the AB and CA elements for single-pole trip applications.



Torque - Fault Type Selection

Fault Type	Voltage V	Current I	Polarization Vpol	Torque T
A to Gnd	Va	Ia + k0 Ir	Va1mem	Tag
B to Gnd	Vb	Ib + k0 Ir	Vb1mem	Tbg
C to Gnd	Vc	Ic + k0 Ir	Vc1mem	Tcg
A to B	Va – Vb	Ia – Ib	-j Vc1mem	Tab
B to C	Vb – Vc	Ib – Ic	-j Va1mem	Tbc
C to A	Vc – Va	Ic – Ia	-j Vb1mem	Tca

K0 = (Z0/Z1 – 1)/3 mem denotes memory voltage

Torque - Fault Type Selection

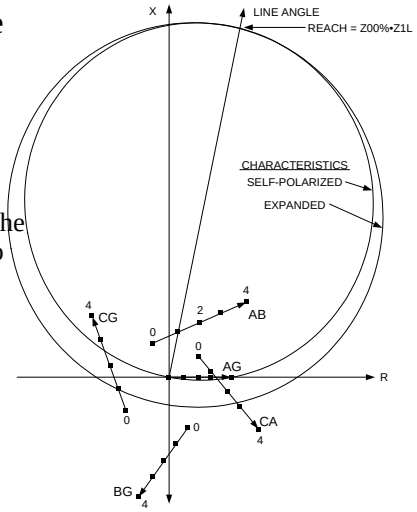
- ZL = 0+, R_F = 0 … 4

R_F	T_{AG}	$\|Z_{AG}\|$	T_{BG}	$\|Z_{BG}\|$	T_{CG}	$\|Z_{CG}\|$
0	118	0.0	-30	3.1	-29	3.1
1	81	0.6	-38	4.1	-6	3.3
2	46	1.2	-33	5.2	2.7	4.1
3	28	1.8	-27	6.5	4.2	5.2
4	17	2.4	-23	7.9	4.0	6.5

R_F	T_{AB}	$\|Z_{AB}\|$	T_{BC}	$\|Z_{BC}\|$	T_{CA}	$\|Z_{CA}\|$
0	56	2.1	0	∞	55	2.1
1	50	2.6	0	∞	22	3.2
2	34	3.9	0	∞	3	4.7
3	22	5.5	0	∞	-5	6.3
4	15	7.1	0	∞	-8	8.0

Torque - Fault Type Selection

- Multiple distance elements detect the AG fault when $R_F = 0$
  - The A, AB, and CA elements all detect the fault
  - All of the noted elements use phase A voltage and current quantities
  - This also emphasizes the need to block the AB and CA elements for single-pole trip applications
- With increasing fault resistance, the number of elements that detect the fault decreases
- With increasing fault resistance, the C-Phase ground distance element develops positive operating torque



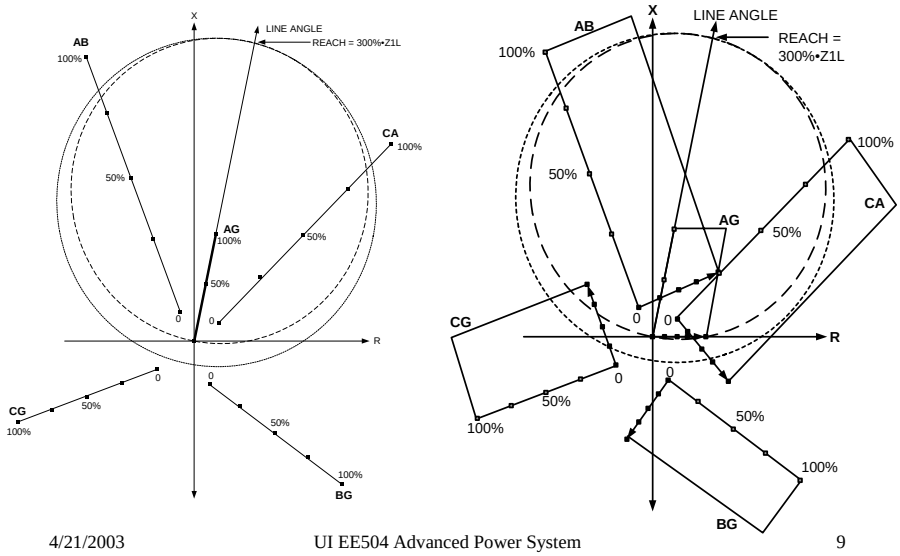
Torque - Fault Type Selection

- Zero ohms fault resistance and fault locations of 0, 25, 50, 75 and 100% of the line length

m(%)	T_{AG}	$\|Z_{AG}\|$	T_{BG}	$\|Z_{BG}\|$	T_{CG}	$\|Z_{CG}\|$
0	118	0.0	-30	3.1	-29	3.1
25	36	2.0	-13	8.0	-13	8.0
50	20	4.0	-9.9	13	-9.7	13
75	13	6.0	-8.5	18	-8.3	18
100	9	8.0	-7.7	23	-7.6	23

m(%)	T_{AB}	$\|Z_{AB}\|$	T_{BC}	$\|Z_{BC}\|$	T_{CA}	$\|Z_{CA}\|$
0	56	2.1	0	∞	55	2.1
25	13	7.8	0	∞	13	7.8
50	4.3	13	0	∞	4.1	13
75	0.7	19	0	∞	0.5	19
100	-1.4	25	0	∞	-1.5	25

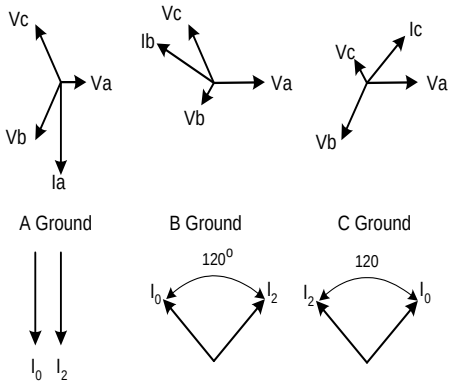
Torque - Fault Type Selection



∠(Ia0-Ia2 - Fault Type Selection

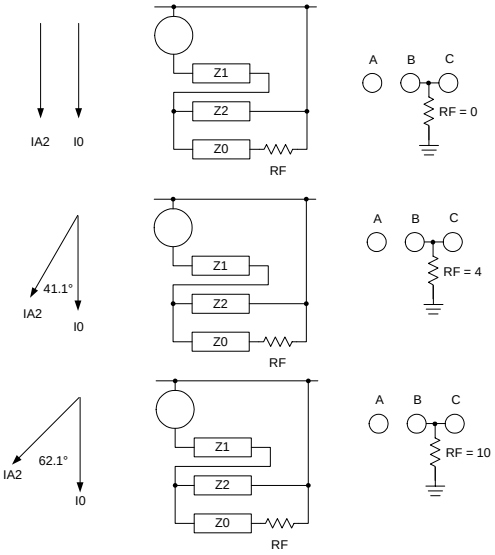
- The fault selection logic differentiates between single-line-ground faults and phase-phase-ground faults

Angle Relationship of Ia2 and Ia0 for Ground Faults



∠(Ia0-Ia2 - Fault Type Selection

Phase angle relationship of Ia2 and Ia0 for BCG faults and the symmetrical component networks that represent the faults



∠(Ia0-Ia2 - Fault Type Selection

- The phase to phase fault resistance can be developed using an approach similar to the phase to ground resistance.

$$Rbc_F = \frac{\mathrm{Im}\left[Vbc\left(\overline{Ibc\ m\ Z1}\right)\right]}{\mathrm{Im}\left[Ibc\left(\overline{Ibc\ m\ Z1}\right)\right]} \qquad Rbc_F = \frac{\mathrm{Im}\left[Vbc\left(\overline{Ibc\ Z1}\right)\right]}{\mathrm{Im}\left[j\sqrt{3}Ia_2\left(\overline{Ibc\ Z1}\right)\right]}$$

$$Rab_F = \frac{\mathrm{Im}\left[Vab\left(\overline{Iab\ Z1}\right)\right]}{\mathrm{Im}\left[ja^2\sqrt{3}Ia_2\left(\overline{Iab\ Z1}\right)\right]},\ a^2 = 1\angle 240°$$

$$Rca_F = \frac{\mathrm{Im}\left[Vca\left(\overline{Ica\ Z1}\right)\right]}{\mathrm{Im}\left[ja\sqrt{3}Ia_2\left(\overline{Ica\ Z1}\right)\right]},\ a = 1\angle 120°$$

∠(Ia0-Ia2 - Fault Type Selection

- Three outputs are available from the fault selector logic, one for each of the three possible ±60° segments
  - . I_0 - I_2 phase comparison fault selection logic

Fault Type	Enabled	Blocked
1	AG and BC	BG, CG, BC, and CA
2	BG and AC	AG, CG, AB, and BC
3	CG and AB	AG, BG, BC, and CA
4	AB, BC, CA	All but ABC-G

∠(Ia0-Ia2 - Fault Type Selection

$$Fault\,Type\,1 = FSA30$$
$$+ FSA60 \bullet Z_{AB-MIN} \bullet \left(|R_{AG}| < |R_{AB}|\right)$$
$$+ FSA60 \bullet Z_{BC-MIN} \bullet \left(|R_{AG}| < |R_{BC}|\right)$$
$$+ FSA60 \bullet Z_{CA-MIN} \bullet \left(|R_{AG}| < |R_{AC}|\right)$$

$$Fault\,Type\,2 = FSB30$$
$$+ FSB60 \bullet Z_{AB-MIN} \bullet \left(|R_{BG}| < |R_{AB}|\right)$$
$$+ FSB60 \bullet Z_{BC-MIN} \bullet \left(|R_{BG}| < |R_{BC}|\right)$$
$$+ FSB60 \bullet Z_{CA-MIN} \bullet \left(|R_{BG}| < |R_{AC}|\right)$$

$$Fault\,Type\,3 = FSC30$$
$$+ FSC60 \bullet Z_{AB-MIN} \bullet \left(|R_{CG}| < |R_{AB}|\right)$$
$$+ FSC60 \bullet Z_{BC-MIN} \bullet \left(|R_{CG}| < |R_{BC}|\right)$$
$$+ FSC60 \bullet Z_{CA-MIN} \bullet \left(|R_{CG}| < |R_{AC}|\right)$$

∠(Ia0-Ia2 - Fault Type Selection

$$Z_{AB-MIN} \Rightarrow mZ_{AB} < mZ_{BC} \text{ and } mZ_{AB} < mZ_{CA}$$

$$Z_{BC-MIN} \Rightarrow mZ_{BC} < mZ_{AB} \text{ and } mZ_{BC} < mZ_{CA}$$

$$Z_{CA-MIN} \Rightarrow mZ_{CA} < mZ_{BC} \text{ and } mZ_{CA} < mZ_{AB}$$

$$mZ_{AB,BC,CA} = \frac{\mathrm{Im}\left(V_{AB} \cdot \overline{I_{AB,BC,CA}}\right)}{\mathrm{Im}\left(\frac{ZL_1}{|ZL_1|} I_{AB,BC,CA} \cdot \overline{I_{AB,BC,CA}}\right)}$$

$$mZ_{A,B,C} = \frac{\mathrm{Im}\left(V_{A,B,C} \cdot \left(\overline{I_{A,B,C}}\right)\right)}{\mathrm{Im}\left(\frac{ZL_1}{|ZL_1|} \cdot \left(I_{A,B.C} + k_0 I_R\right)\left(\overline{I_{A,B,C}}\right)\right)} \quad I_R = \left(I_A + I_B + I_C\right) = 3I_o$$

∠(Ia0-Ia2 - Fault Type Selection

$$Va = Ia\,(mZL_1) + Ia \cdot Rag$$

$$Va\ \left(\overline{m\,(Ia\ ZL_1)}\right) = m\,(Ia\ ZL_1)\left(\overline{m\,(Ia\ ZL_1)}\right) +$$

$$\left(Ia\ Rag\right)\left(\overline{m\,(Ia\ ZL_1)}\right)$$

$$Rag = \frac{\mathrm{Im}\left[Va\ \left(\overline{Ia\ ZL_1}\right)\right]}{\mathrm{Im}\left[\left(Ia\ \right)\left(\overline{Ia\ ZL_1}\right)\right]} \qquad Ia \cong \frac{3}{2}(Ia_0 + Ia_2)$$

$$Rag = \frac{\mathrm{Im}\left[Va\ \left(\overline{Ia\ ZL_1}\right)\right]}{\mathrm{Im}\left[\left(\frac{3}{2}(Ia_0 + Ia_2)\right)\left(\overline{Ia\ ZL_1}\right)\right]}$$

∠(Ia0-Ia2 - Fault Type Selection

$$Rbc_F = \frac{\mathrm{Im}\left[Vbc\left(\overline{Ibc\ m\ ZL_1}\right)\right]}{\mathrm{Im}\left[Ibc\left(\overline{Ibc\ m\ ZL_1}\right)\right]}$$

$$Rbc_F = \frac{\mathrm{Im}\left[Vbc\left(\overline{Ibc\ ZL_1}\right)\right]}{\mathrm{Im}\left[j\sqrt{3}Ia_2\left(\overline{Ibc\ ZL_1}\right)\right]}$$

$$Rab_F = \frac{\mathrm{Im}\left[Vab\left(\overline{Iab\ ZL_1}\right)\right]}{\mathrm{Im}\left[ja^2\sqrt{3}Ia_2\left(\overline{Iab\ ZL_1}\right)\right]},\ a^2 = 1\angle 240°$$

$$Rca_F = \frac{\mathrm{Im}\left[Vca\left(\overline{Ica\ ZL_1}\right)\right]}{\mathrm{Im}\left[ja\sqrt{3}Ia_2\left(\overline{Ica\ ZL_1}\right)\right]},\ a = 1\angle 120°$$