CROSS COUNTRY FAULTS- PROTECTION CHALLENGES AND IMPROVEMENTS

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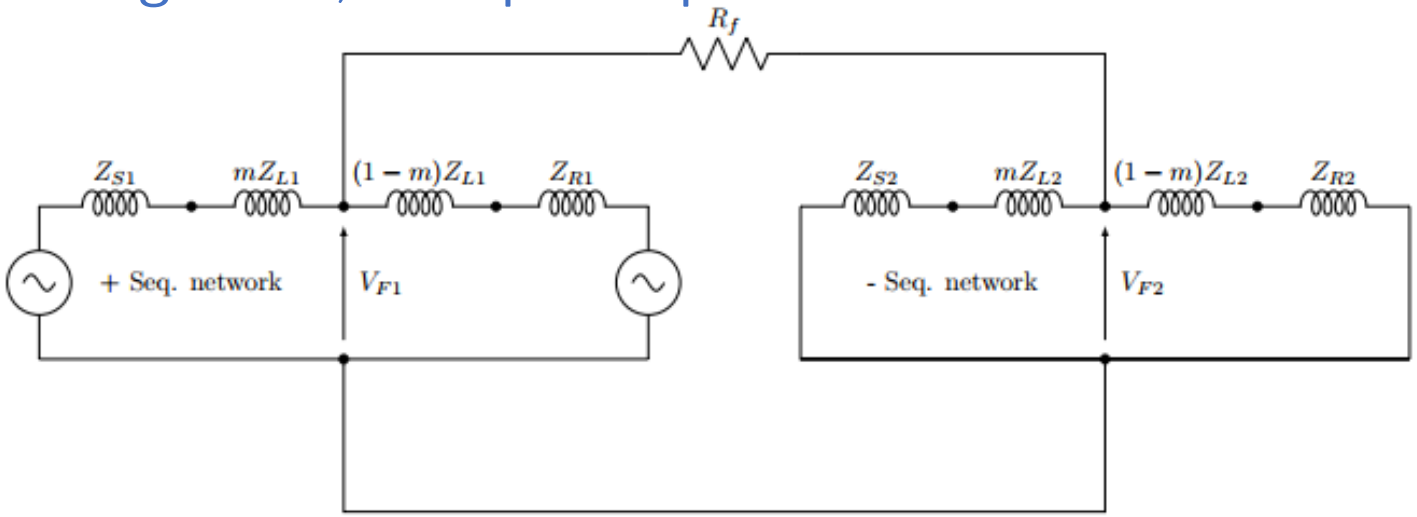
2021 CONFERENCE FOR PROTECTIVE RELAY ENGINEERS

Overview

- Phase Selector – Why we need it?
- Phase Selector types
- Cross Country faults
  - Solid Grounded System – Challenges and Improvements
- Cross Country faults
  - Isolated/Compensated System
- Summary

Phase Selector – Why we need it?

During faults, multiple loops can be activated



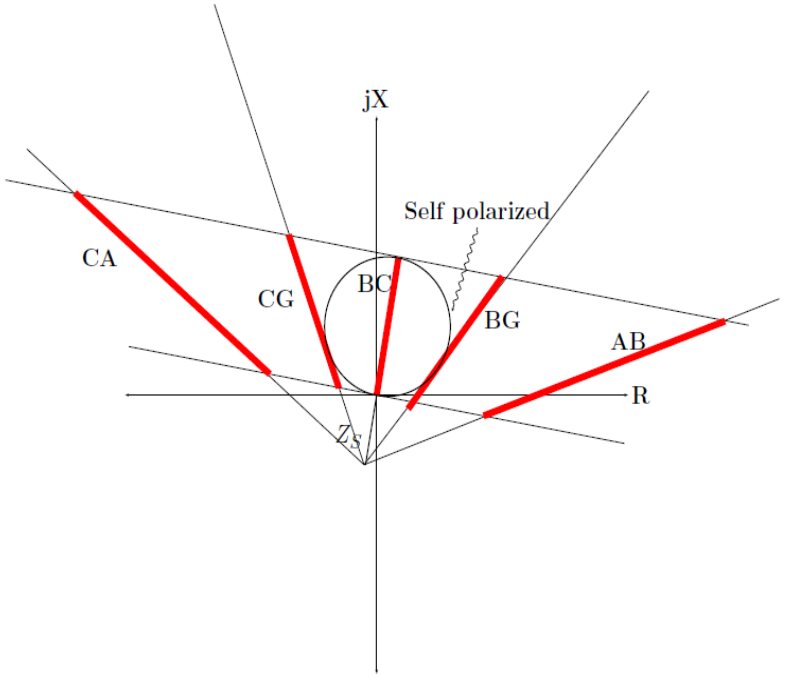
Sequence connection for phase-to-phase BC fault

Analytical expression for phase-to-phase fault BC in all 6 loops

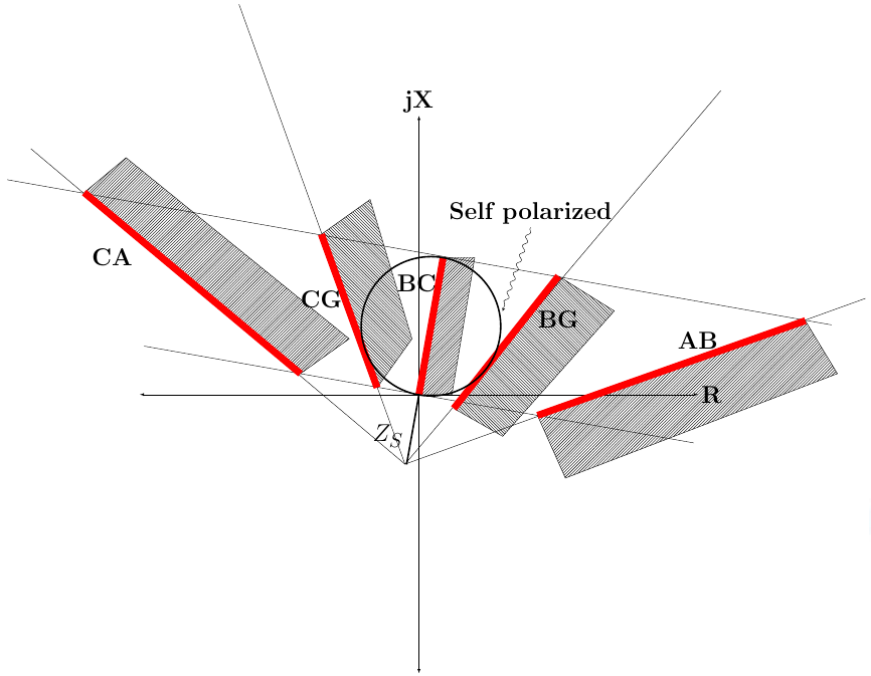
Element	Voltage	Current	Expression
AG	V_A	$I_A + kI_0$	∞
BG	V_B	$I_B + kI_0$	$mZ_{L1}+\frac{mZ_{L1}+Z_{s1}}{\sqrt{3}}\angle\text{-}90°$
CG	V_C	$I_C + kI_0$	$mZ_{L1}+\frac{mZ_{L1}+Z_{s1}}{\sqrt{3}}\angle 90°$
AB	$V_A - V_B$	$I_A - I_B$	$mZ_{L1}+(mZ_{L1}+Z_{s1})\sqrt{3}\angle\text{-}90°$
BC	$V_B - V_C$	$I_B - I_C$	mZ_{L1}
CA	$V_C - V_A$	$I_C - I_A$	$mZ_{L1}+(mZ_{L1}+Z_{s1})\sqrt{3}\angle 90°$

Phase Selector – Why we need it?

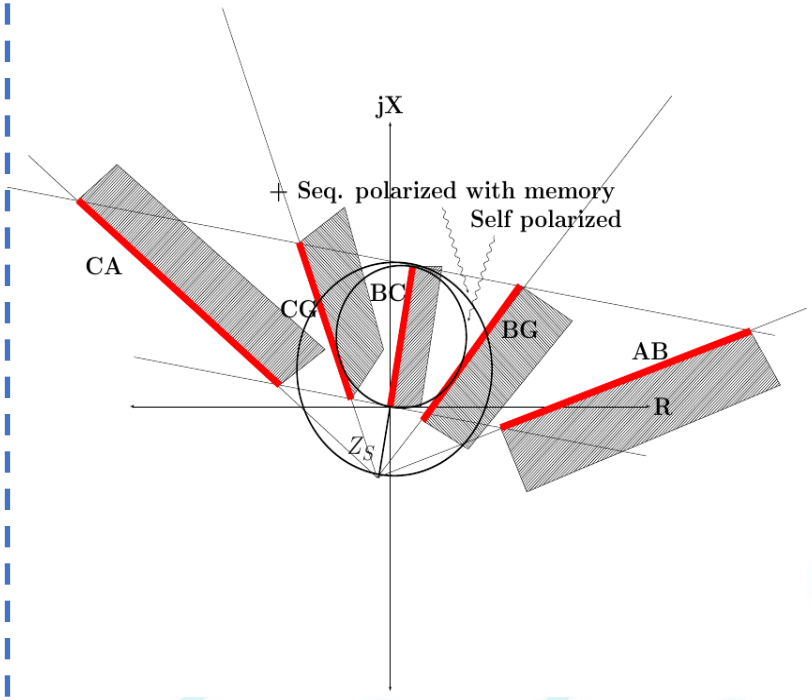
During faults, multiple loops can be activated



Self-polarized with R_f=0



Self-polarized with R_f



V_{1M} polarized with R_f

Phase Selector Types

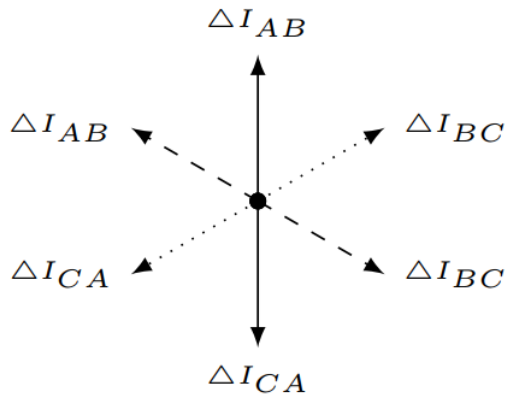
Major Phase Selector Types

- Overcurrent based phase selection
  - Sensitivity issues –e.g. Weak source, high fault resistance results in low short circuit currents
- Voltage based phase selection
  - Sensitivity issues – e.g. fault impedance
- Phase selection using wave information
- Delta quantities-based phase selection
- Phase selection using sequence-components planes

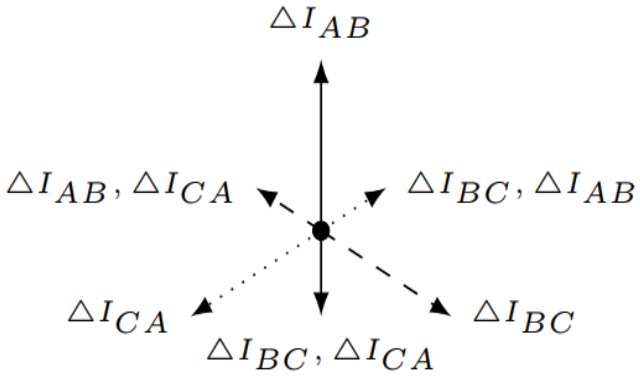
Phase Selector Types

Delta quantities-based phase selection

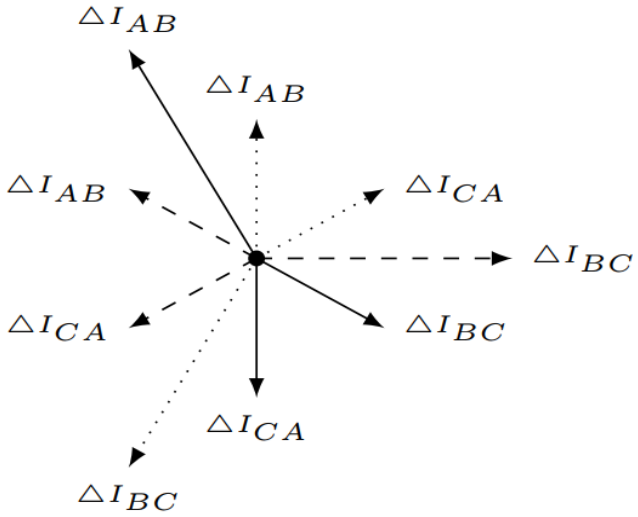
$$
\begin{aligned}
\triangle I_X &= I_X - I_{X,pre-fault} \\
\triangle I_Y &= I_Y - I_{Y,pre-fault} \\
\triangle I_{XY} &= \triangle I_X - \triangle I_Y
\end{aligned}
$$



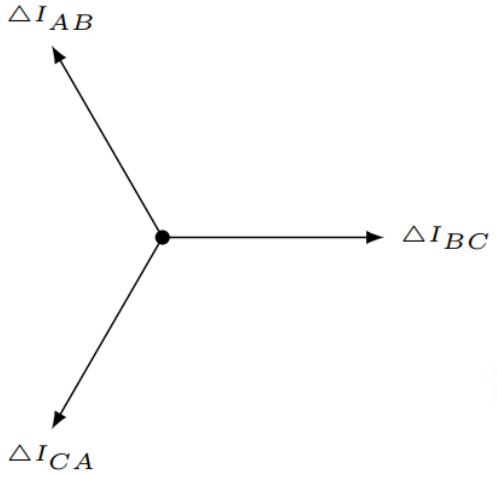
Phase-to-ground fault
Solid –AG,
Dashed-BG,
Dotted-CG



Phase-to-phase fault
Solid –AB,
Dashed-BC,
Dotted-CA



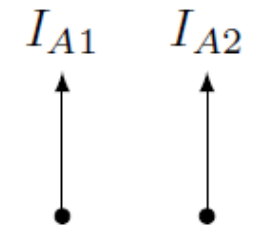
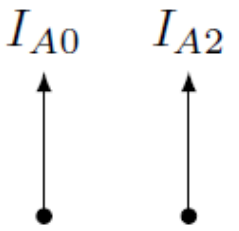
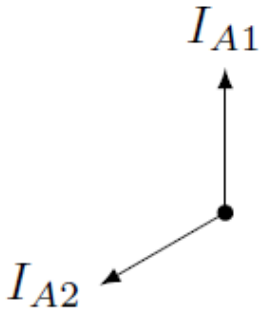
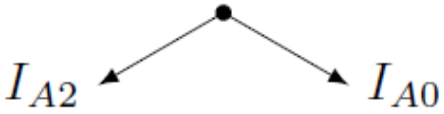
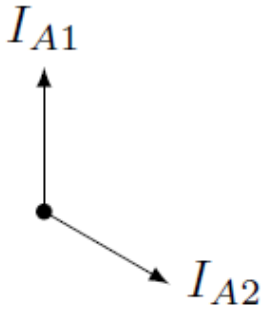
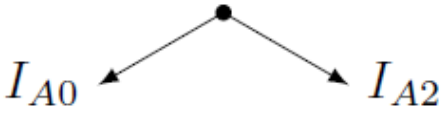
Phase-to-phase to ground fault
Solid –ABG,
Dashed-BCG,
Dotted-CAG

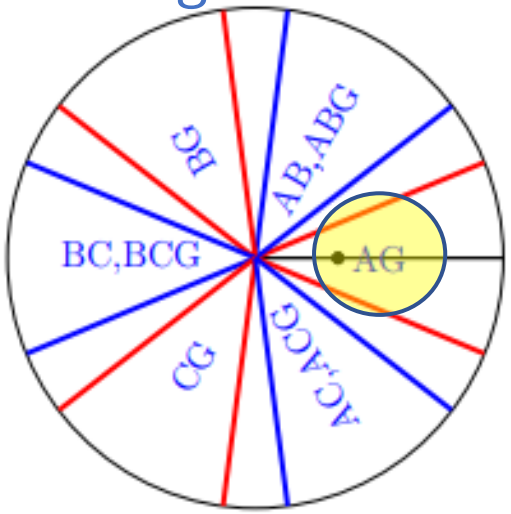


3-phase fault

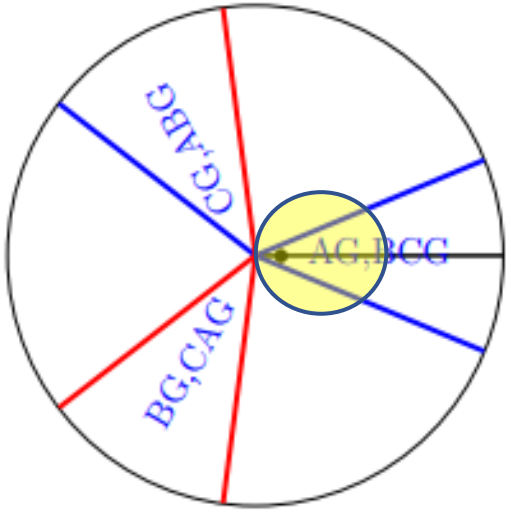
Phase Selector Types

Phase selection using sequence-components planes, single-phase-to-ground

Fault Type	I_2 Vs I_1 Plane	I_2 Vs I_0 Plane
AG Fault		
BG Fault		
CG Fault		



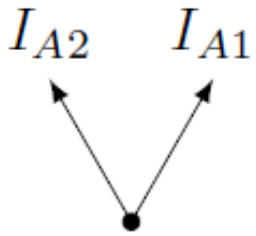
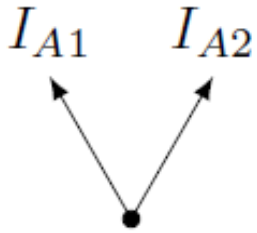
(a) 'Neg. Seq' vs 'Pos. Seq' plane

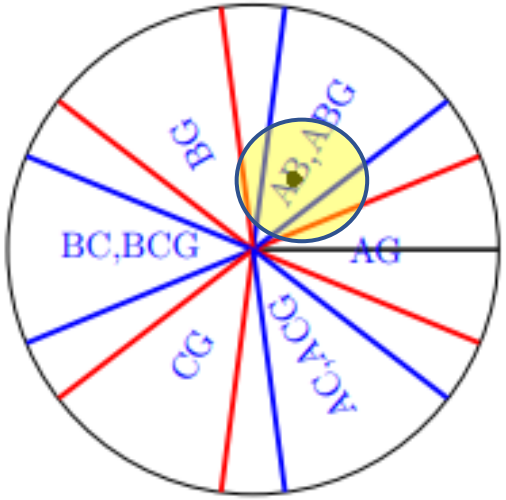


(b) 'Neg. Seq' vs 'Zero. Seq' plane

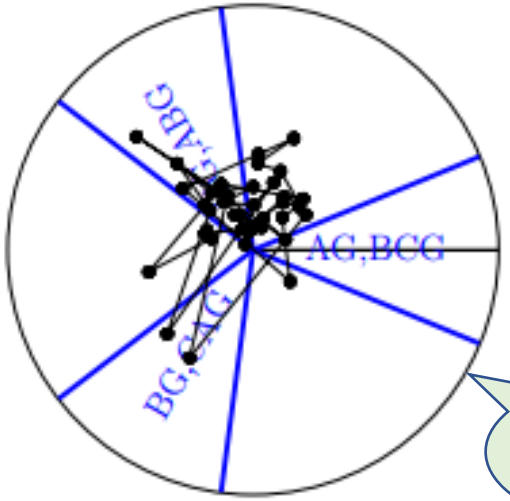
Phase Selector Types

Phase selection using sequence-components planes, phase-to-phase

Fault Type	I_2 Vs I_1 Plane	I_2 Vs I_0 Plane
AB Fault		-
BC Fault		-
CA Fault		-



(a) 'Neg. Seq' vs 'Pos. Seq' plane

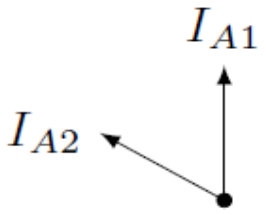
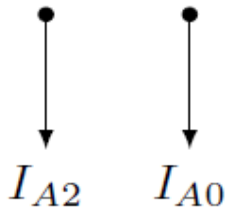
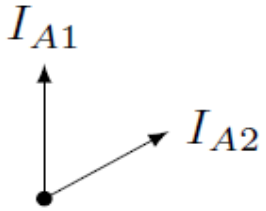
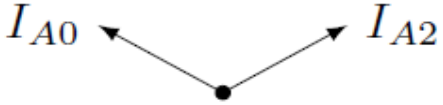


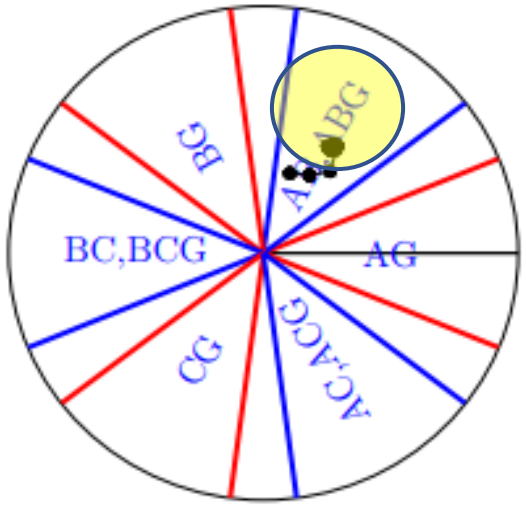
(b) 'Neg. Seq' vs 'Zero. Seq' plane

Not relevant

Phase Selector Types

Phase selection using sequence-components planes, phase-to-phase-to-ground

Fault Type	I_2 Vs I_1 Plane	I_2 Vs I_0 Plane
ABG Fault		
BCG Fault		
CAG Fault		



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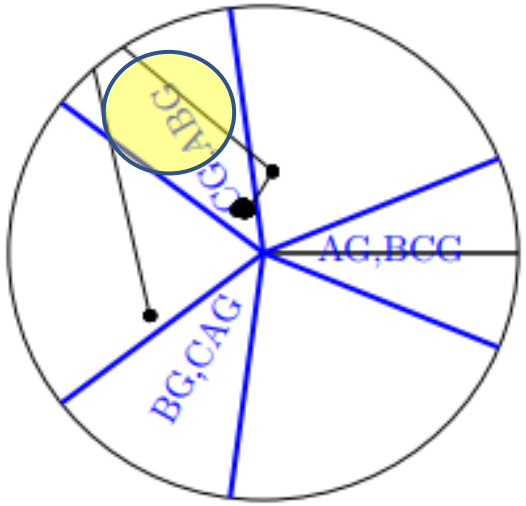
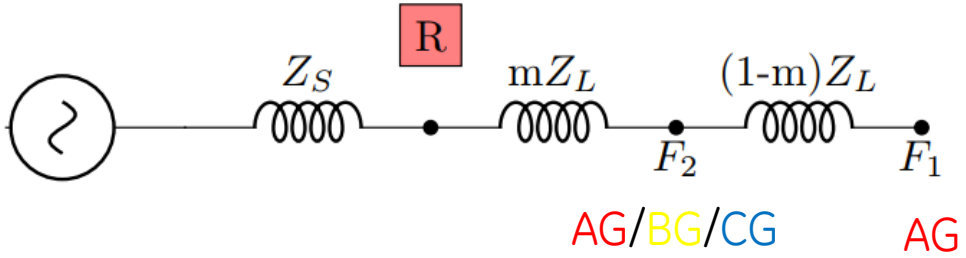


(b) 'Neg. Seq' vs 'Zero. Seq' plane

Cross Country faults - Solid Grounding

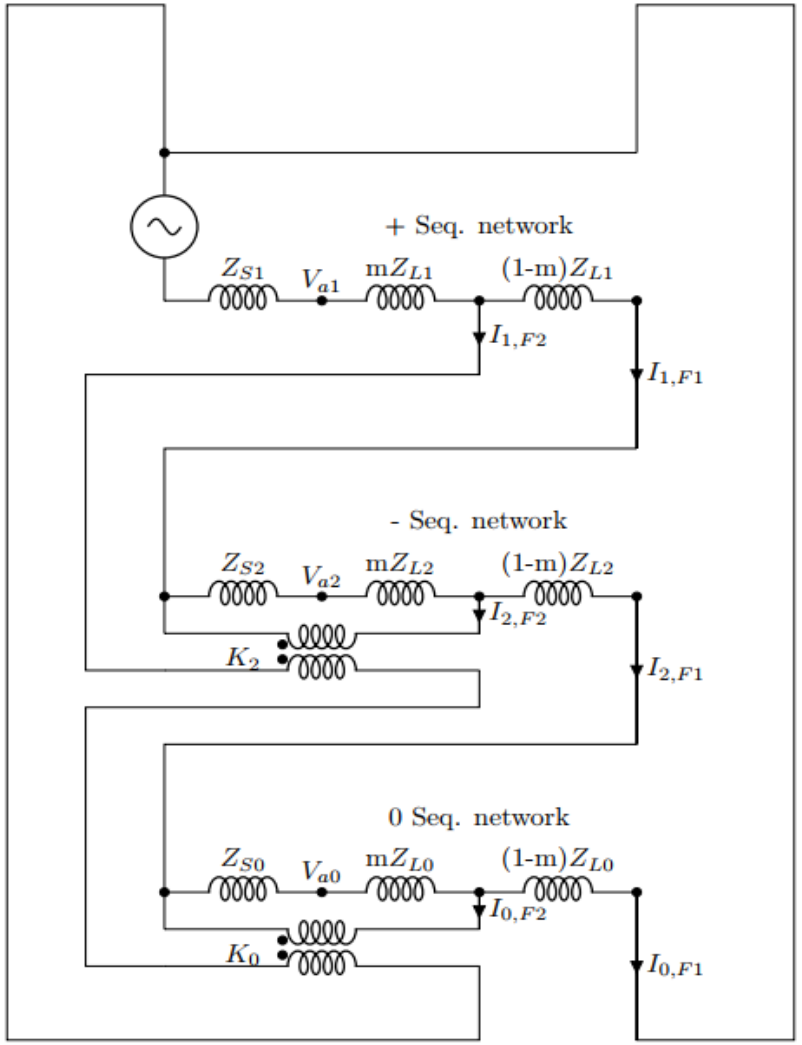
Analytical expression for cross-country faults



Cross country fault

$$\frac{V_r}{I_r(1+k)} = Z_{L1} - \underbrace{(1-m)Z_{L1}\frac{I_{r,F2}}{I_r}}_{error}$$

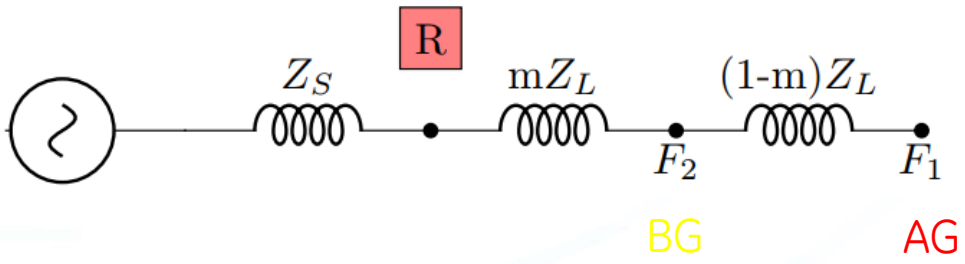
- When m=1, it is a phase to phase to ground fault and the error term boils to zero
- When fault F_1 is removed, $I_{r,F2}=I_r$, correct estimation is achieved as it is no longer a cross-country fault
- Error varies, when two faults move apart

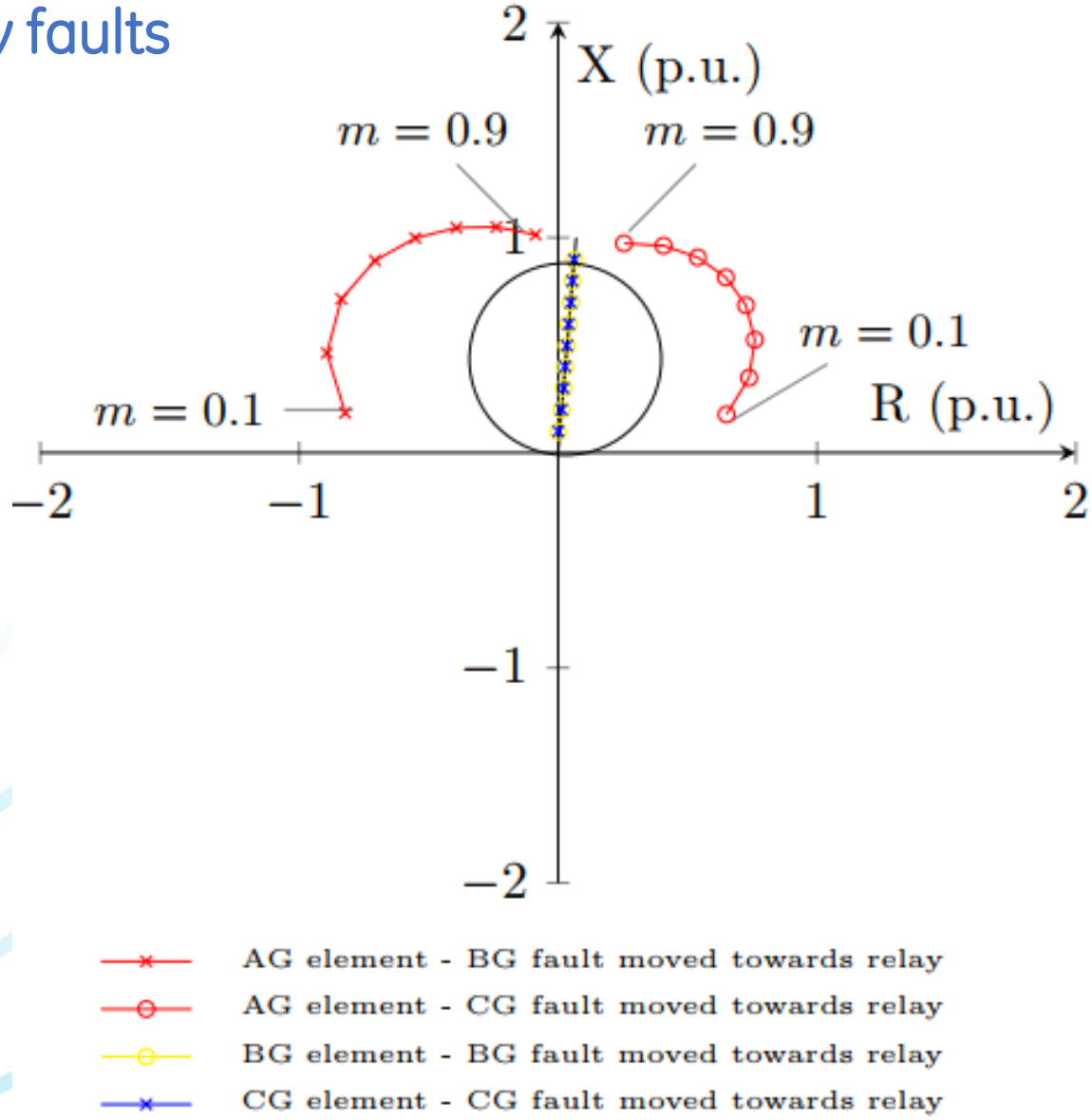


Sequence connection for cross-country fault

Cross Country faults - Solid Grounding (Contd...)

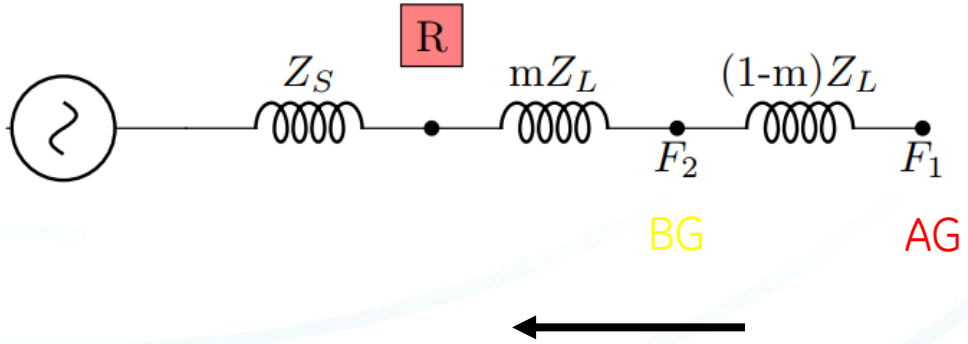
Ground element behavior during cross-country faults

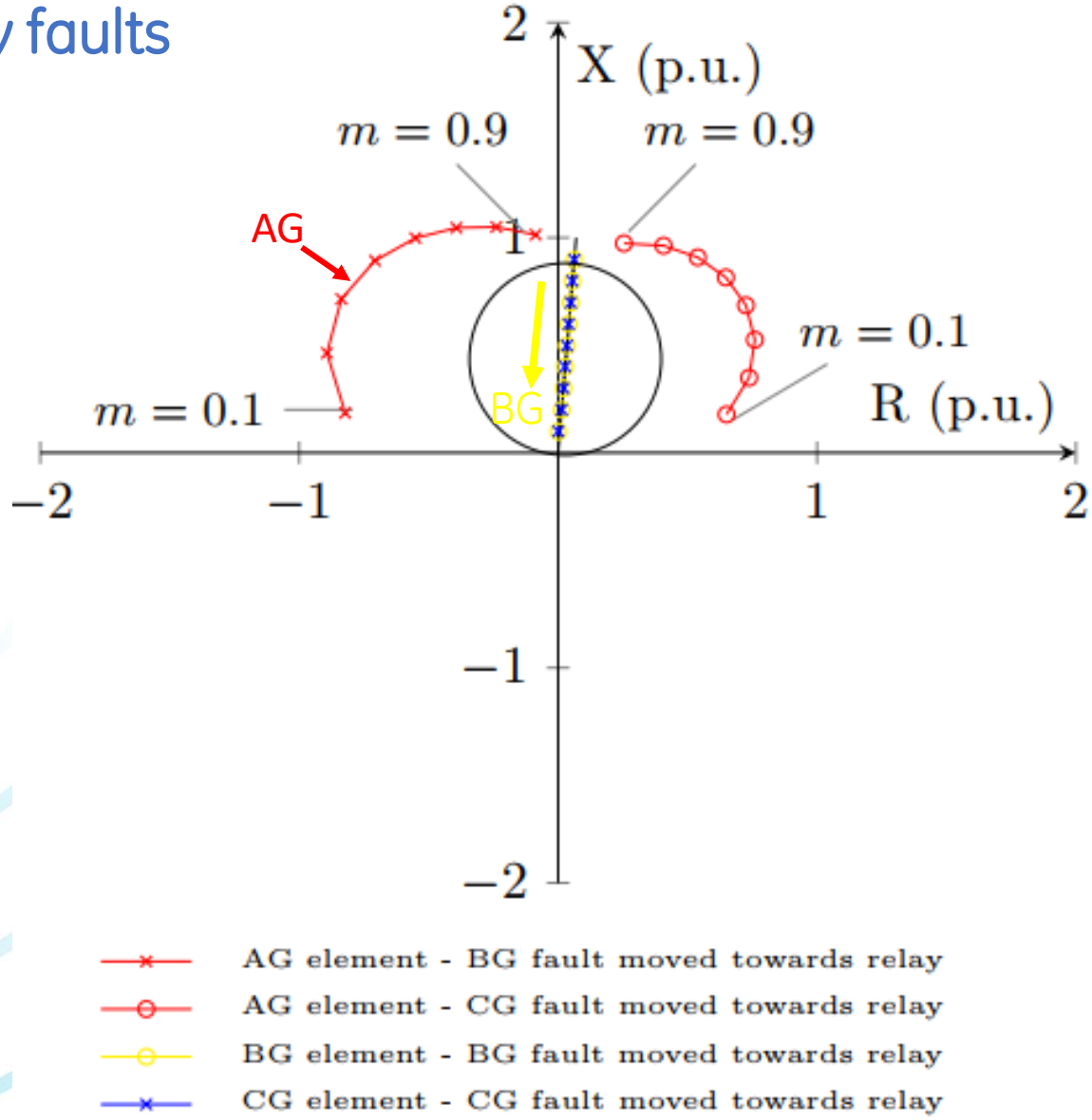




Cross Country faults - Solid Grounding (Contd...)

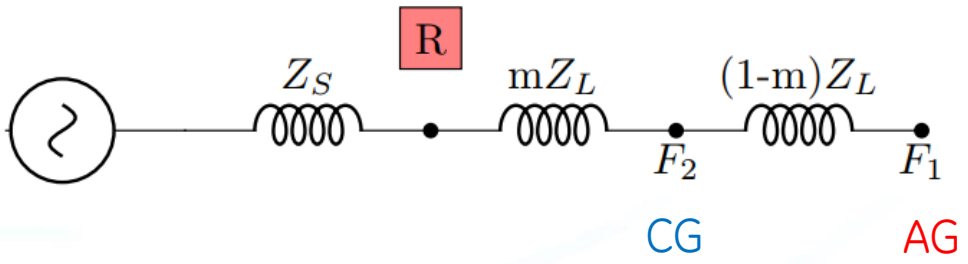
Ground element behavior during cross-country faults

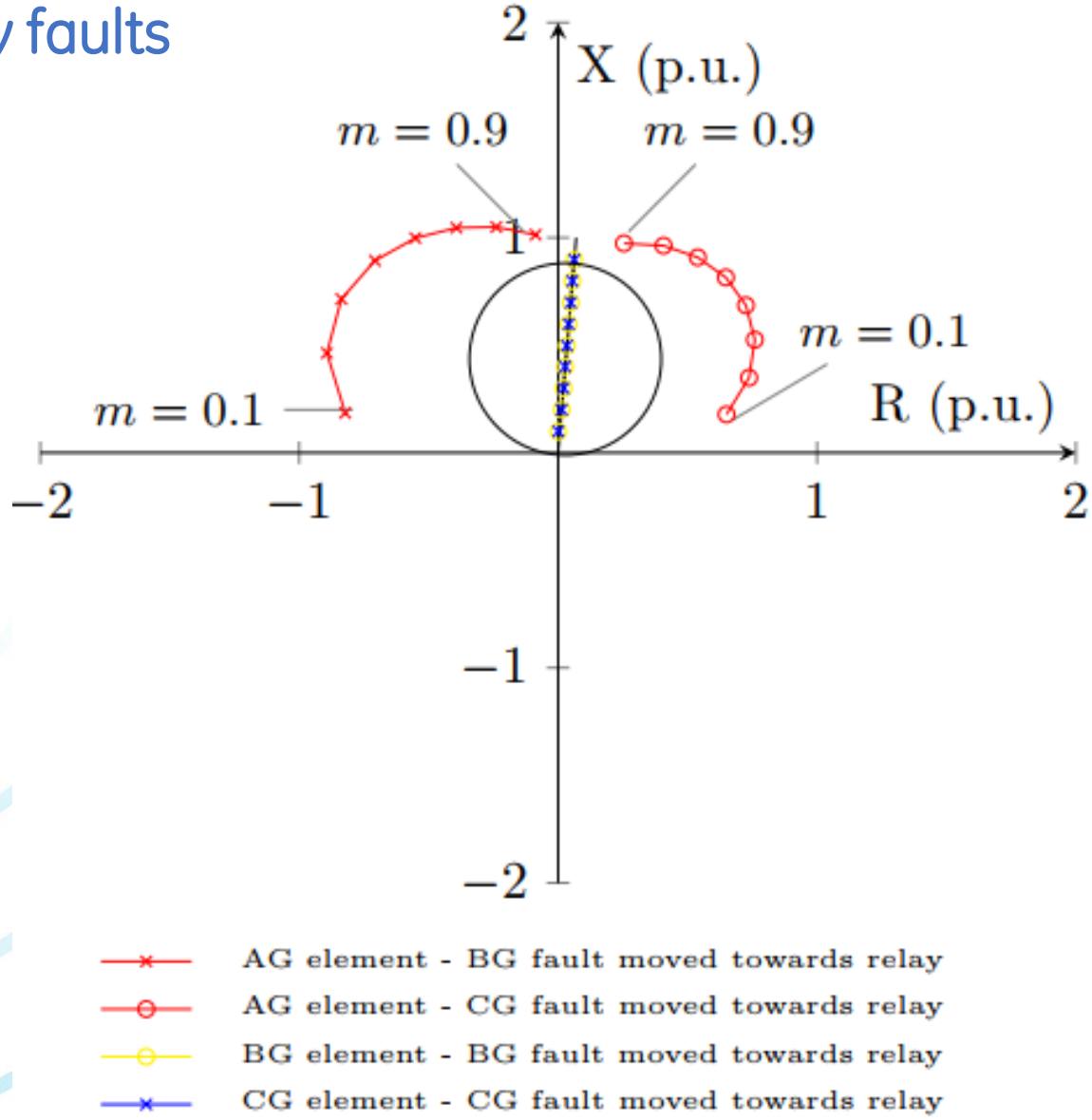




Cross Country faults - Solid Grounding (Contd...)

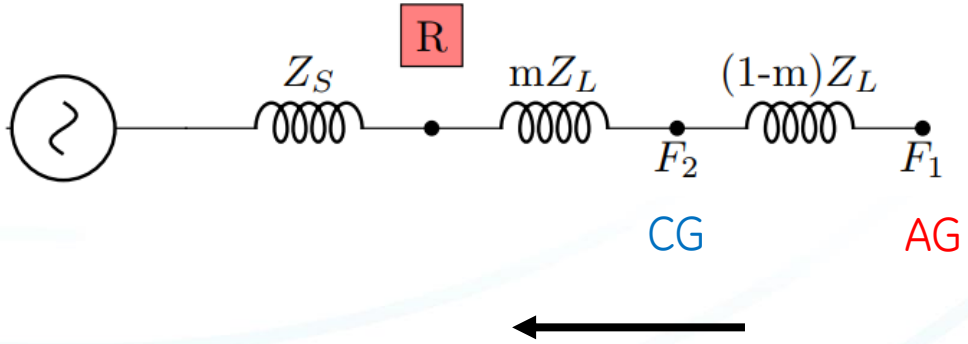
Ground element behavior during cross-country faults

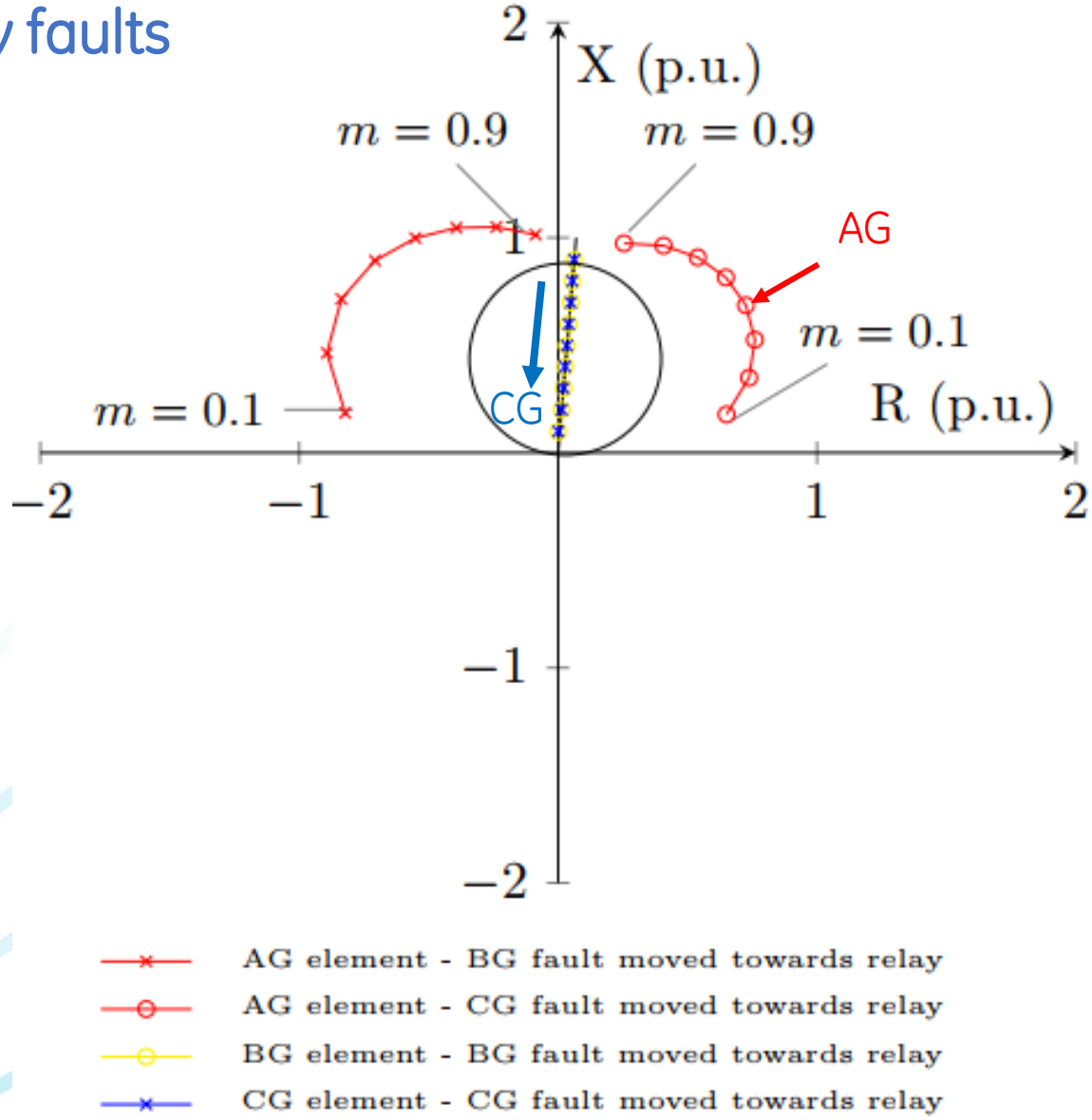




Cross Country faults - Solid Grounding (Contd...)

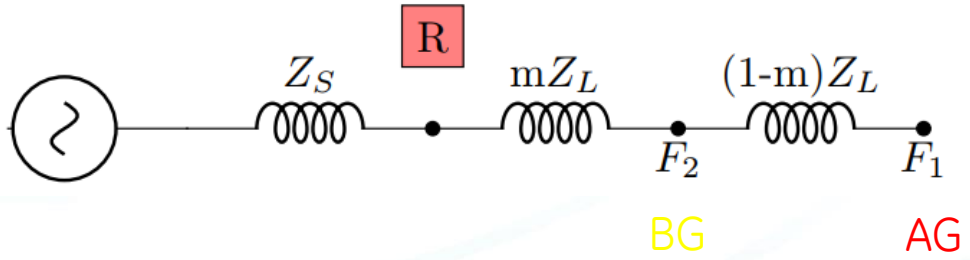
Ground element behavior during cross-country faults

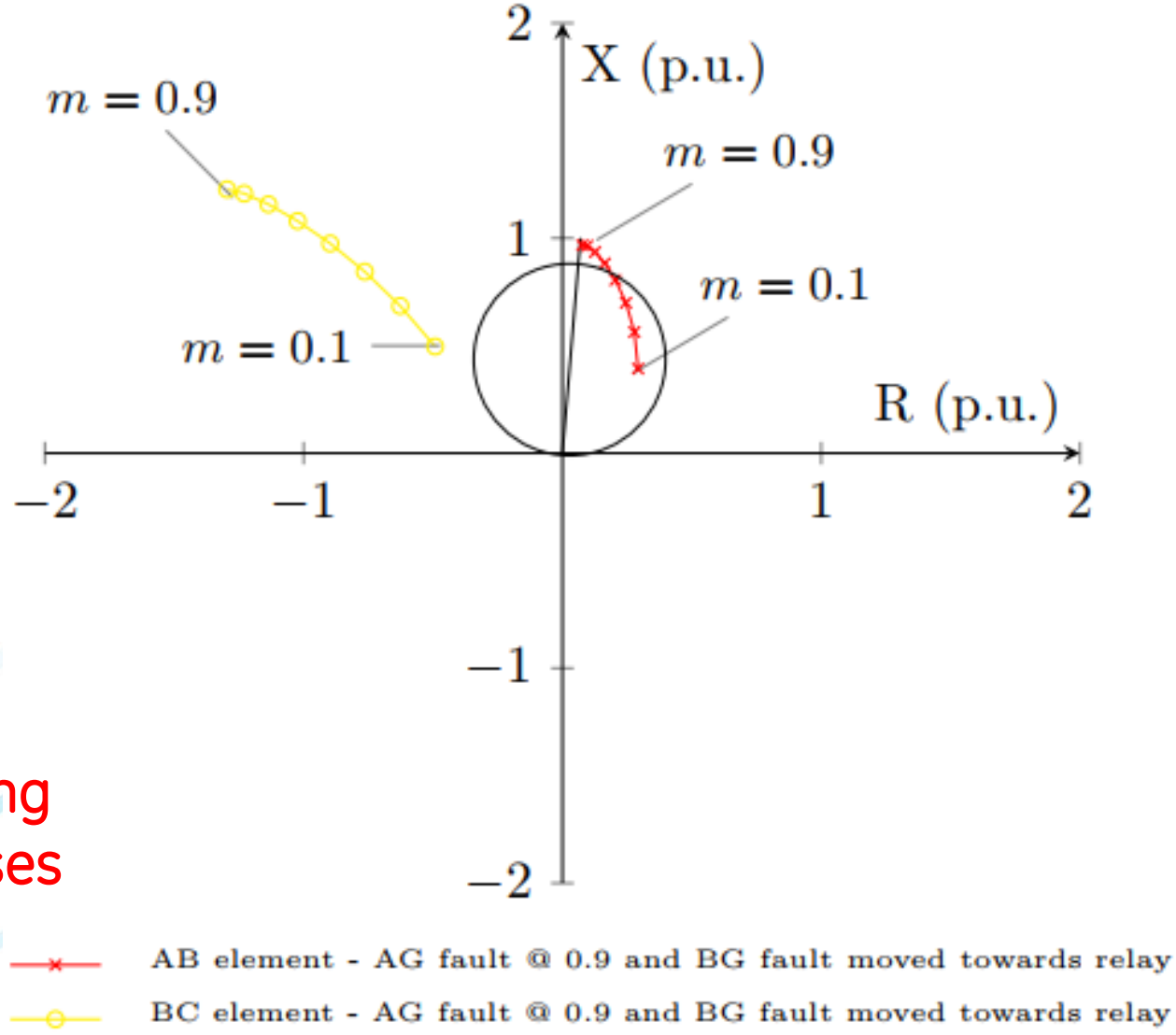




Cross Country faults - Solid Grounding (Contd...)

Phase element prone to mal-operate during Cross-country fault

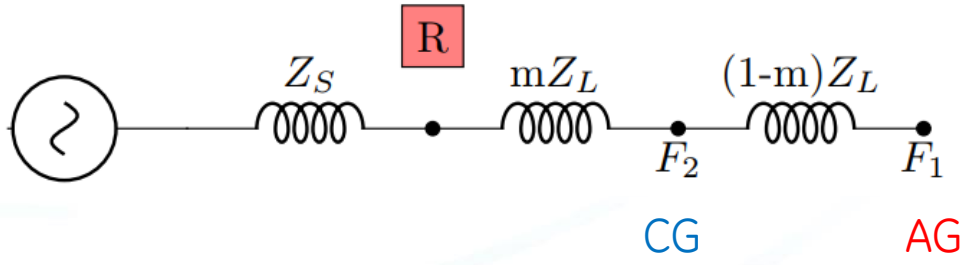


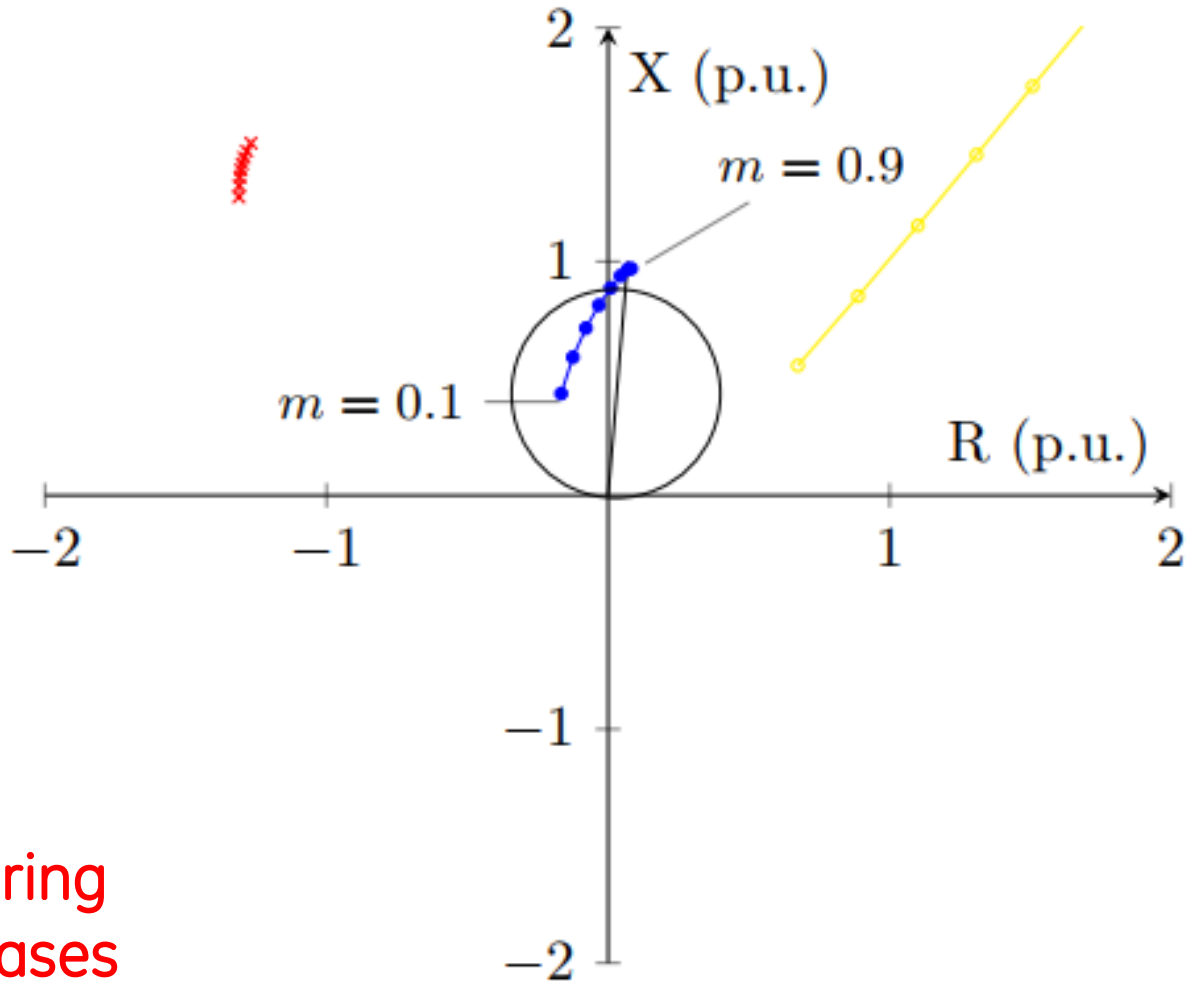


AB Phase element prone to mal-operate during Cross-country fault involving AG and BG phases

Cross Country faults - Solid Grounding (Contd...)

Phase element prone to mal-operate during Cross-country fault





CA Phase element prone to mal-operate during Cross-country fault involving AG and CG phases

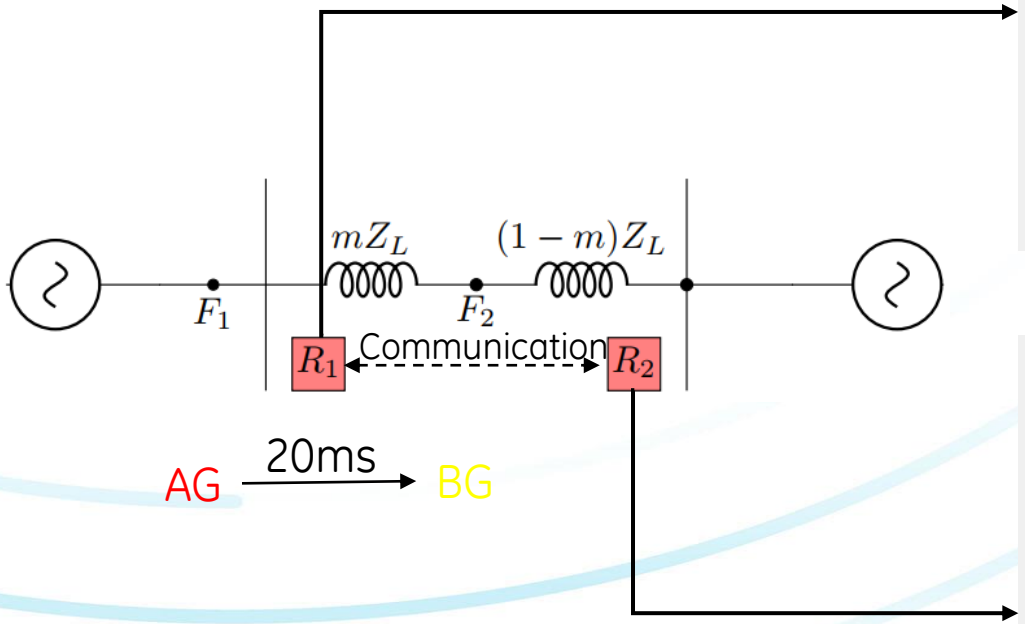
AB element - AG fault @ 0.9 and CG fault moved towards relay

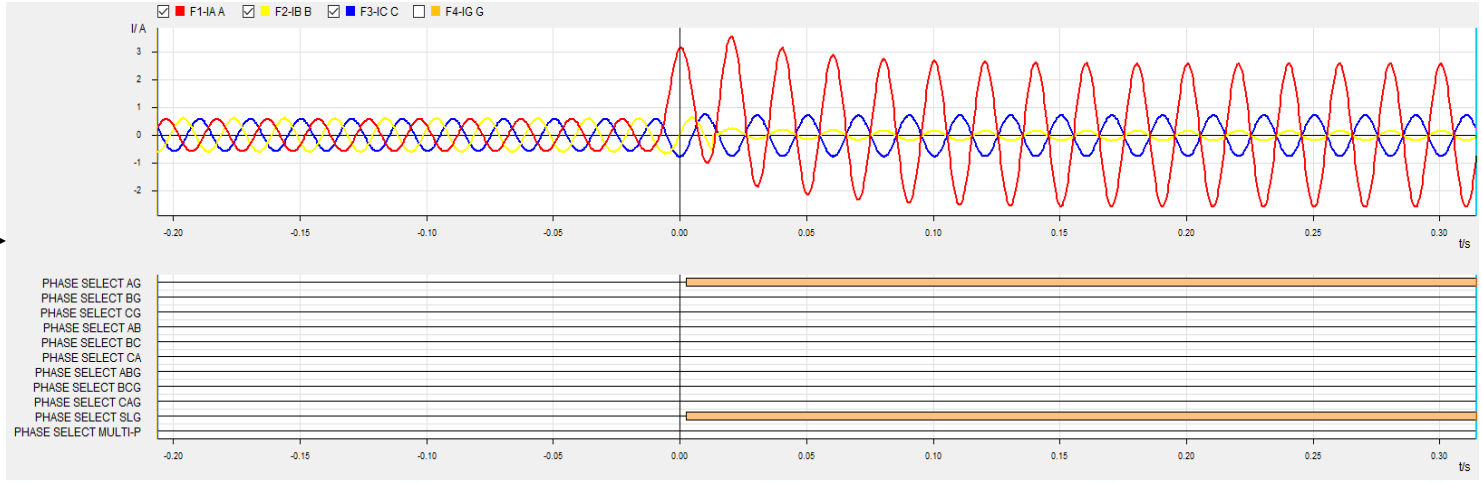
BC element - AG fault @ 0.9 and CG fault moved towards relay

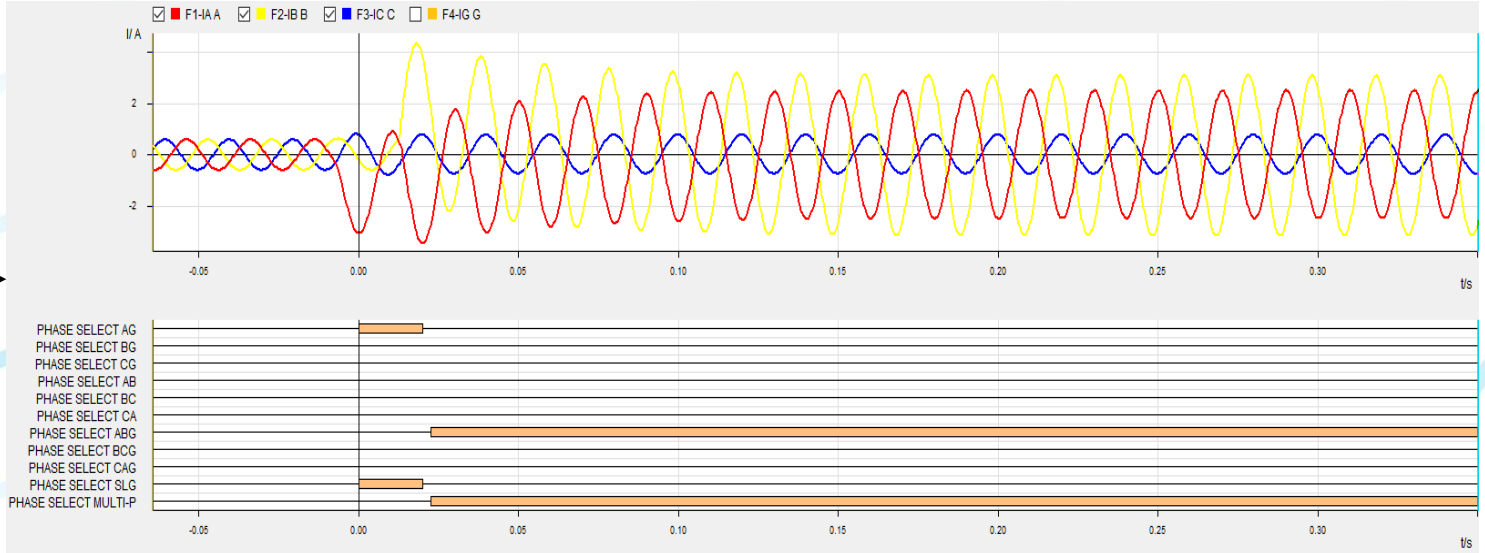
CA element - AG fault @ 0.9 and CG fault moved towards relay

Phase Selector – Challenges

Challenges with communication assisted phase selection

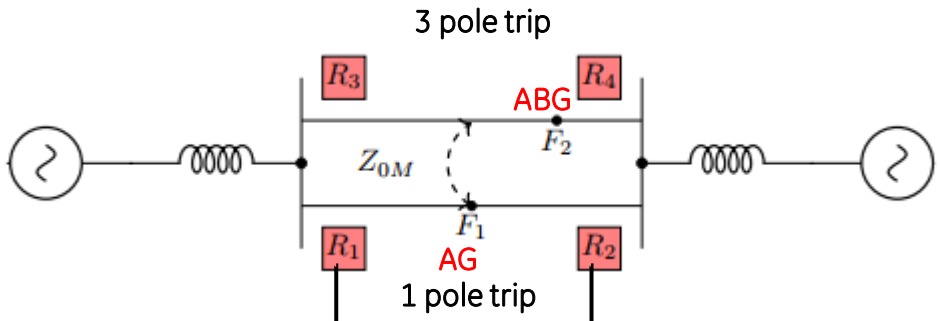




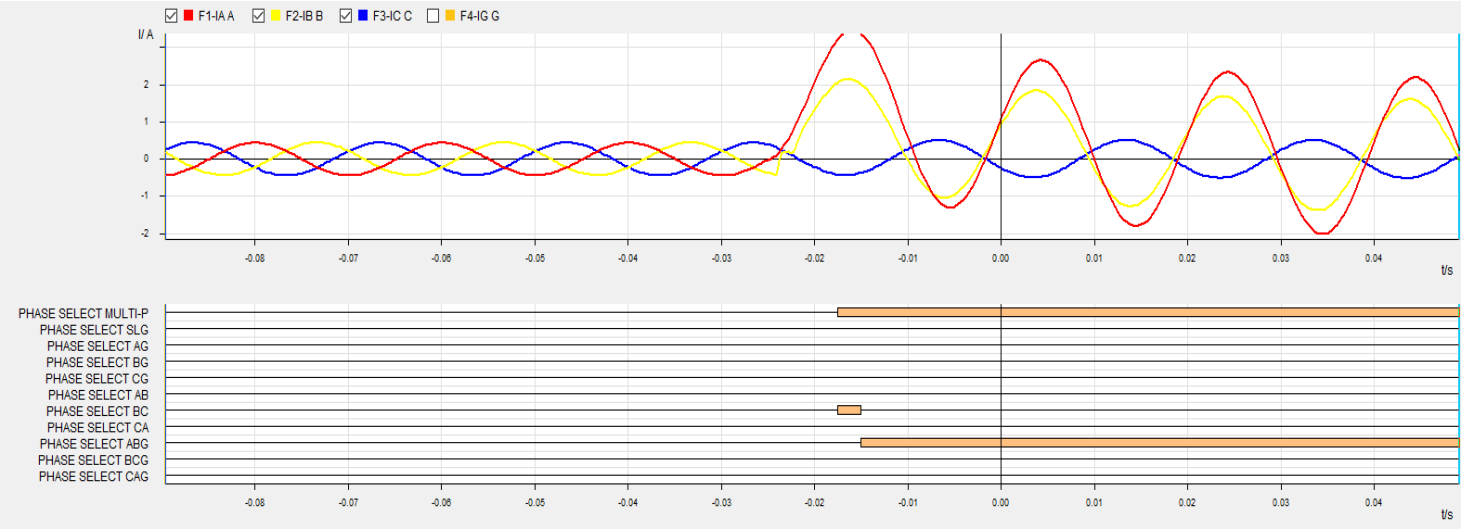


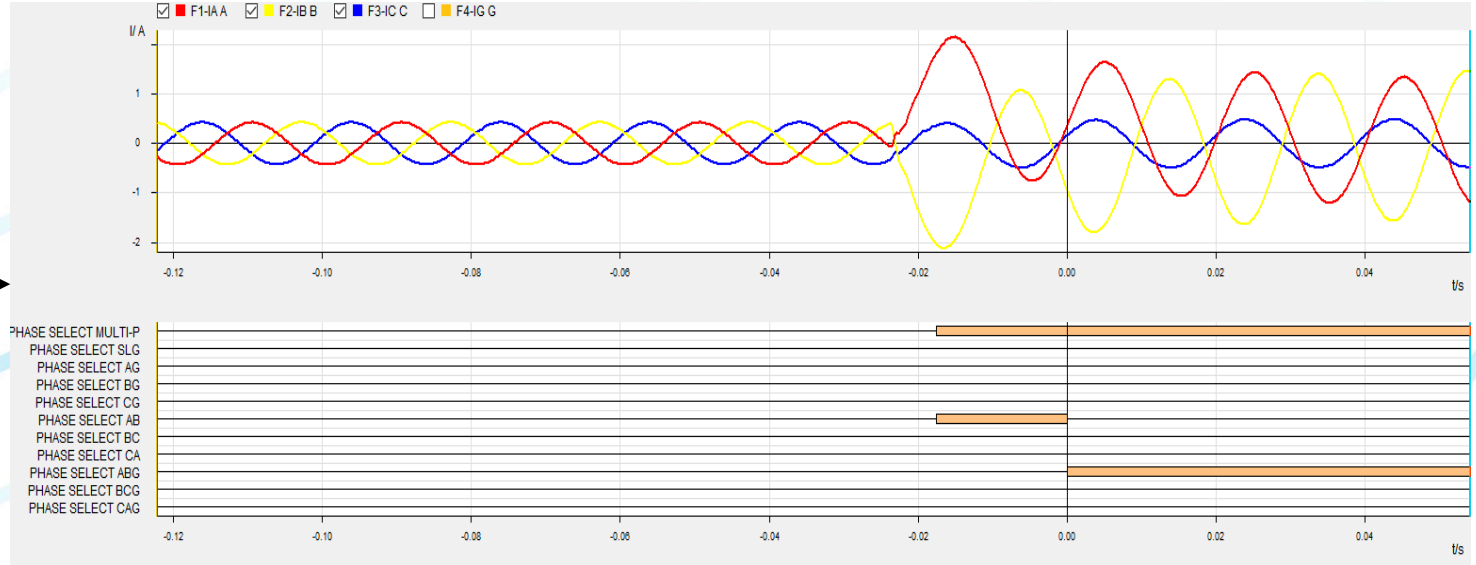
Phase Selector – Challenges (Contd…)

Challenges with communication assisted phase selection



Cross country fault F_1 close to R_2 ,F_2 close to R_4

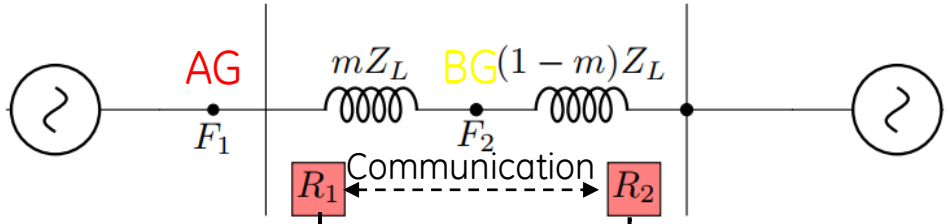




- Correct phase selection CANNOT be achieved even with communication medium,
- This could lead to loss of both lines and system split.

Phase Selector – Challenges and Improvements

Phase Selector improvements and its performance



Symmetrical Components based phase selector

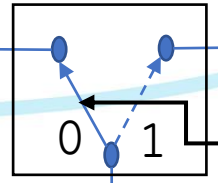
Under-reaching Max Torque (Metallic-fault)

Over-reaching Characteristic

PS –AG/BG/CG

PS – AB/BC/CA

PS – ABG/BCG/CAG



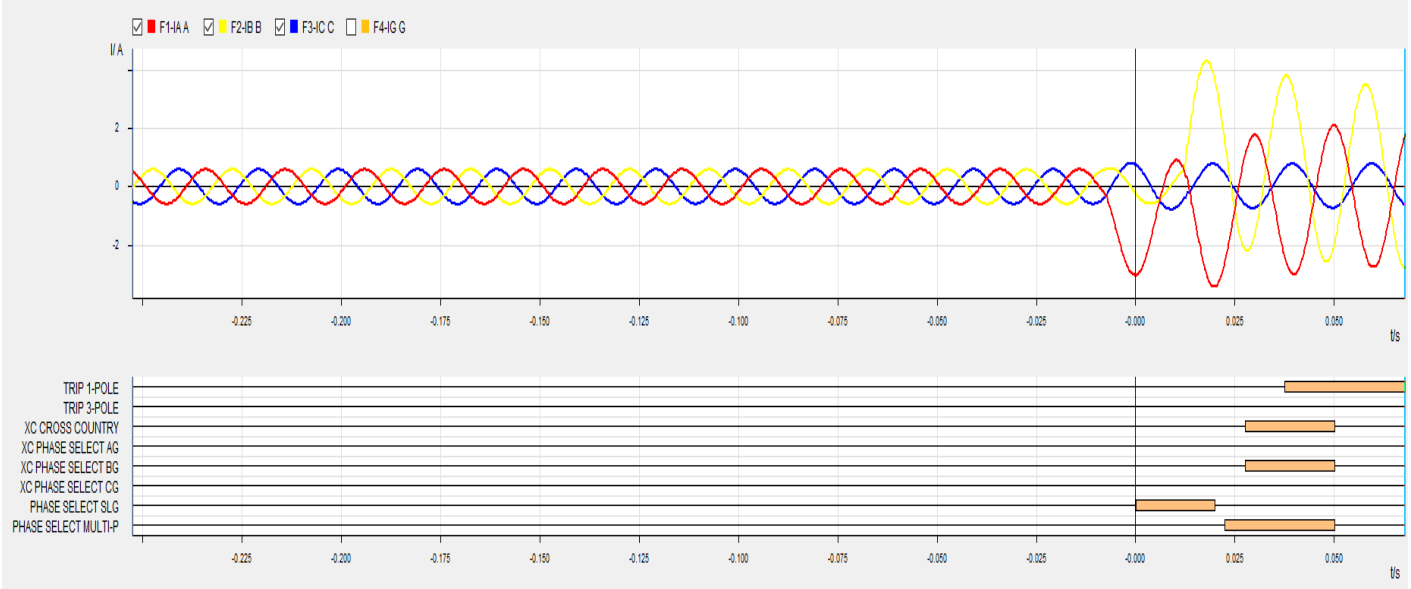
XC - AG

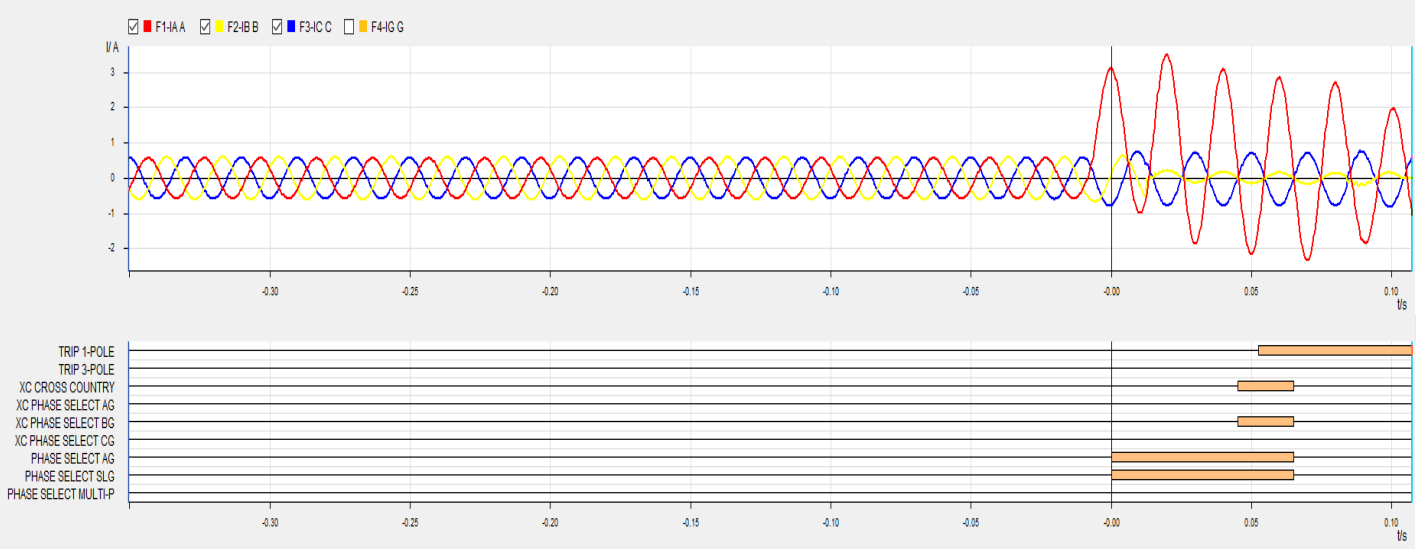
XC – BG

XC - CG

XC - Detected

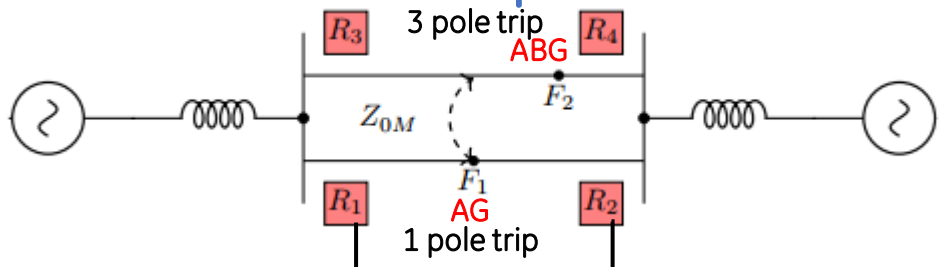
To Supervise distance

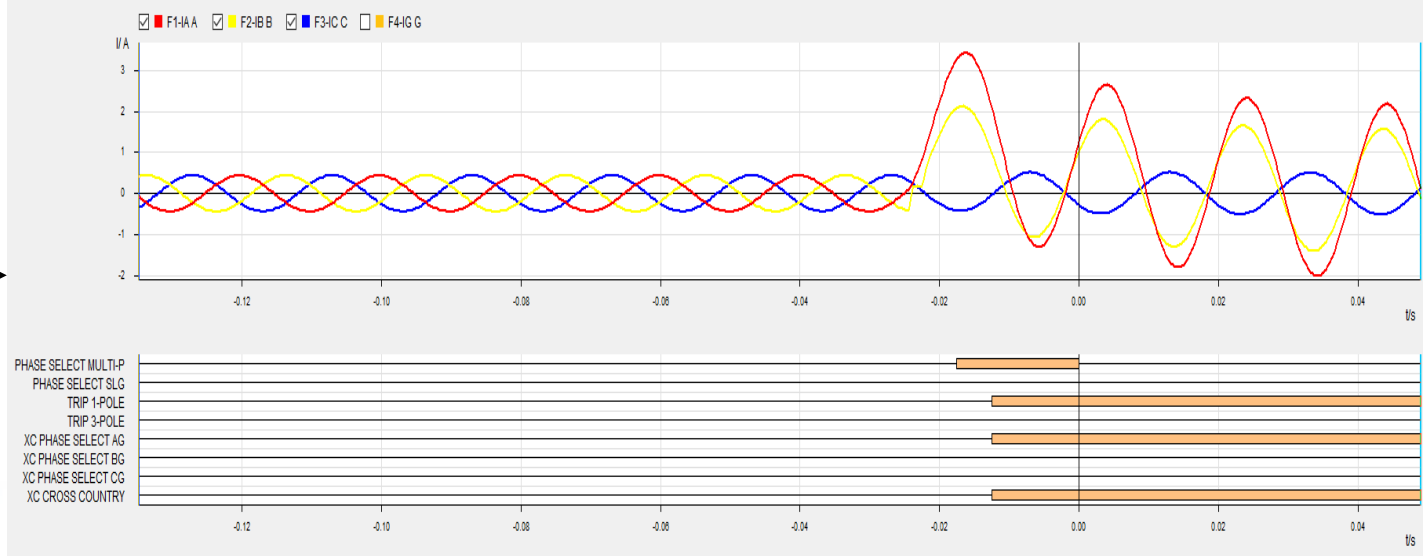


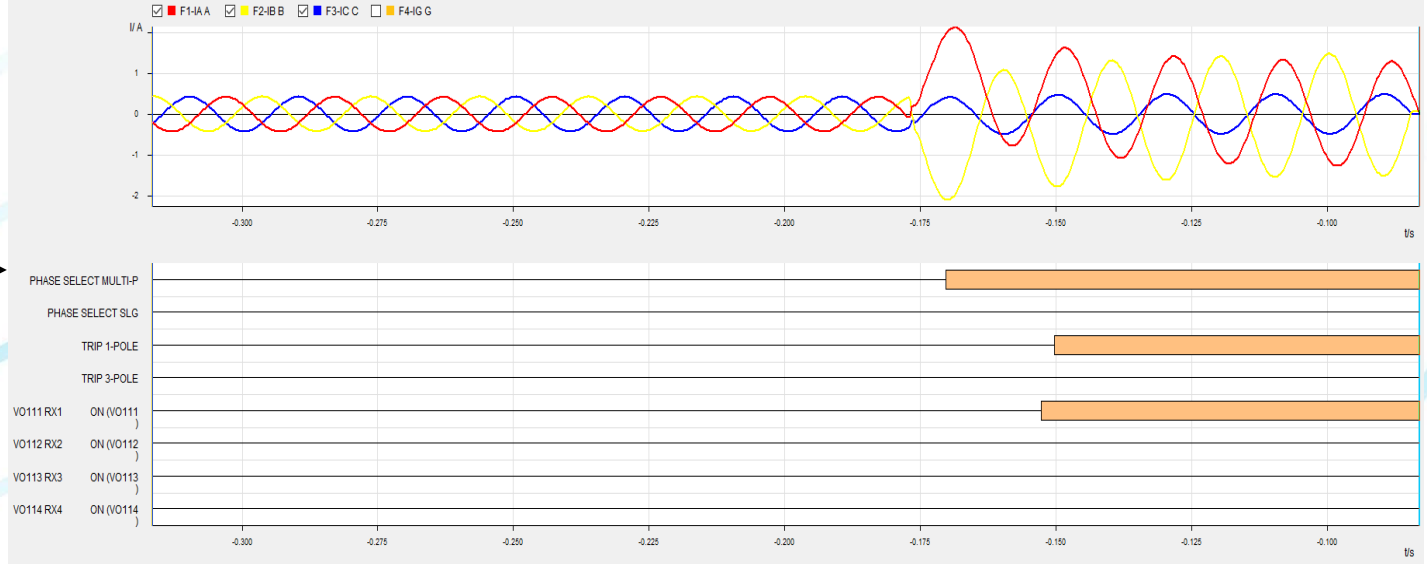


Phase Selector – Challenges and Improvements

Phase Selector improvements and its performance







Symmetrical Components based phase selector

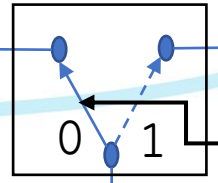
Under-reaching Max Torque (Metallic-fault)

Over-reaching Characteristic

PS –AG/BG/CG

PS – AB/BC/CA

PS – ABG/BCG/CAG



XC - AG

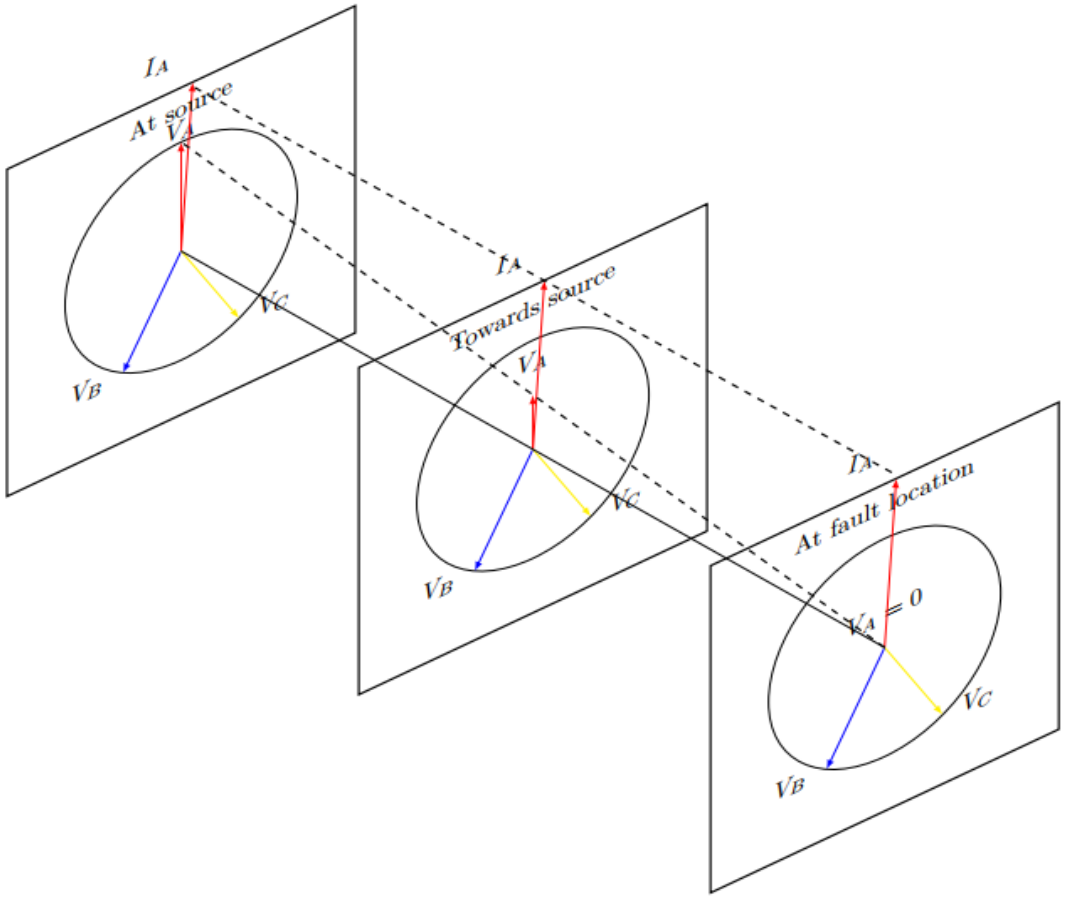
XC – BG

XC - CG

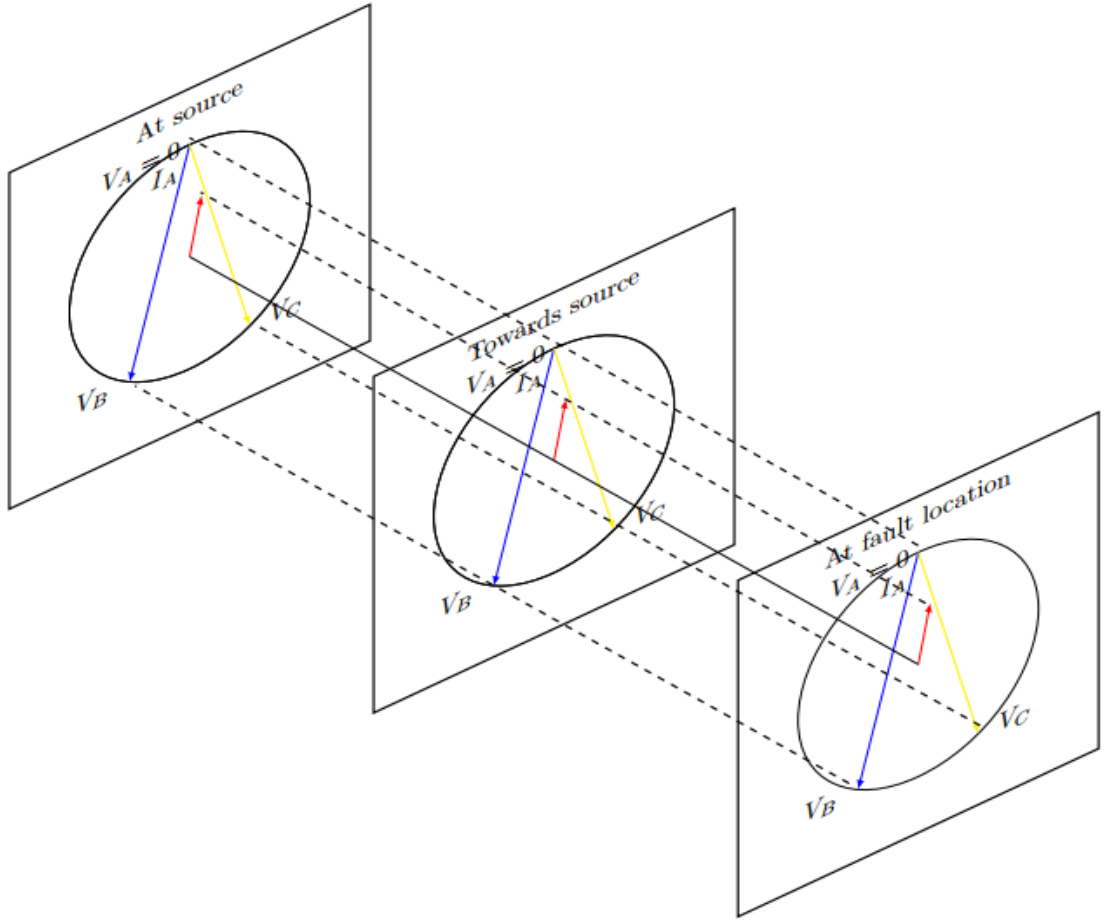
XC - Detected

To Supervise distance

Isolated/Compensated – Single phase to ground faults

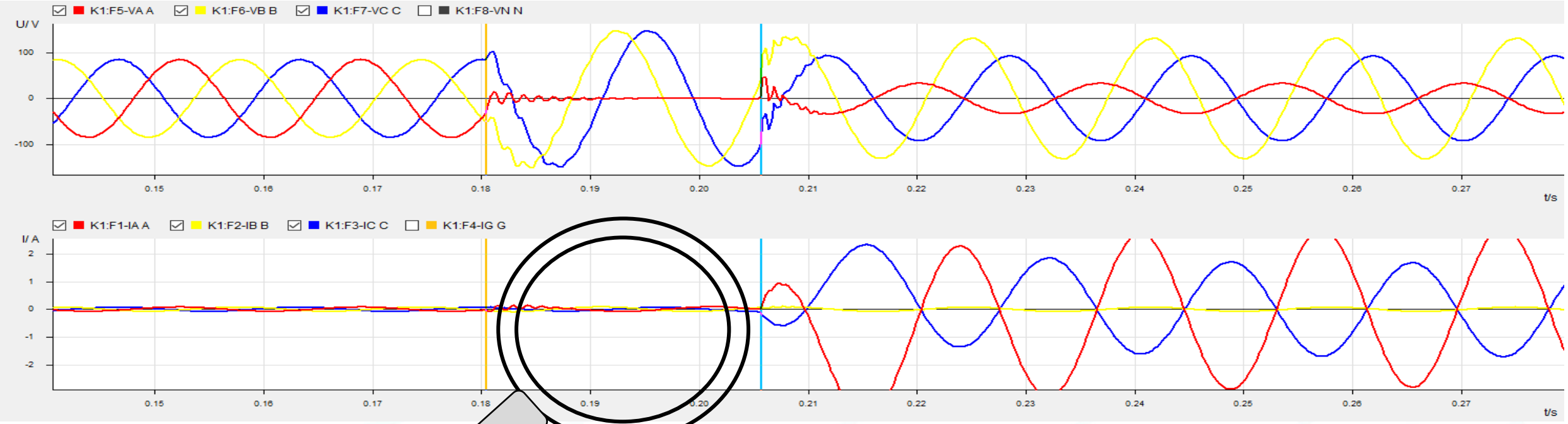


Solid grounded system- Single phase to ground fault



Isolated/Compensated -Single phase to ground fault

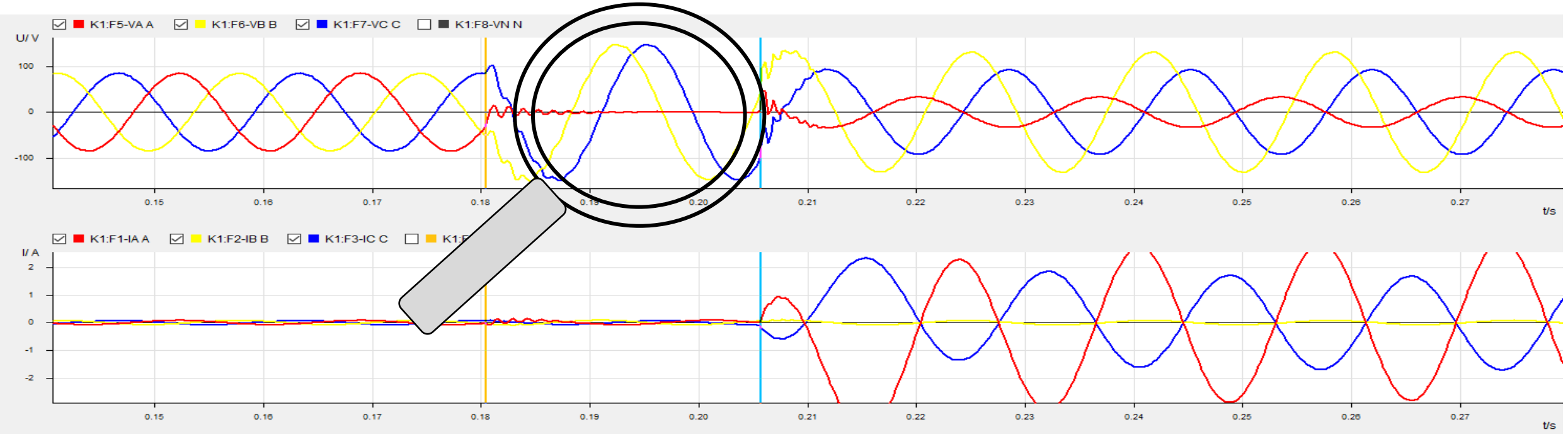
Isolated/Compensated – Single phase to ground faults



Faults in Isolated/Compensated system

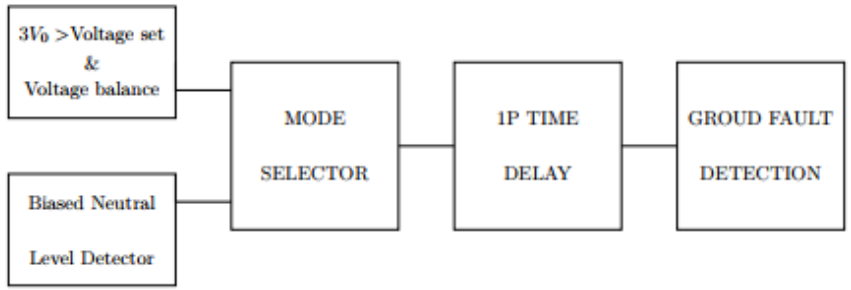
- Tripping should not happen for single phase to ground faults and the system can remain connected providing uninterrupted supply.

Isolated/Compensated – Single phase to ground faults



Faults in Isolated/Compensated system

- Tripping should not happen for single phase to ground faults and the system can remain connected providing uninterrupted supply.
- Presence of single phase to ground fault is expected to cause increase in healthy phase to ground voltages leading to cross-country faults.



Ground fault detection

Isolated/Compensated – Single phase to ground faults

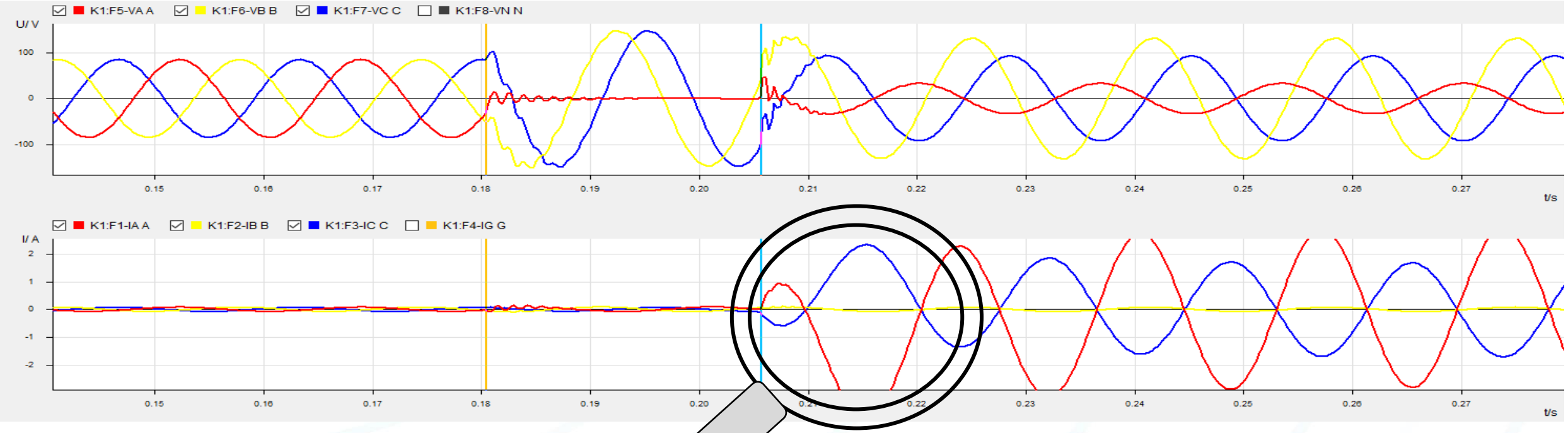
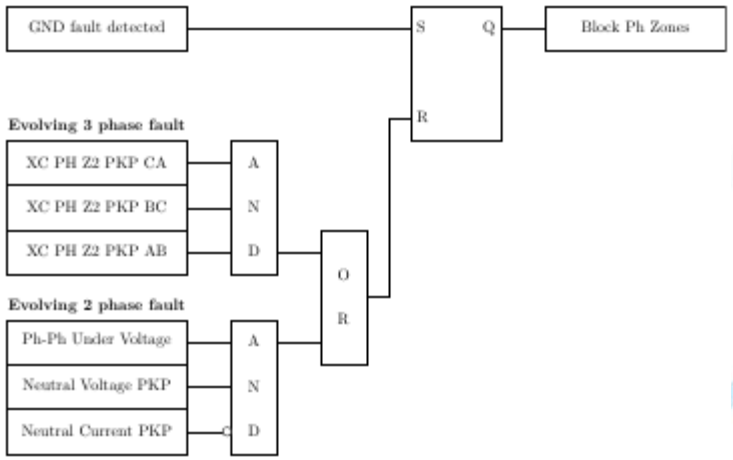


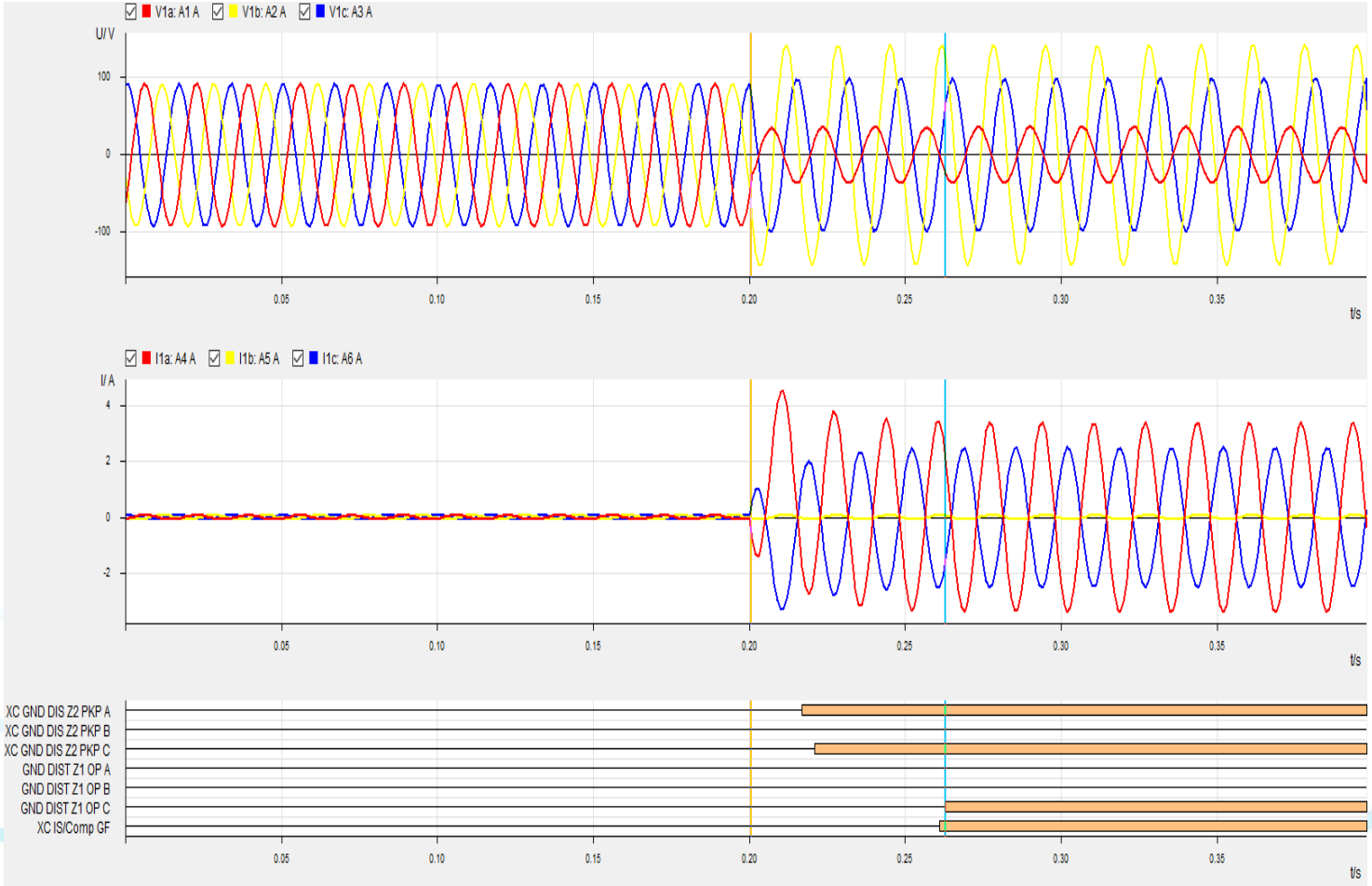
Fig. : Faults in I d/Compensated system

- Tripping should not happen for single phase to ground faults and the system can remain connected providing uninterrupted supply.
- Presence of single phase to ground fault is expected to cause increase in healthy phase to ground voltages leading to cross-country faults.
- Phase distance is blocked during cross-country faults



Phase Zone Unblocking logic

Isolated/Compensated – Cross-Country faults



Tripping priority

Selection	Priority	Loops	Selected Phase
C(A) acyclic	C before A, A before B	AG, BG	AG
		BG,CG	CG
		CG,AG	CG
		AG,BG,CG	CG

Phase preference tripping during cross-country faults AG @25 % and CG @75% of protected line

Summary

- Solid grounded systems – Cross country faults
  - Distance elements alone cannot ensure correct 1-pole tripping and it needs to be supervised by phase selector
  - Communication-assisted phase selection can work correctly, only if at least one end of the protected line is able to detect the phase correctly
  - Phase selection during cross-country is a challenge and it can lead to 3-pole tripping even with communication assistance, especially critical for parallel lines where both lines can be tripped 3-pole
  - Improved phase selection logic,
    - Detects cross-country faults and identify the faulted phases correctly
    - Ensures correct 1-pole tripping from both ends of the line
- Isolated/Compensated Systems – Cross country faults
  - Line is isolated from network based on the preferred priority, with the expectation that fault at the other location will self-extinguish
  - Phase distance is blocked during cross-country faults, however, during evolving two phase faults or three phase faults phase distance is released

Thank You

Questions?