Considerations in Choosing Directional Polarizing Methods for Ground Overcurrent Elements in Line Protection Applications

Technical Report to the Line Protection Subcommittee of the PES, Power Systems Relaying Committee

Presented by Working Group D-3

Line Protection Subcommittee

Considerations in Choosing Directional Polarizing Methods for Ground Overcurrent Elements in Line Protection Applications

Working Group D-3 Members:

John Appleyard, Jeffrey Barsch, Gabriel Benmouyal, Art Buanno, Randy Crellin, Randy Cunico, Normann Fischer, Michael Fleck, Robert Frye, Charles Henville, Meyer Kao (Chair), Shoukat Khan, Gary Kobet, Alex Lee, Don Lukach, Walter McCannon, Joe Mooney, Jim O'brien, Cristian Paduraru, Suhag Patel, Russell Patterson, Frank Plumptre, Elmo Price (Vice-chair), Ryland Revelle, Sinan Saygin, Mark Schroeder, Steve Turner

IEEE PES Power & Energy Society

IEEE

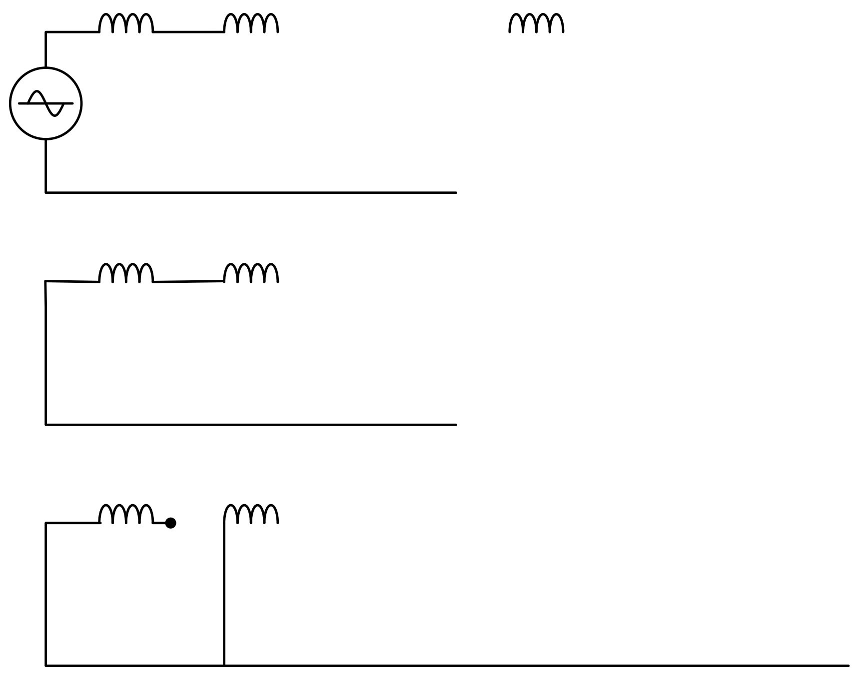
What is Polarization

- The process of comparing a reference phasor, voltage or current, to line current phasor to determine the direction to a fault
- The reference phasor is generally referred to as the polarizing quantity
- Basis for design of directional elements

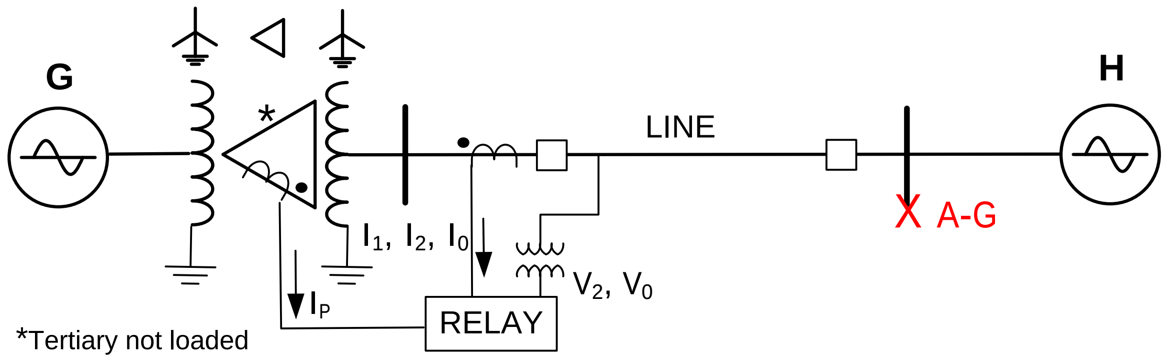
Why Use It for Ground Overcurrent Application

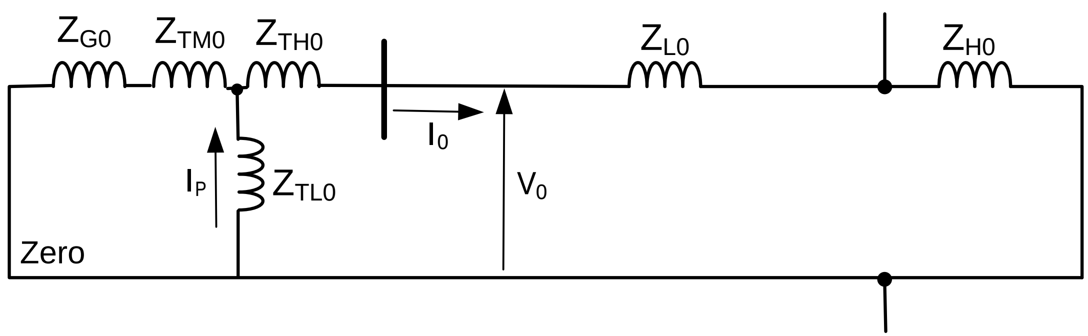
- In a network transmission system, ground overcurrent elements can be very difficult to coordinate
- Ground directional elements are used to supervise ground overcurrent elements so that they only operate for faults in a desired direction

Sequence Network for Ground Faults



Sequence Network for Ground Faults, Cont.

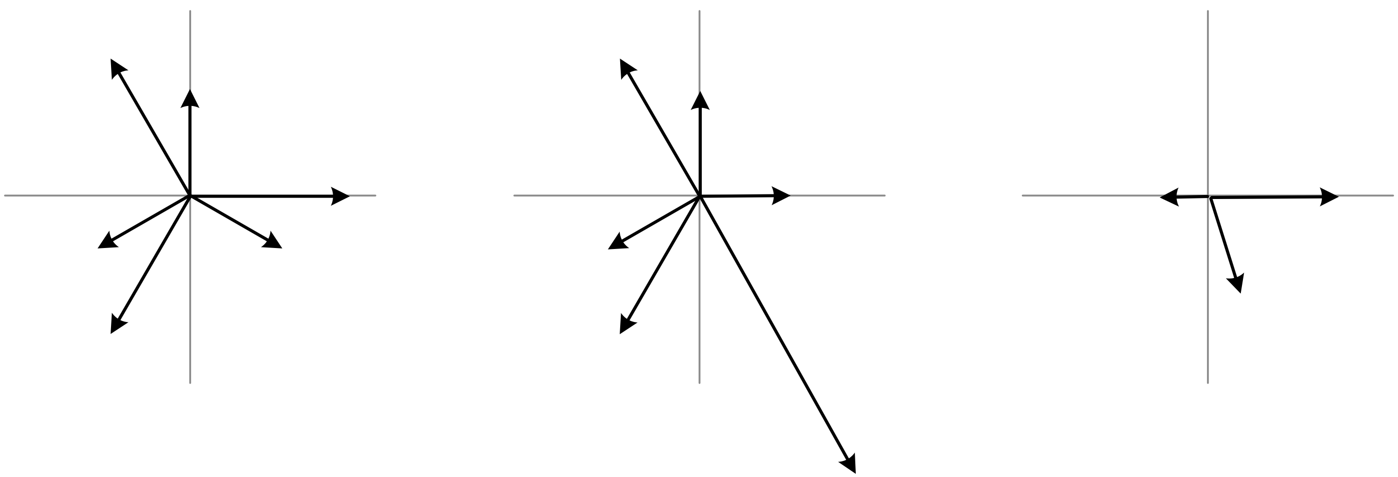




Polarizing Methods for Ground Directional Elements

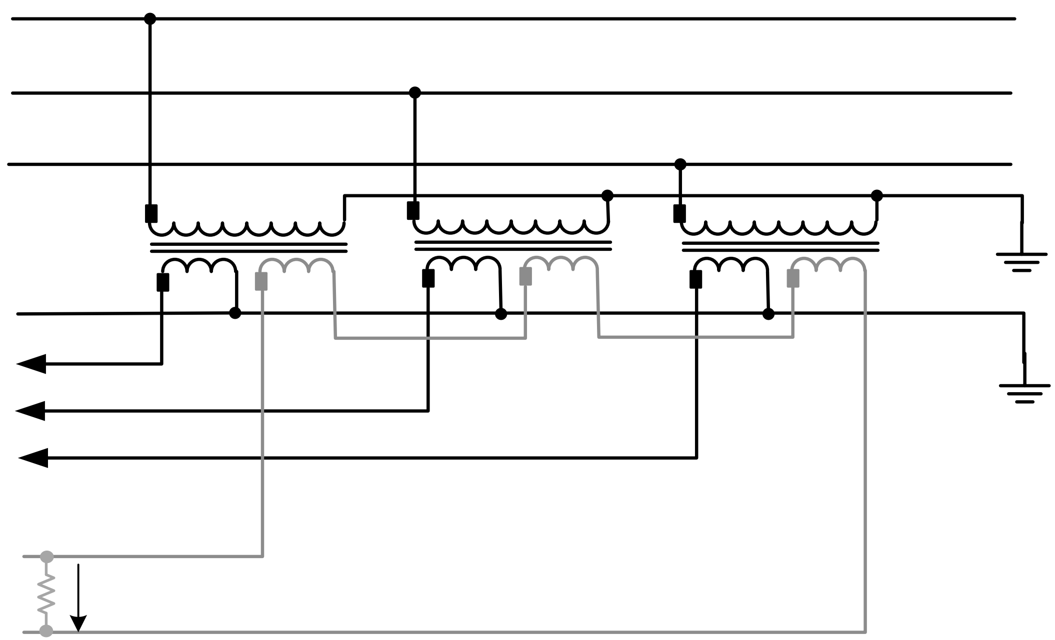
- Zero sequence voltage
- Negative sequence voltage
- Zero sequence current
- Dual Polarizing, combination of zero sequence voltage and zero sequence current
- Negative sequence and zero sequence impedance
- Virtual polarizing
- Voltage compensation

System Vectors, Balanced and During a Single Line to Ground (SLG) Fault

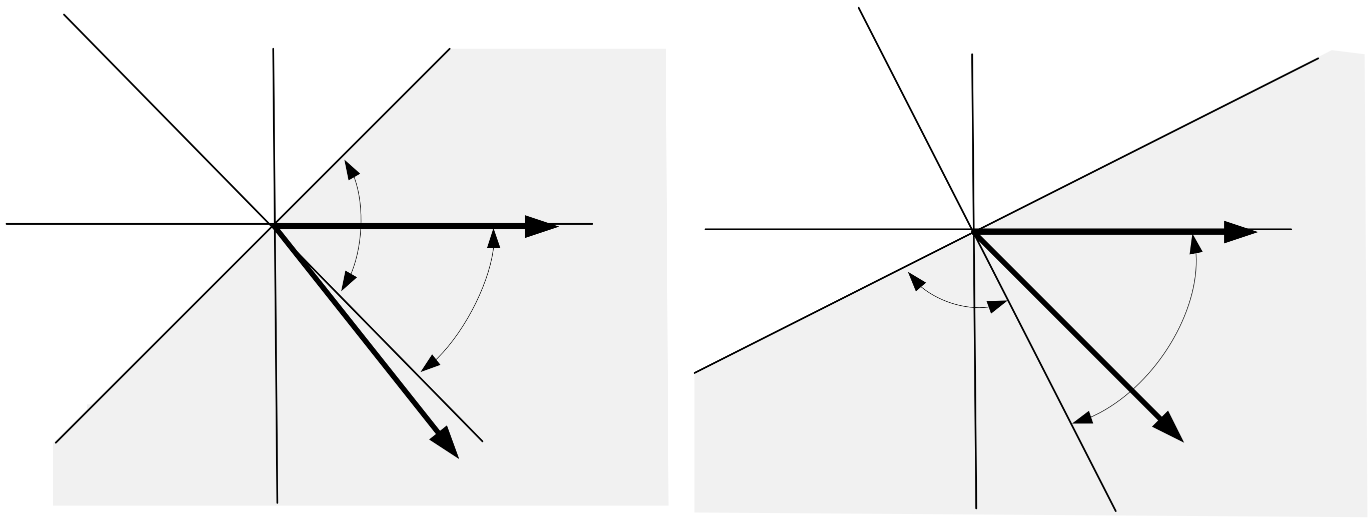


Zero and Negative Sequence Voltage Polarizing Source

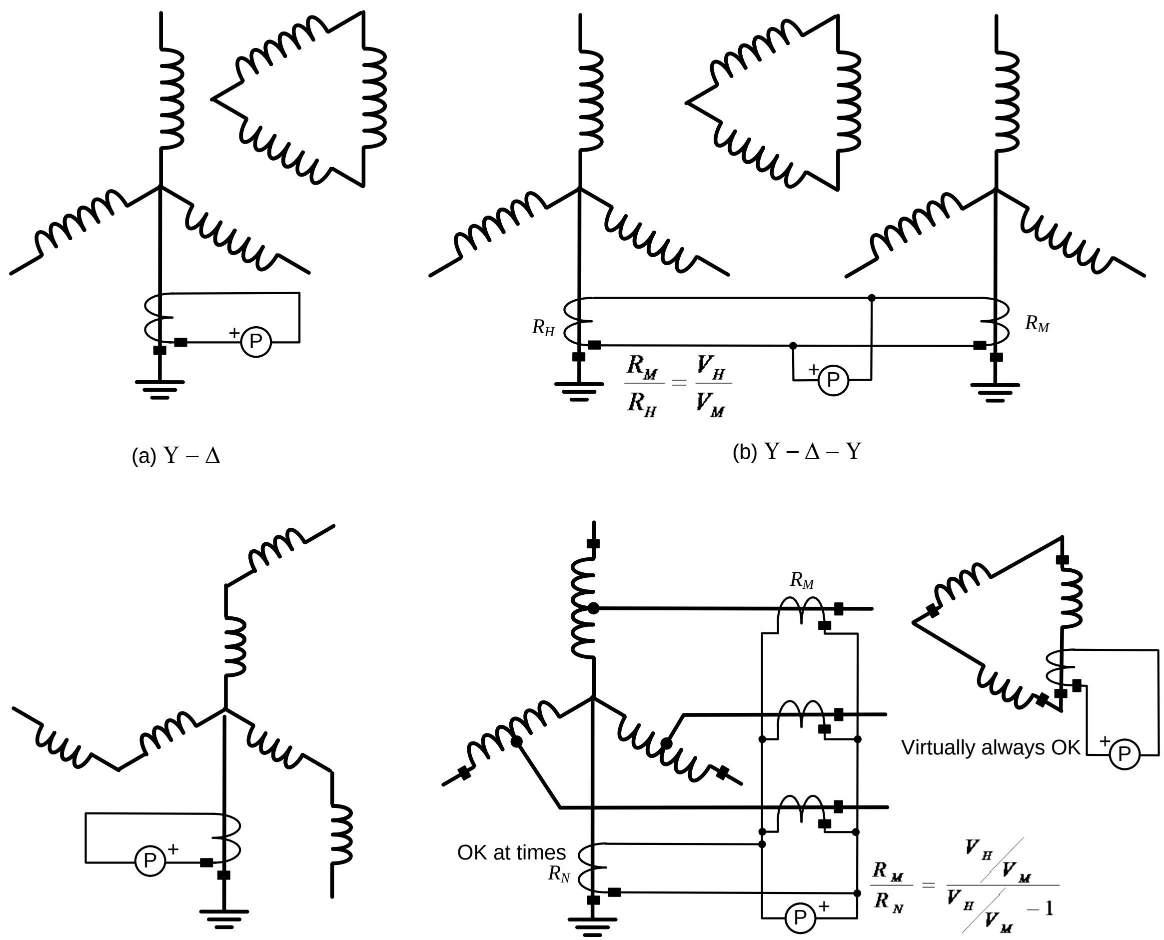
- Sequence voltages are obtained from the three phase to neutral voltages, or
- -3V0 obtained from broken delta connection



Zero and Negative Sequence Voltage Directional Operating Characteristics



Zero Sequence Current (Current Polarizing) Polarizing Source



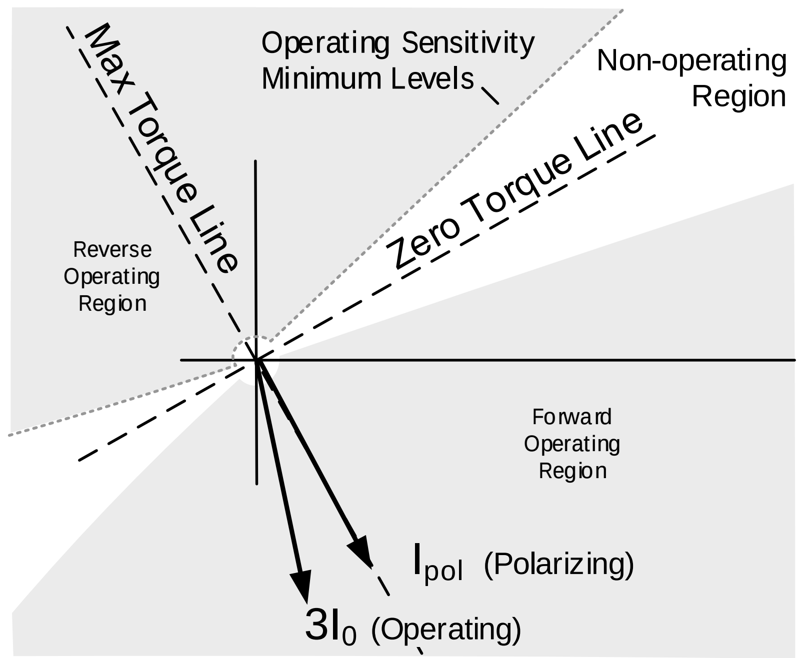
(a) Y – Δ

(b) Y – Δ – Y

(c) Zig-zag

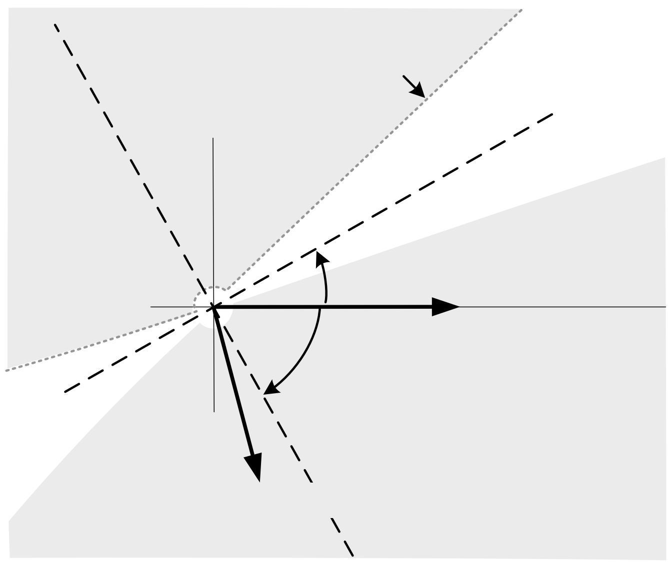
(d) Auto – with Δ tertiary

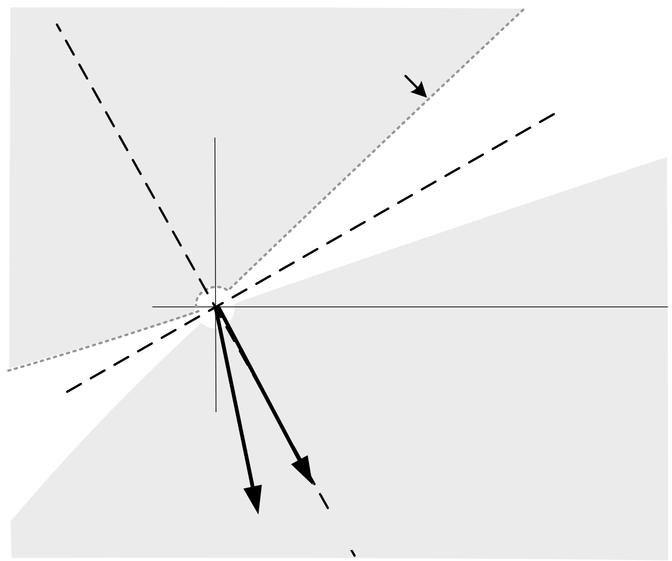
Zero Sequence Current (Current Polarizing) Directional Operating Characteristics



Transformer Zero Sequence Current Polarized
Directional Ground Fault Function

Dual Polarizing, Combination of Zero Seq. Voltage and Zero Seq. Current



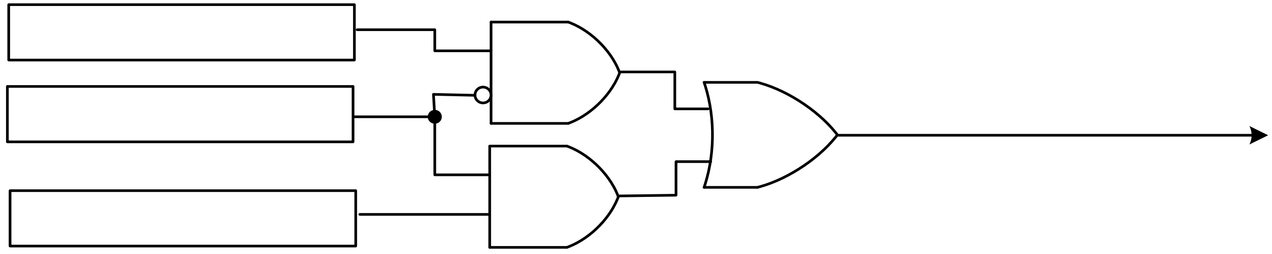


Dual Polarizing, Multiple Directional Element Designs

- Electromechanical Designs
  - Separate voltage polarized and current polarized units with their forward (closing torque) operating contacts arranged in parallel so that either unit may indicate forward ground fault direction
  - A single directional unit that has both polarizing elements acting simultaneously on the same unit, so that a single contact that operates on the sum of the torque is developed by the two methods

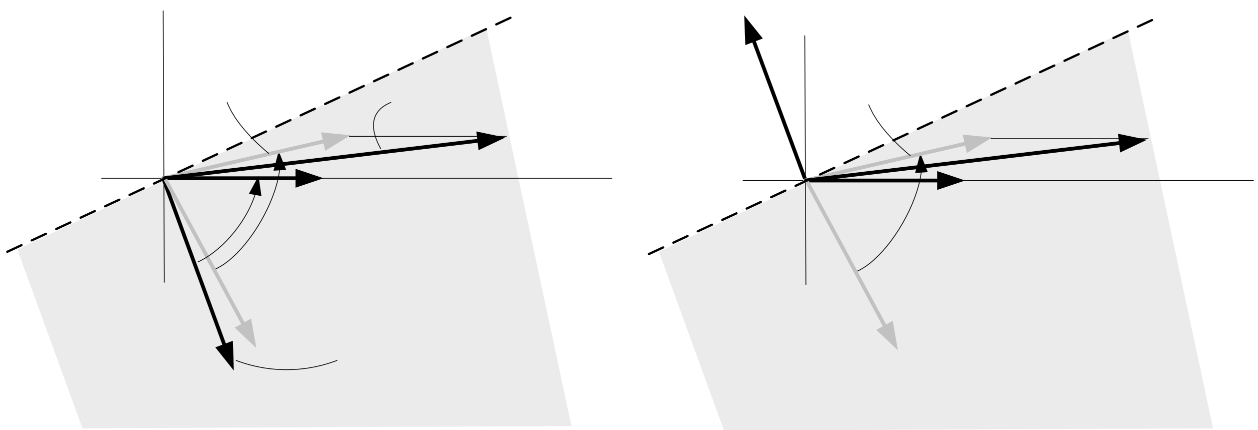
Dual Polarizing, Multiple Directional Element Designs, Cont.

- Numerical Relay Designs
  - Paralleling (OR gate) of the appropriate outputs of the two methods, however, the voltage polarizing unit is blocked if polarizing current is available. The voltage unit will only operate if polarizing current is not available.



Dual Polarizing, Multiple Directional Element Designs, Cont.

- Numerical Relay Designs, Cont.
  - Dual polarization by summing the polarizing voltage phasor, –3V0, and the polarizing current phasor rotated by the angle α, the arg(V0/I0) for a strong forward fault.



Other Methods

- Negative and zero sequence impedance
  - Negative sequence Impedance:

$$Z_2 = \frac{Re[V_2 \cdot (\angle\theta_2 \cdot I_2)^*]}{|I_2|^2}$$

  - Zero sequence Impedance:

$$Z_0 = \frac{Re[V_0 \cdot (\angle\theta_0 \cdot I_0)^*]}{|I_0|^2}$$

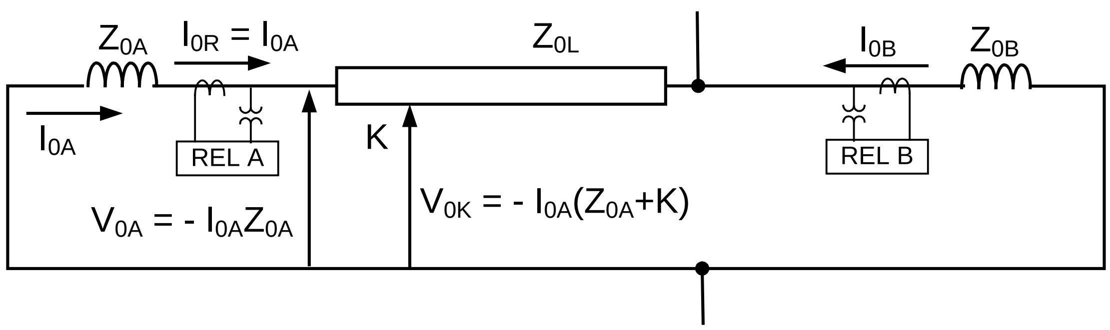
Other Methods, Cont.

- Virtual polarization
  - Based on phase selector has identified the faulted phase

Phase Selector Pickup	Virtual Residual, VN polarizing
A Phase Fault	$V_B + V_C$
B Phase Fault	$V_A + V_C$
C Phase Fault	$V_A + V_B$
No selection	$V_A + V_B + V_C$

Other Methods, Cont.

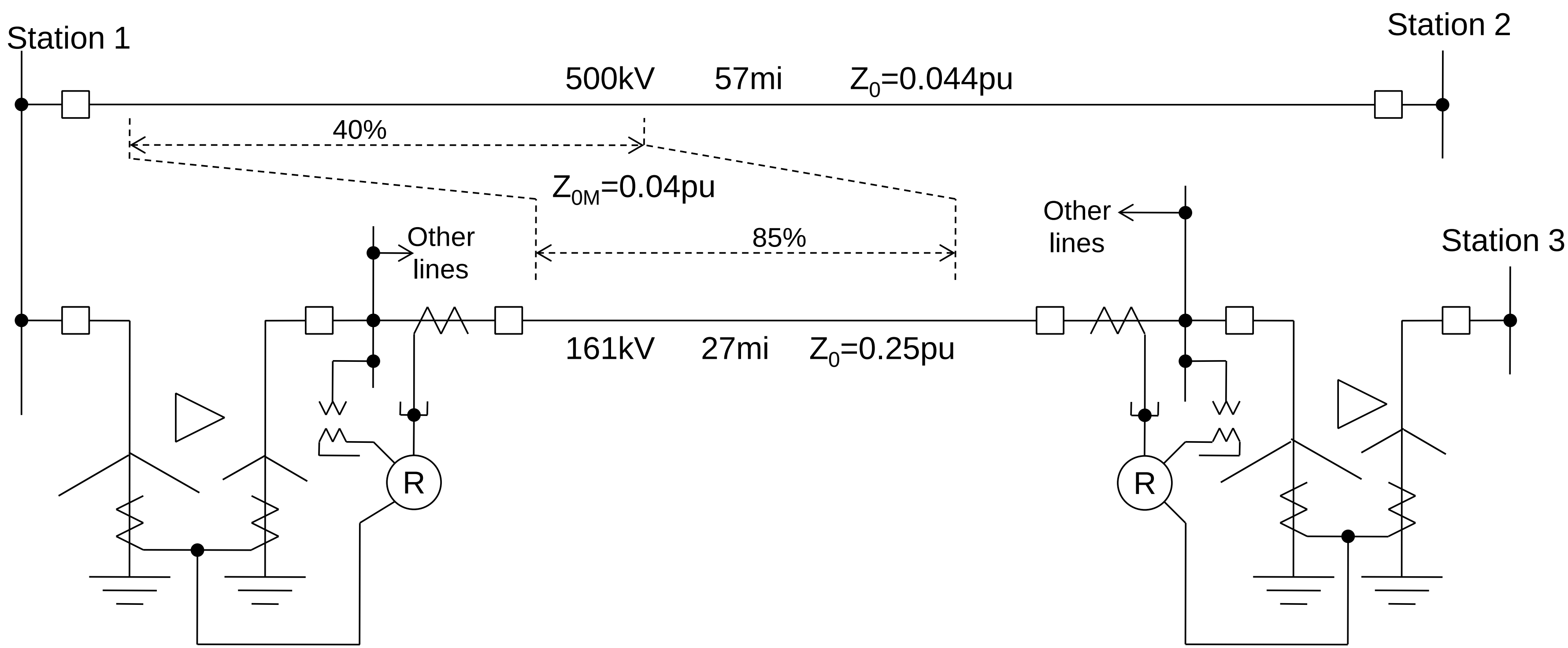
- Voltage Compensation
  - Either negative or zero sequence voltage compensation
  - Long line and resistive fault applications; low operating current and strong source with low source impedance
  - Vpol = $-V_{0A} + I_{0R} * K * e^{jRCA}$; care when choosing K so that the direction is not forward for a reverse fault



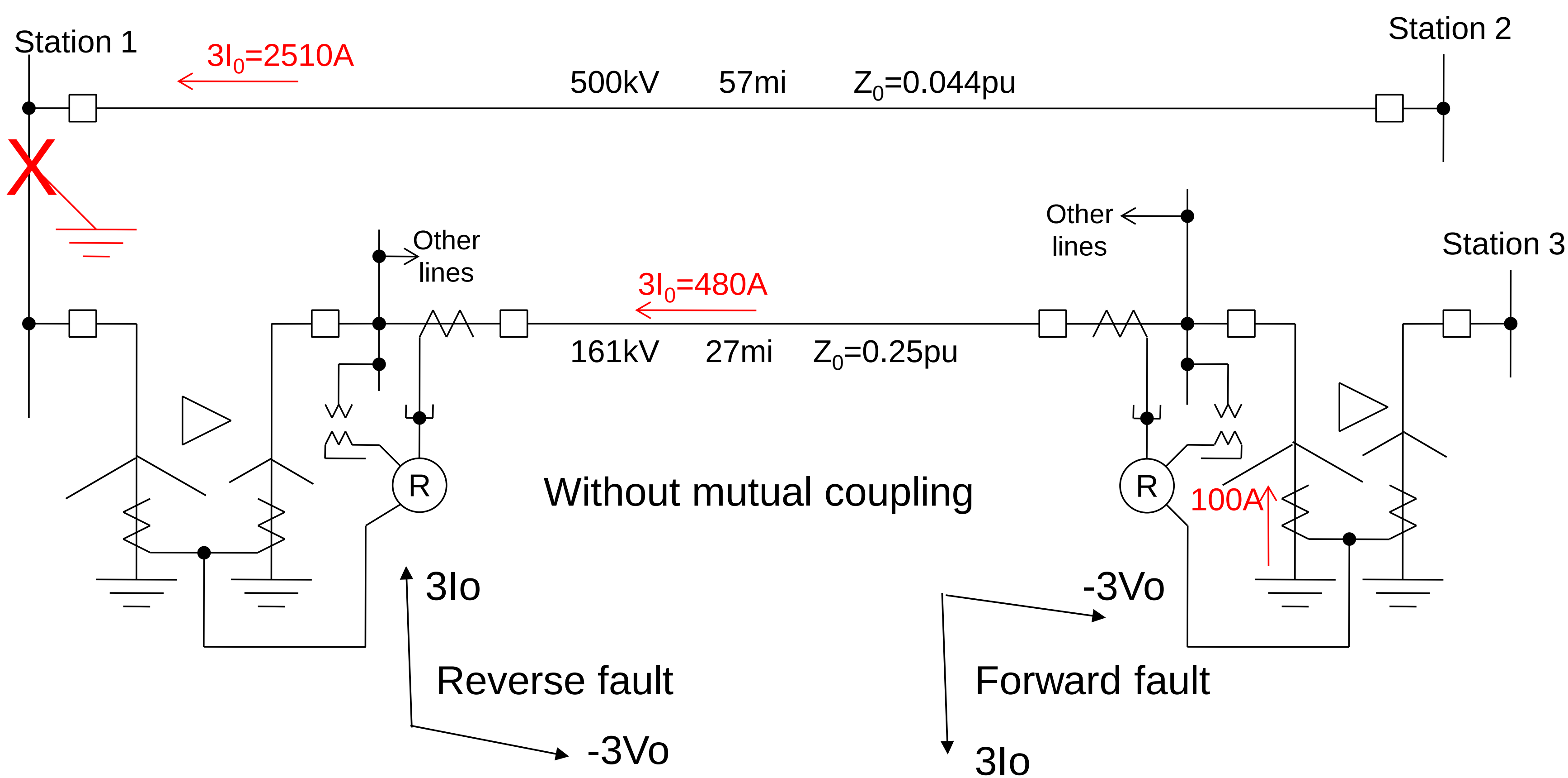
Application Consideration of Different Methods

- Zero sequence mutually coupled lines
- Line and source impedance consideration
- Mismatch of polarization methods on line terminals in communication assisted trip scheme
- Other considerations

Zero Sequence Mutually Coupled Lines: Application Example (Zero Seq. Voltage and Zero Seq. Current Polarized)



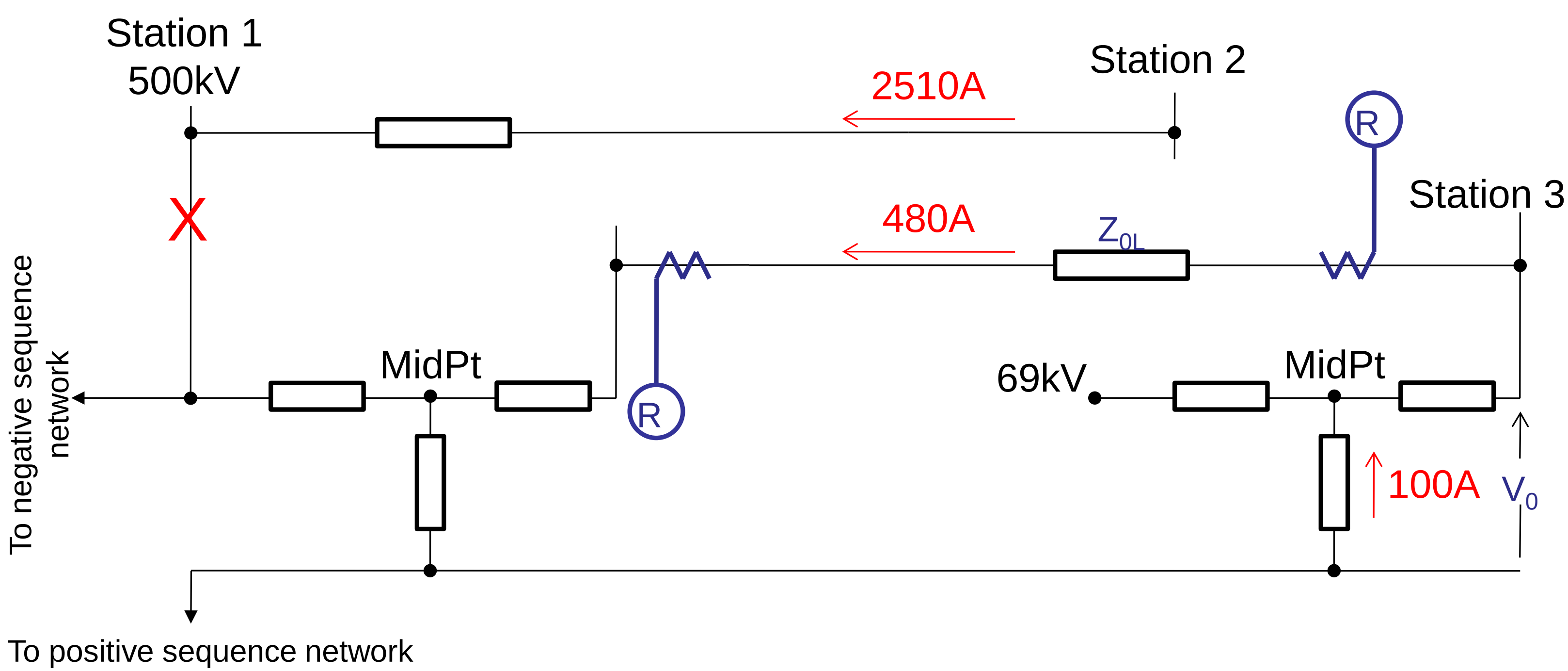
Fault on 500kV Bus at Station 1 (Neglect Mutual Coupling)



IEEE PES Power & Energy Society

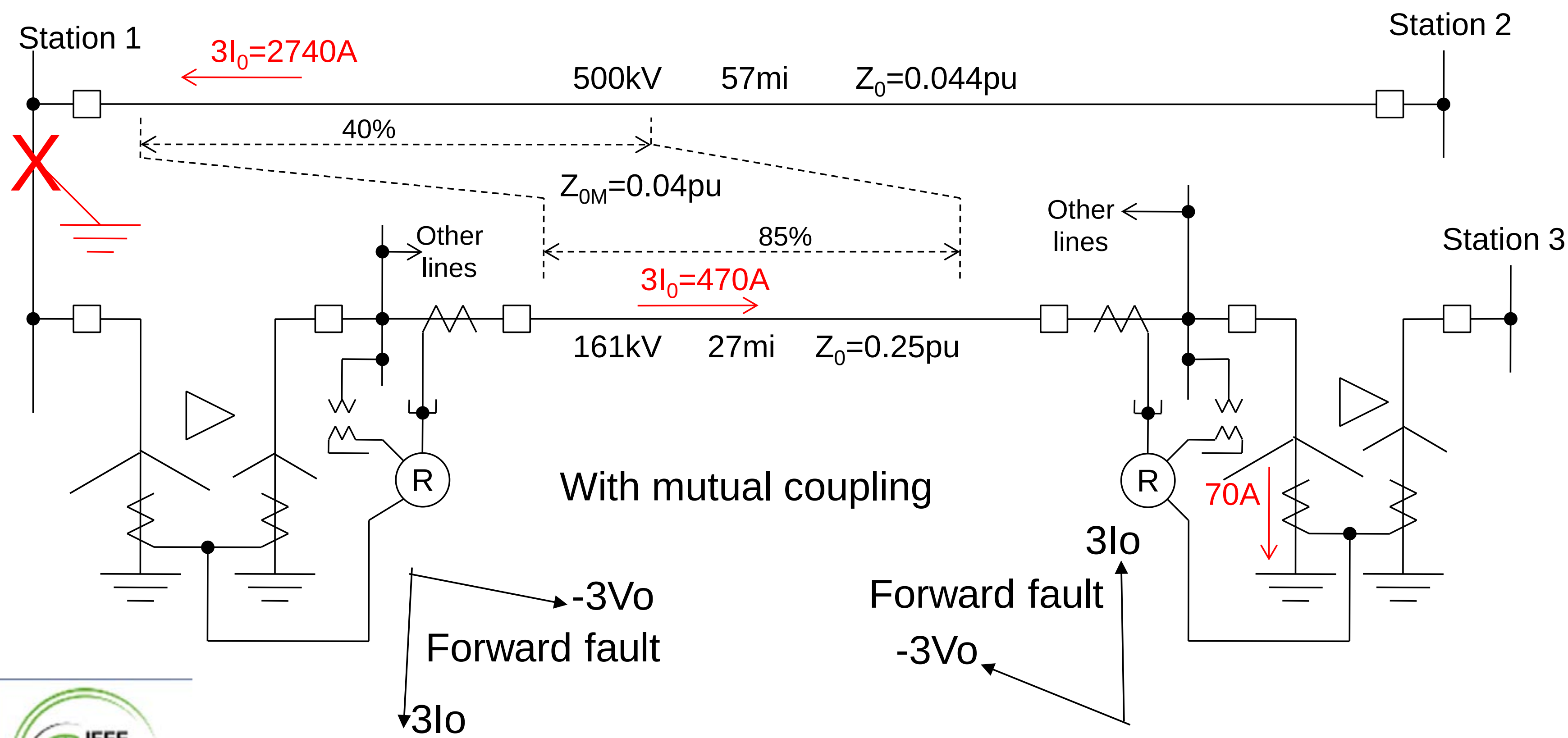
IEEE

Fault on 500kV Bus at Station 1, Partial Zero Seq. Network (Neglect Mutual Coupling)

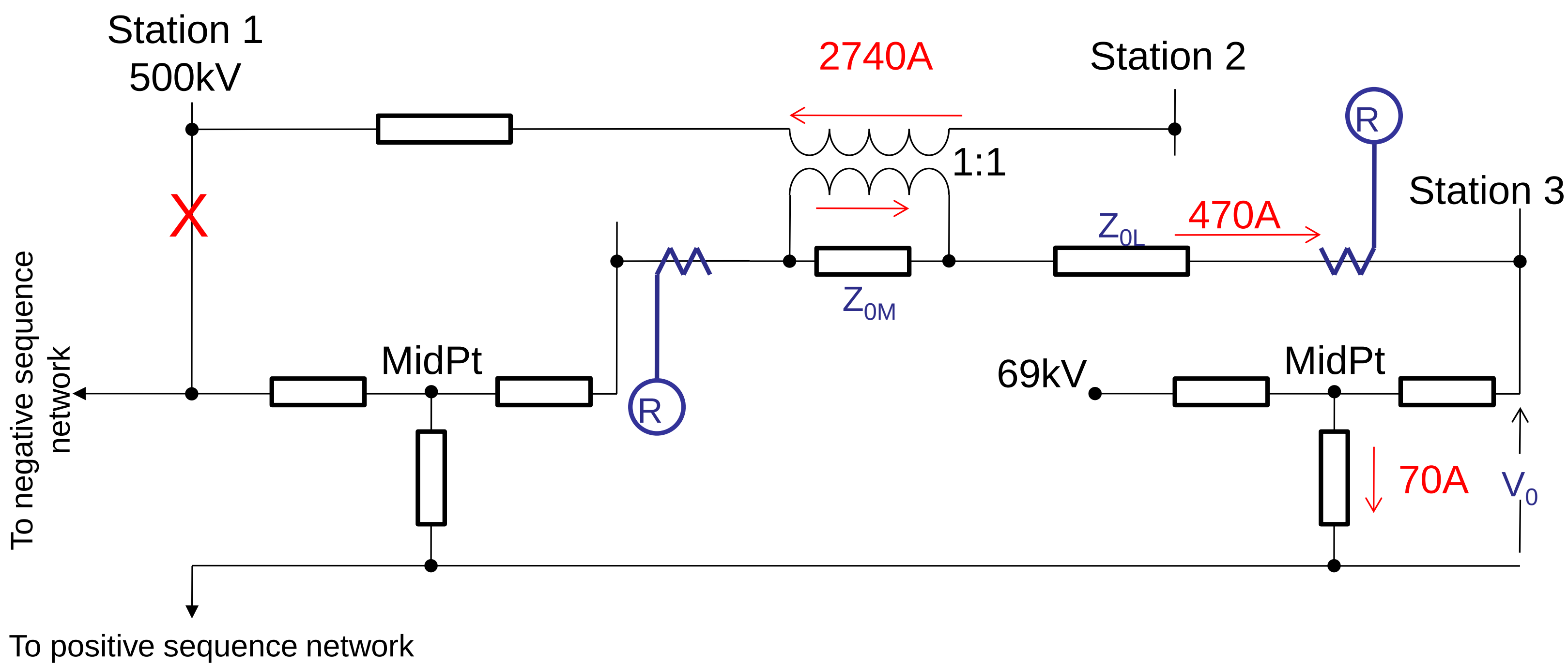


Fault on 500kV Bus at Station 1 (With Mutual Coupling)

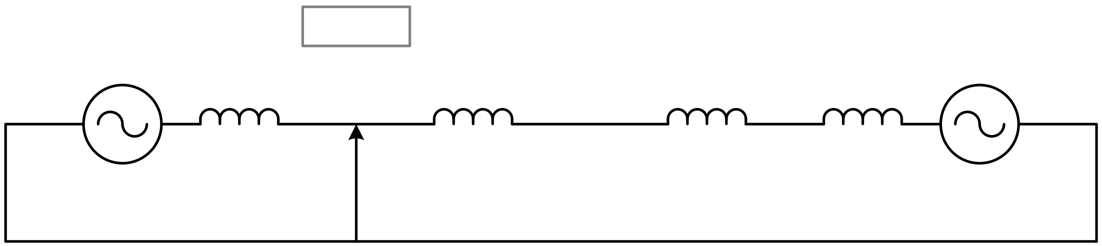
At Station 3, forward direction asserted for both zero sequence voltage and current polarizing elements



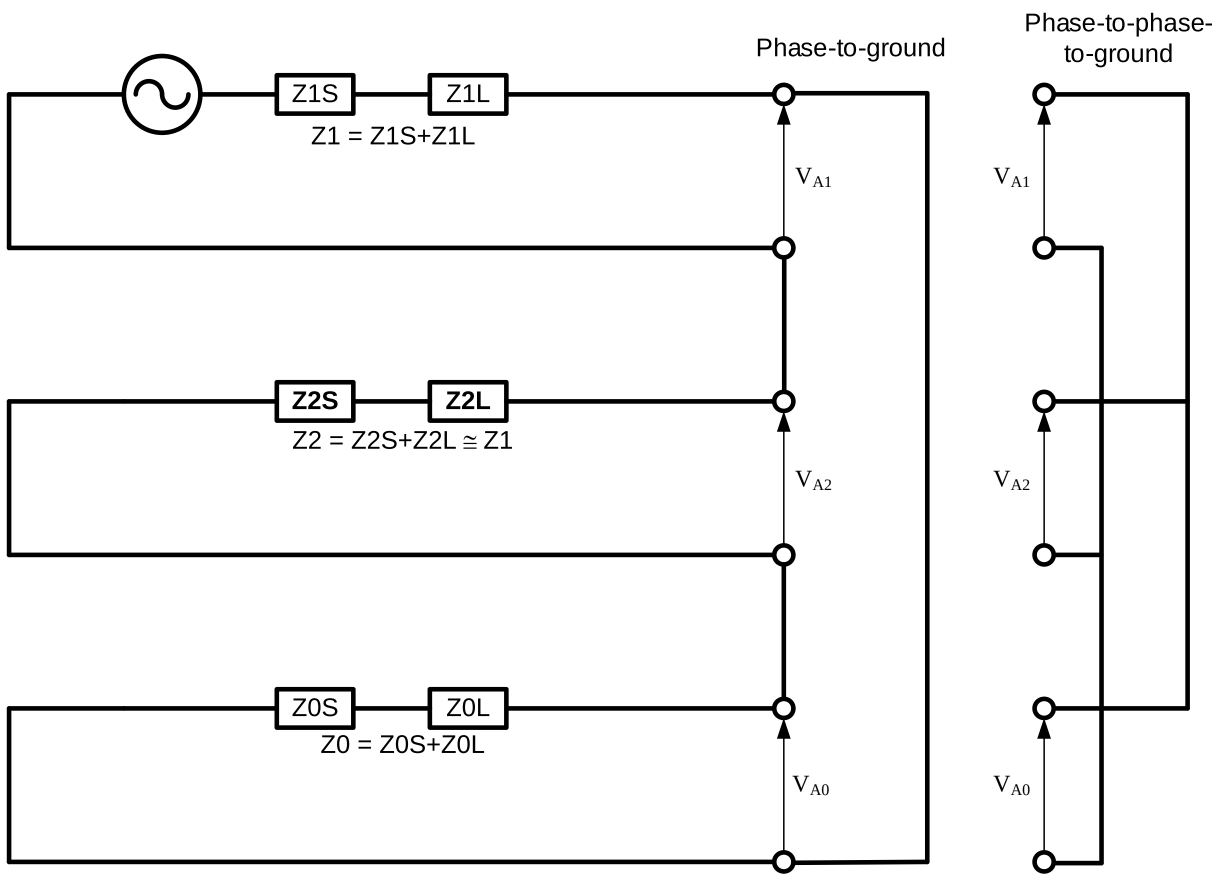
Fault on 500kV Bus at Station 1, Partial Zero Seq. Network (With Mutual Coupling)



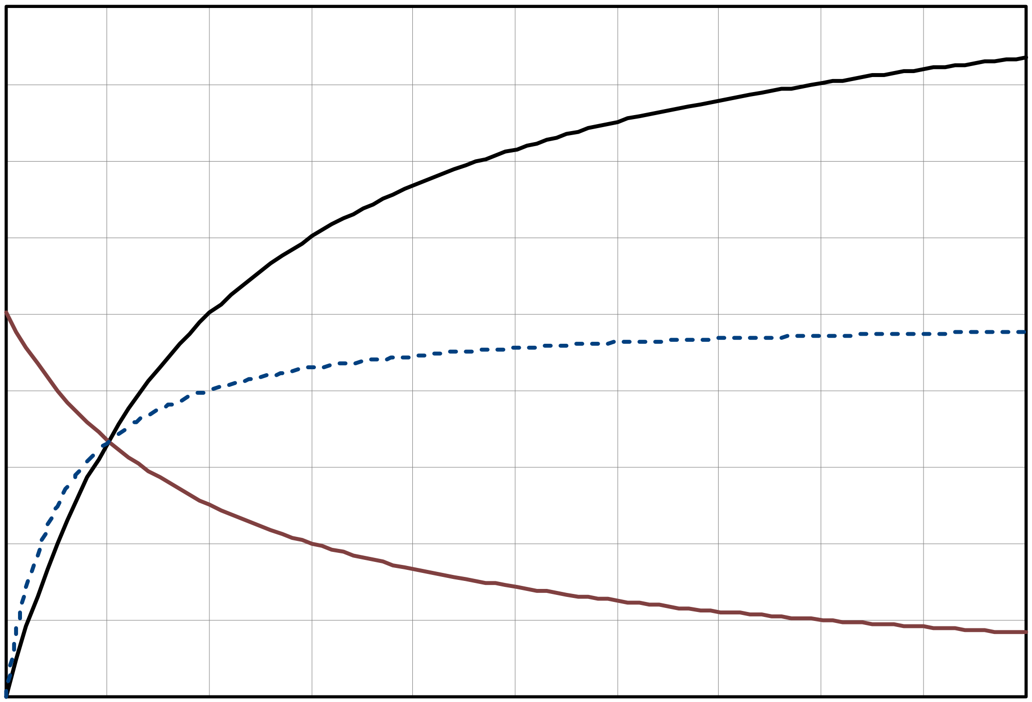
Evaluation of Polarizing Method Considering Line and Source Impedance, Z0 and Z2



Simplified Sequence Network at the Fault Location



Magnitude of Sequence Voltages Vary with Fault Type and the Z0/Z1 Ratio, As Viewed from the Fault Point



Single Line-to-Ground (SLG)

$$V_{A0} = \frac{Z_0/Z_1}{Z_0/Z_1 + 2}$$

$$V_{A2} = \frac{1}{Z_0/Z_1 + 2}$$

Line-to-Line-to-Ground (LLG)

$$V_{A0} = V_{A2} = \frac{Z_0/Z_1}{2Z_0/Z_1 + 1}$$

Evaluation of Polarizing Method Considering Line and Source Impedance, Z0 and Z2

Observations:

- If the system is homogeneous, that is if the ratios of source to line impedances are similar in the zero and negative sequence networks then the ratios of voltages at the relay will be the same as at the fault. Because line zero sequence impedance is roughly three times that of positive/negative sequence impedance, zero sequence voltage polarizing is superior.

Evaluation of Polarizing Method Considering Line and Source Impedance, Z0 and Z2

Observations (Cont.):

- Where the system is not homogeneous, the relative zero and negative sequence voltages at the relay can be easily estimated for ground fault at any point on the line

$$\frac{V_{A0R}}{V_{A2R}} = \frac{Z_0}{Z_2} \cdot \left(\frac{1+n \cdot Z_{1L}/Z_{1S}}{1+n \cdot Z_{0L}/Z_{0S}}\right)$$ SLG

$$\frac{V_{A0R}}{V_{A2R}} = \left(\frac{1+n \cdot Z_{1L}/Z_{1S}}{1+n \cdot Z_{0L}/Z_{0S}}\right)$$ LLG

Evaluation of Polarizing Method Considering Line and Source Impedance, Z0 and Z2

Observations (Cont.):

- The magnitude of the negative- or zero-sequence voltages are directly proportional to the current and the source impedance behind the relay location. Therefore, it can be seen that given a long line with a strong source behind the relay (Z2L >> Z2S or Z0L >> Z0S) the negative or zero-sequence voltage at the relay location can be relatively small.

Evaluation of Polarizing Method Considering Line and Source Impedance, Z0 and Z2

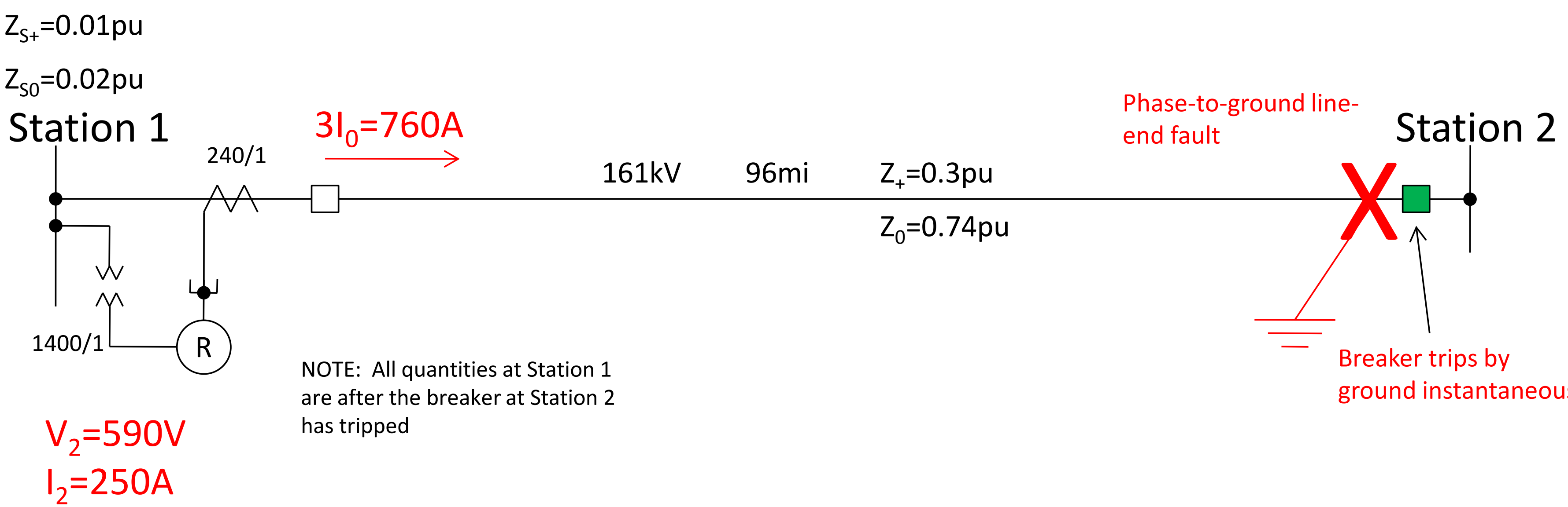
Observations (Cont.):

- To evaluate the choice of the sequence voltages at the relay, the magnitude of zero and negative sequence voltages at the relay can be estimated for ground fault at end of the line

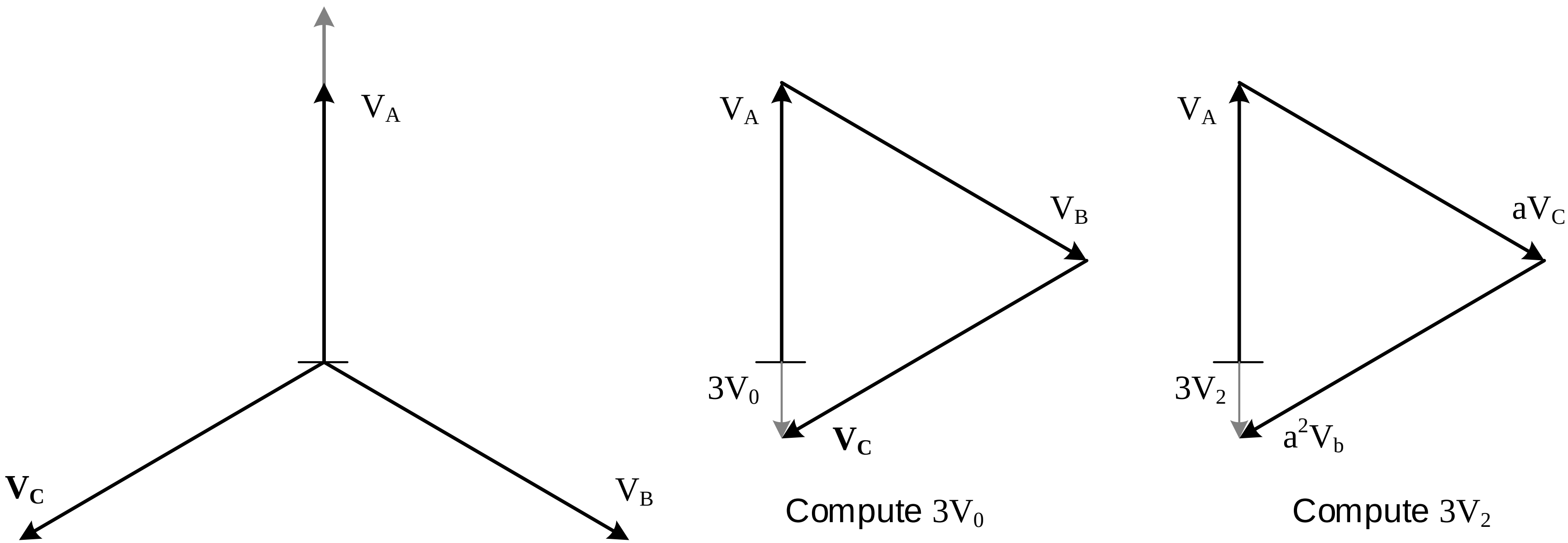
$$V_{A2R} = \left(\frac{1}{Z_0/Z_1+2}\right)\cdot\left(\frac{1}{Z_{2L}/Z_{2S}+1}\right) \text{ per unit}$$

$$V_{A0R} = \left(\frac{Z_0/Z_1}{Z_0/Z_1+2}\right)\cdot\left(\frac{1}{Z_{0L}/Z_{0S}+1}\right) \text{ per unit}$$

Inadequate Negative Sequence Voltage Example

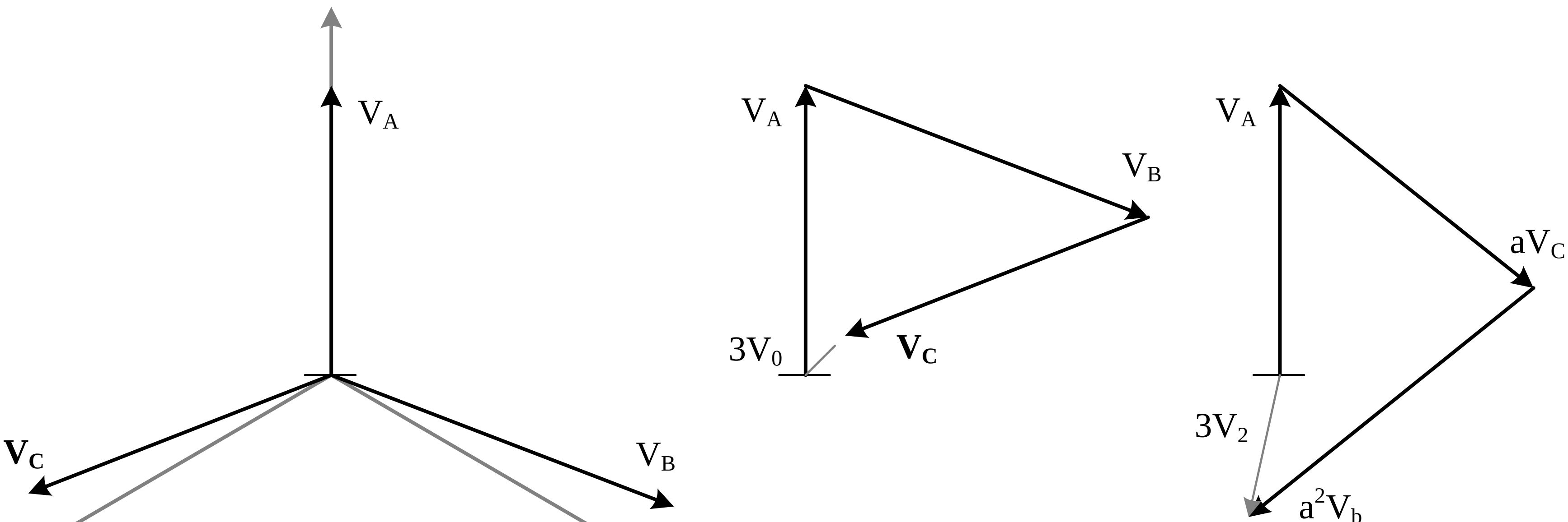


Sources of Error in calculating V2 and V0 – Untransposed Lines



Normally Expected Phase and Sequence Fault Voltages, A Phase SLG

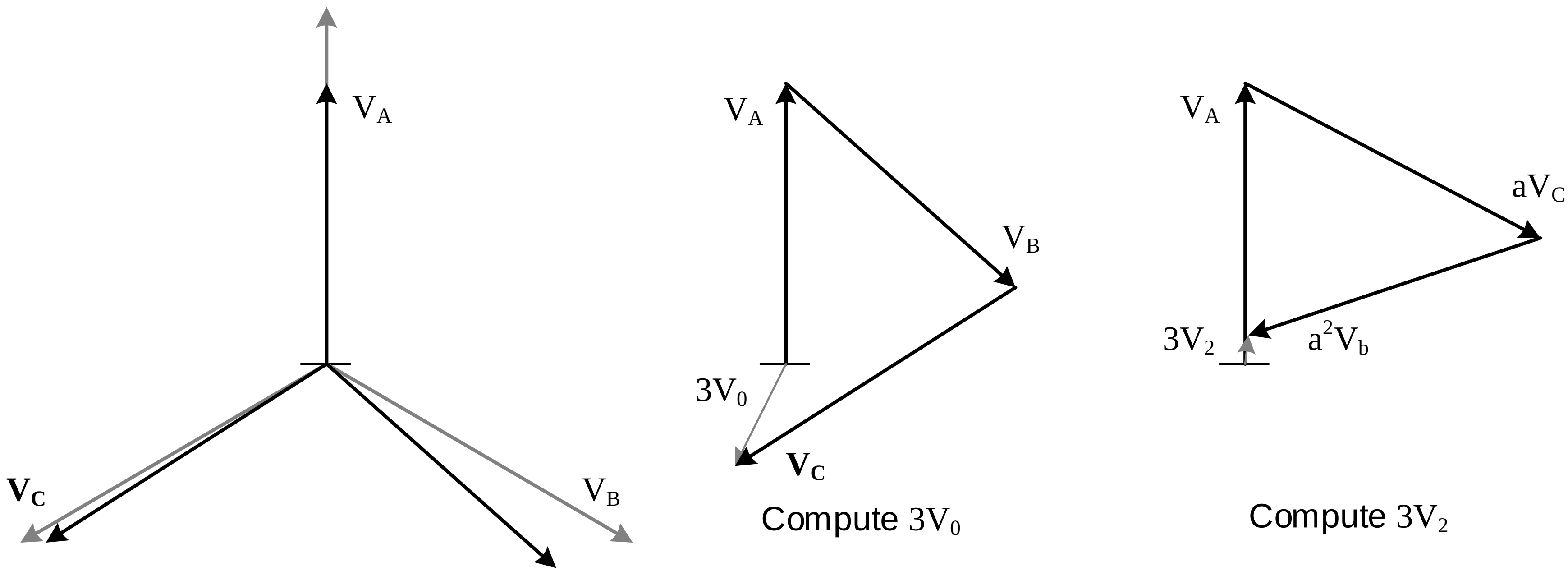
Sources of Error in calculating V2 and V0 – Untransposed Lines, Cont.



Compute $3V_0$ Compute $3V_2$

Phase and Sequence Fault Voltages Showing Reversal of $3V_0$, A Phase SLG

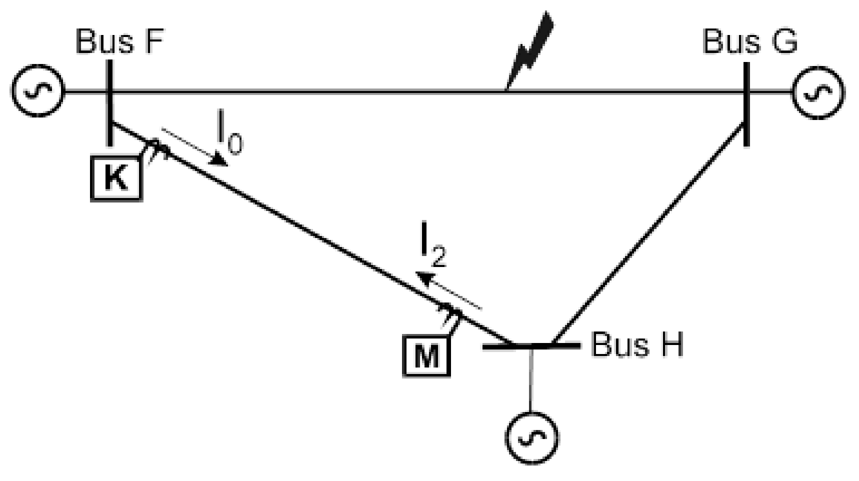
Sources of Error in calculating V2 and V0 – Untransposed Lines, Cont.



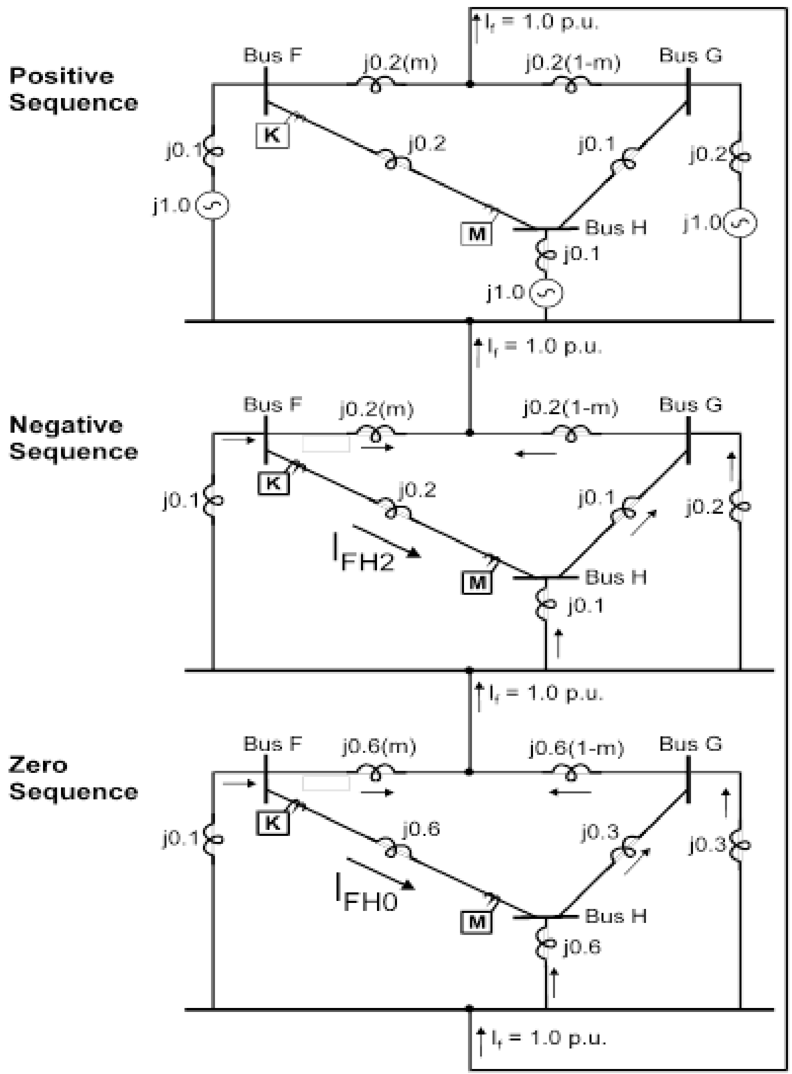
Phase and Sequence Fault Voltages Showing Reversal of $3V_2$, A Phase SLG

Mismatch of polarization methods on line terminals in communication assisted trip scheme

- Bus F, relay system K: Zero sequence voltage and current polarized
- Bus H, relay system M: Negative sequence voltage polarized

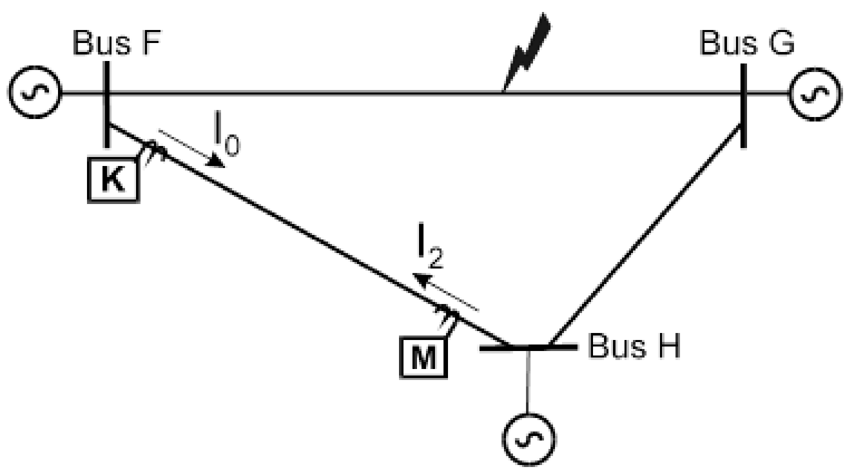


Mismatch of polarization methods on line terminals in communication assisted trip scheme, Cont.



Mismatch of polarization methods on line terminals in communication assisted trip scheme, Cont.

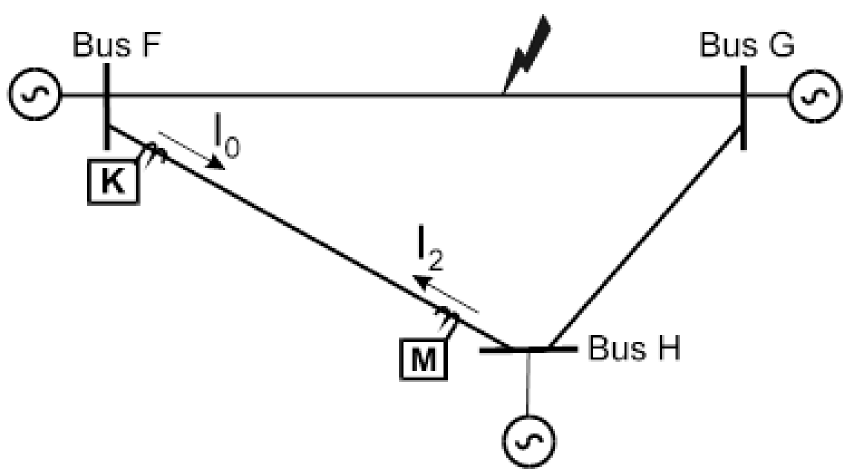
Sequence Currents (IFH2 and IFH0) in Per Unit of If on Line FH for Different Fault Locations on Line FG m Distance from Bus F



Mismatch of polarization methods on line terminals in communication assisted trip scheme, Cont.

The negative and zero sequence currents will flow in opposite directions on line FH for faults between 0.45 and 0.835 p.u. of line FG length as measured from Bus F

m	0	.1	0.2	0.3	0.4	0.45	0.5	0.6	0.7	0.8	0.835	0.9	1.0
IFH2	-.196	-.173	-.149	-.125	-.102	-	-.078	-.055	-.031	-.007	0	.016	.039
IFH0	-.078	-.061	-.043	-.026	-.009	0	.009	.026	.043	.061	-	.078	.096



Other Considerations

- Single pole open affecting an adjacent line
- Series compensated lines or lines near series compensated lines and static var compensator
- Inherently directional; strong source impedance behind and weak forward source impedance
- Current polarizing at stations with more than one transformer and split low-sides
- Modeling of ground directional element in software

Recommendation on Choosing Appropriate Method

Configuration:	Significant Zero Sequence Mutual Coupling	Negative Sequence Voltage	Zero Sequence (Voltage, Current, or Dual)
Short and medium length lines (SIR > 0.5)	No	OK*	OK*
	Yes	OK*	NR
Long lines** (SIR ≤ 0.5)	No	SR	OK*
	Yes	SR	NR
DCB or POTT Relay at the remote terminal with zero sequence polarizing	No	NR	OK*
	Yes	NR	SR

* - OK, but study recommended
NR - Not recommended
SR - Study required
** - special compensation may be required or inherent directionality may make directional control unnecessary

Summary:

- Choice of polarizing method for directional ground elements is an important decision that should not be overlooked or reduced to a "cookie-cutter" approach.
- Each application should be carefully evaluated for adequacy.
- Manufacturer recommendations and/or traditional utility practices should never be used in lieu of thorough study of the particular relay in question on the protected line.