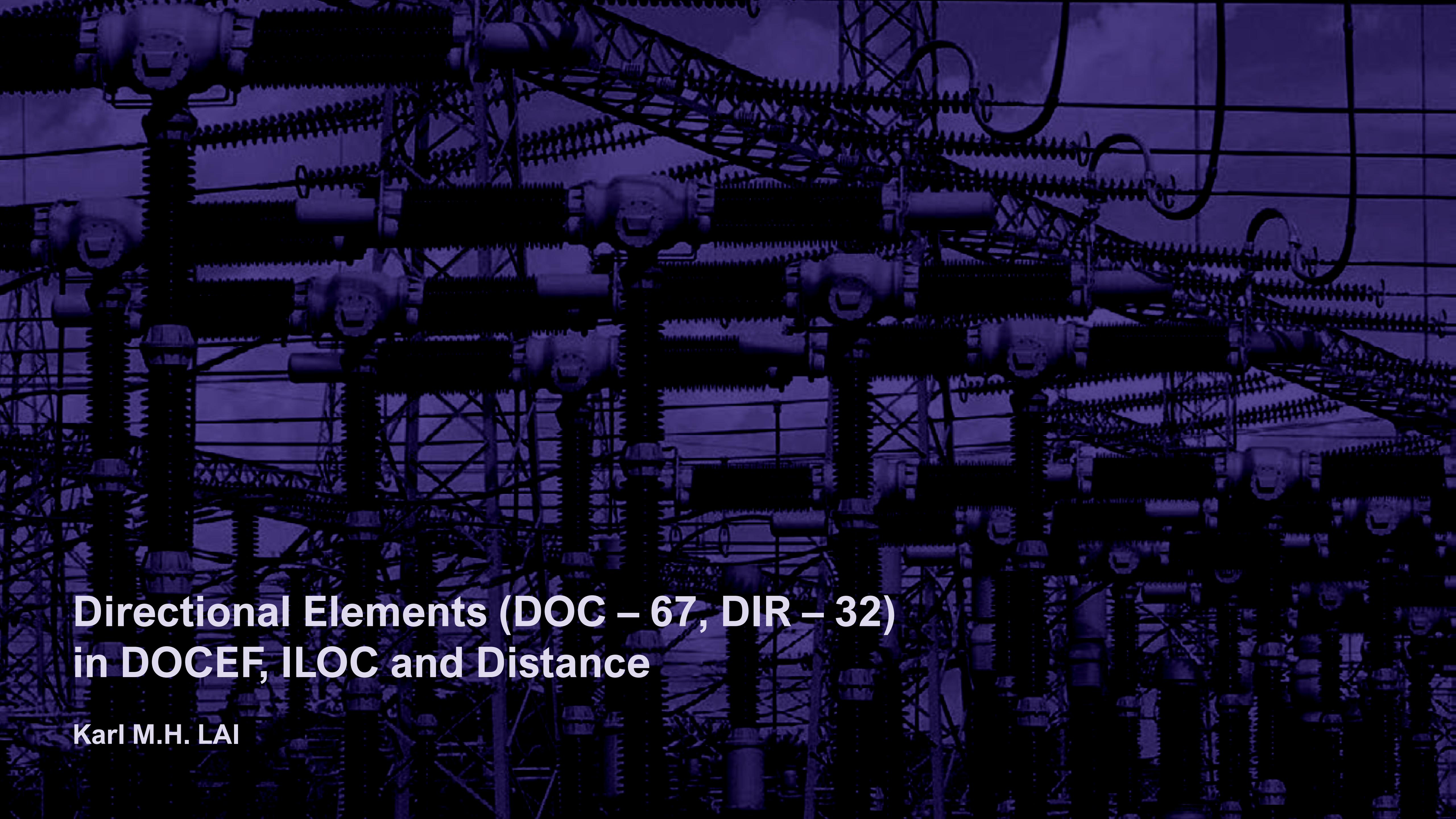


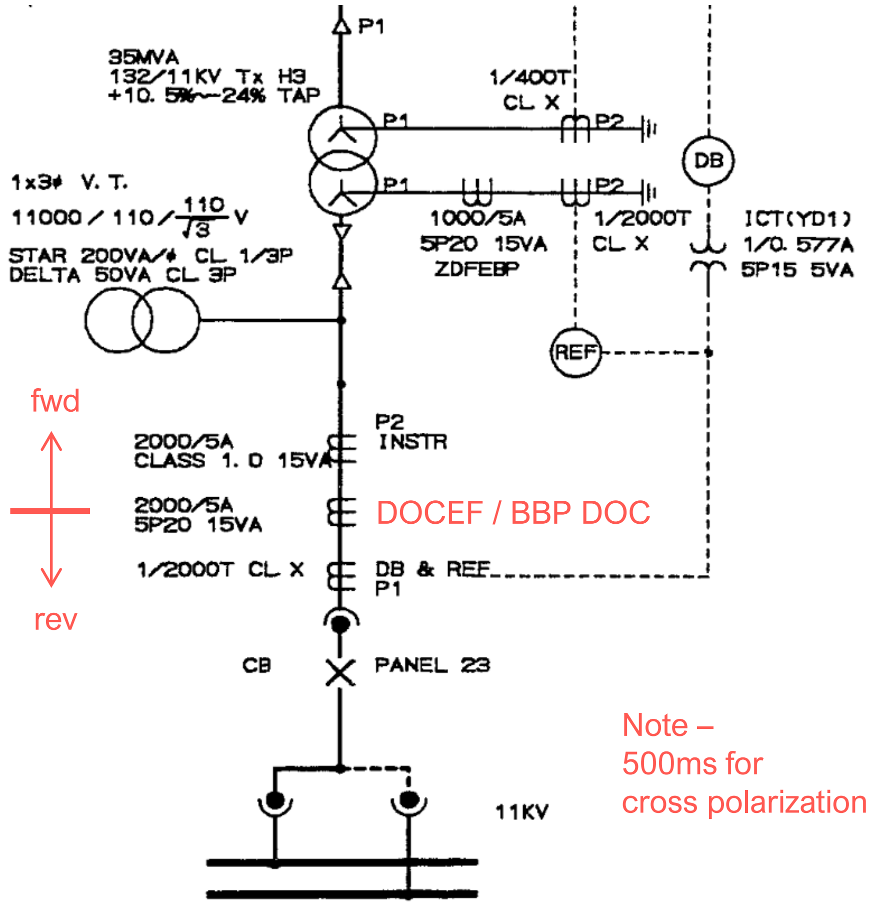
# Directional Elements (DOC – 67, DIR – 32) in DOCEF, ILOC and Distance

Karl M.H. LAI

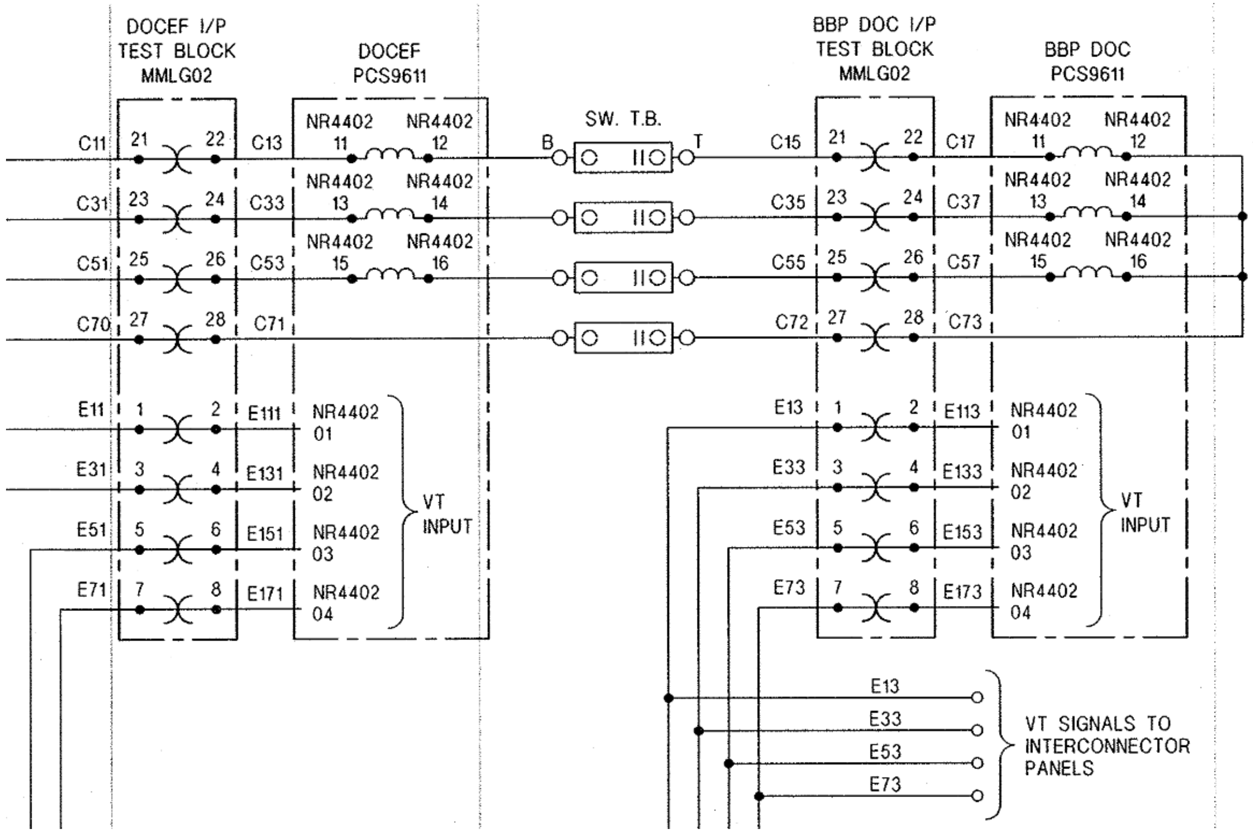
# DOCEF and BBP DOC

**ILOC (BBP DOC) – 2000/5**

DOC2 REV (BFP Unblock), I_OC2 = 6A (0.1s)
DOC3 FWD (Reverse Blocking), I_OC3 = 6A ( 0s)
DOC5 REV (Trip), I_OC5 = 11.25A ( 0s)
**# Forward Blocking**




Note – 500ms for cross polarization



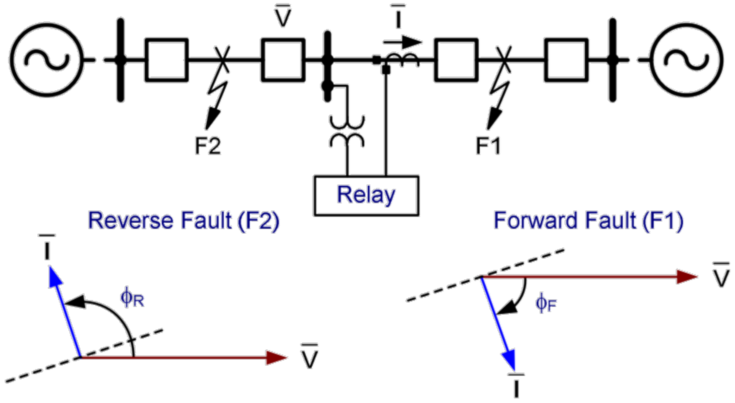

**PAM 3.6 Transformer Protection Scheme – DOCEF**

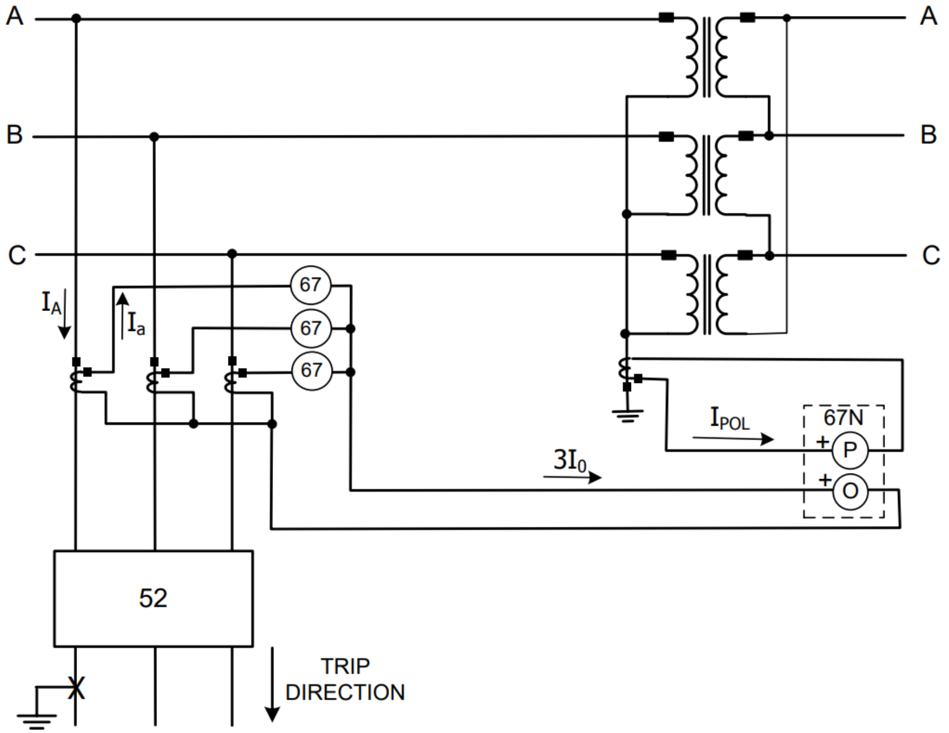
DOCEF is to detect reverse flow of current through transformer, with transformer fault or feeder fault at HV side.
It also provides backup to Intertripping facilities.

**DOCEF (2000/5)**

DOC1 (FWD): I_OC1 = 2.5A, TMS_InvOC = 0.1, NI
DEF1 (FWD): I_ROC1 = 1.0A, TMS_InvROC = 0.1, NI
P/F Char Angle = + 45° E/F Char Angle = - 45°
**# Forward Operate**

# Directional Element




**Why do we need to have directional element?**

- To identify fault direction. (e.g. ILOC)
- To increase sensitivity toward OCEF element. (e.g. DOCEF for 35MVA // Tx)
- To provide blocking to avoid tripping healthy lines. (e.g. current reversal in distance)

**Challenges**

- To obtain a reliable polarizing quantities (often voltage memorized cross polarizing) regardless of fault location, system configuration, load flow and unbalance.
- To obtain a reliable directional detection with unreliable voltage and current measurement –
  - Zero-sequence voltage elements are especially susceptible to voltage transformer (VT) grounding errors
  - Zero-sequence current elements are vulnerable to mutual coupling and uncertain zero sequence circuit

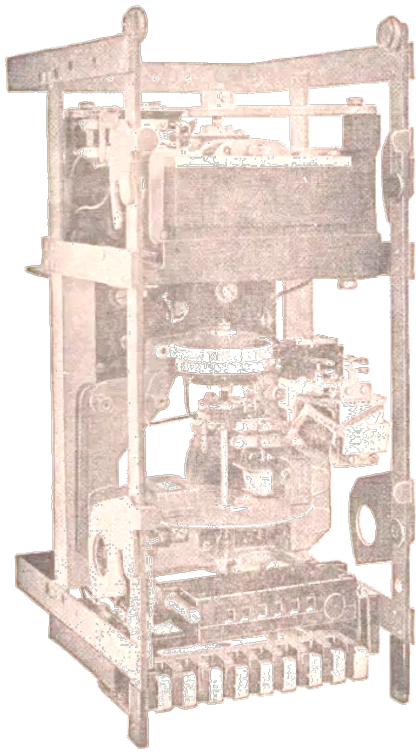
# Directional Relay based on Induction Principle

- A wattmeter develops maximum torque when I and V are in phase.
- If maximum torque angle (MTA) is defined as the angle between voltage and current at which the relay develops the maximum torque, then a wattmeter can be called a directional relay with MTA of zero degree.

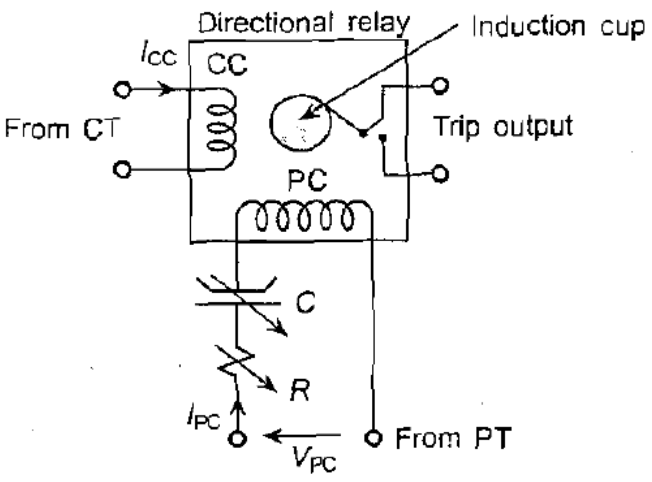
$$\mathrm{T_{op}} = \mathrm{K}\, \phi_{PC}\, \phi_{CC} \sin(\theta + \theta_{PC}) = \mathrm{K}\, \phi_{PC}\, \phi_{CC} \cos(\theta - \tau) = \mathrm{K}'\, V_{PC}\, I_{CC} \cos(\theta - \tau)$$

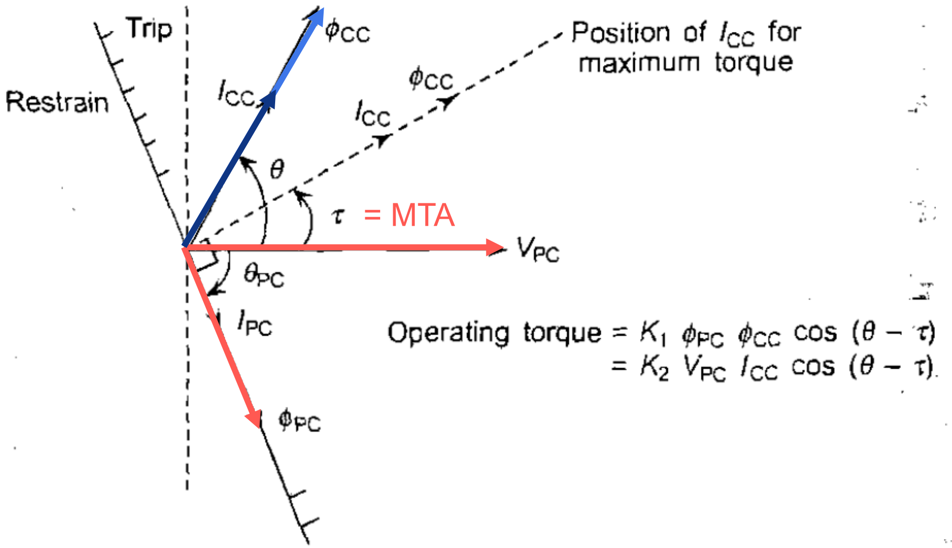
$$\tau = 90^{o} - \theta_{PC}$$

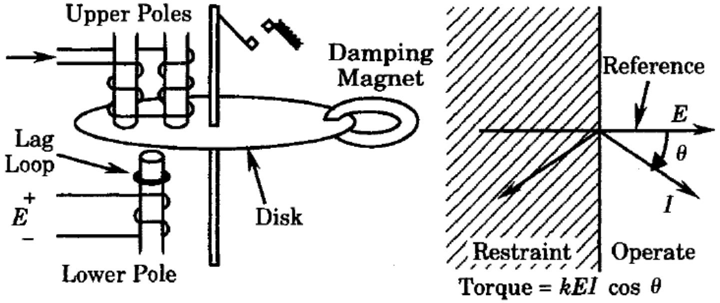
- Since the pressure coil is highly inductive, and $\theta_{PC}$ is of the order of 70º to 80º. It gives an MTA of 20º to 10º.
  Additional RC is introduced into the pressure coil circuit to achieve required MTA.



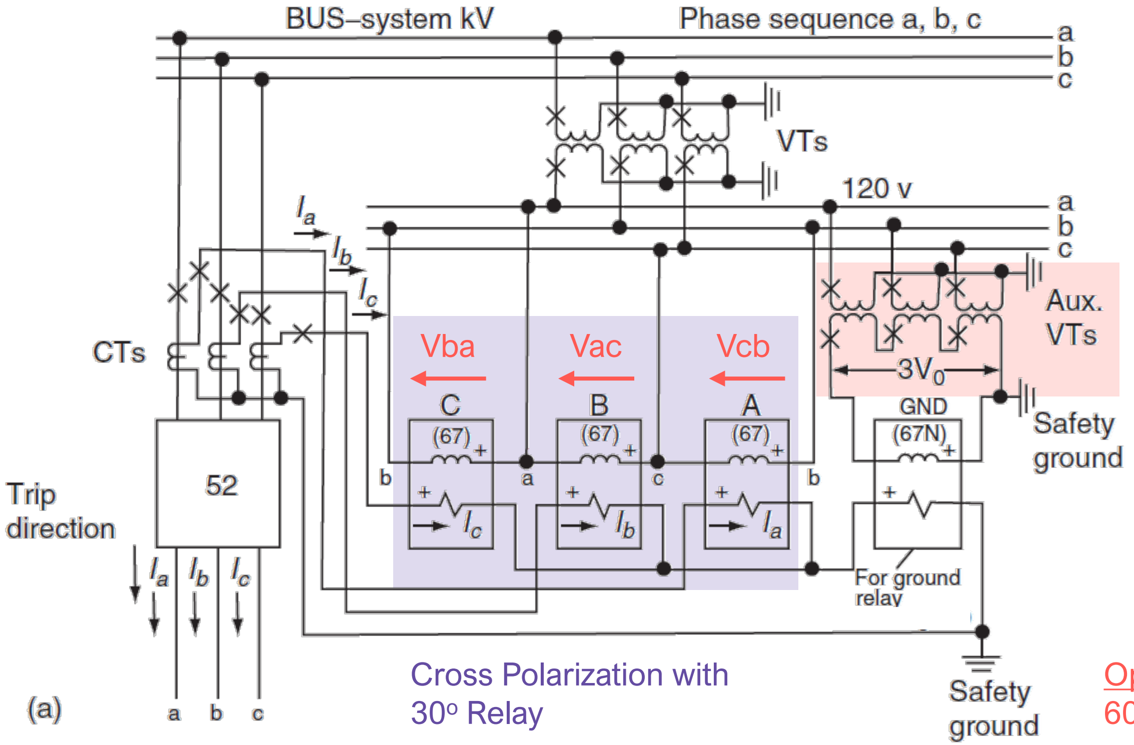
CDD21 Directional OCEF (e.g. MWC H1)



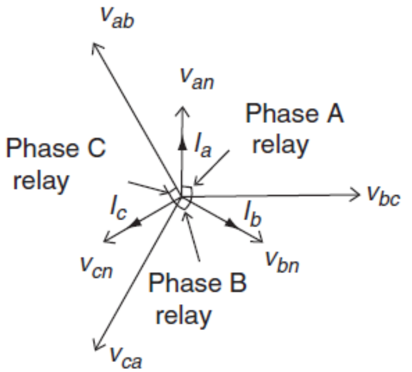



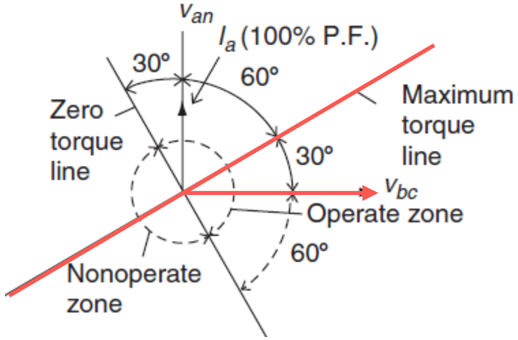
# Directional Relay based on Induction Principle



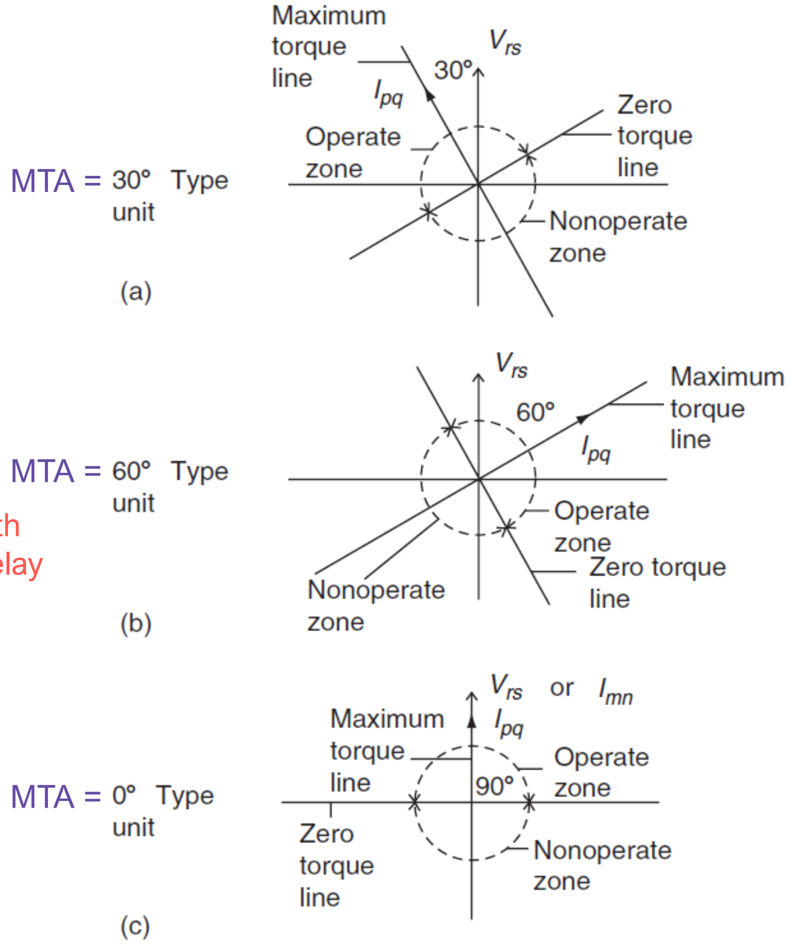

Cross Polarization with 30° Relay

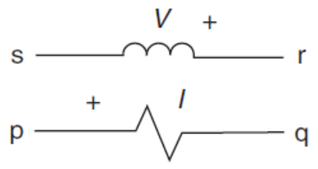
Open Delta with 60° Ground Relay



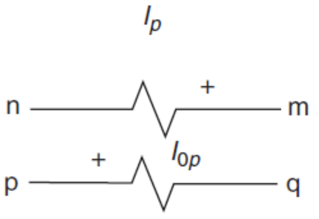




Other than defining the relay type with phase difference between UPF of two quantities, MTA is also used for defining the relay type.



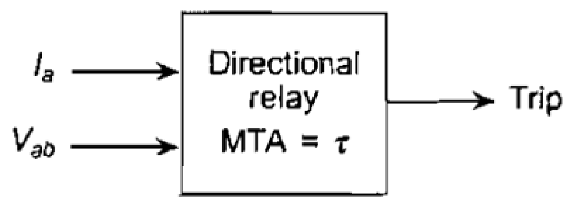

Voltage polarized directional relay

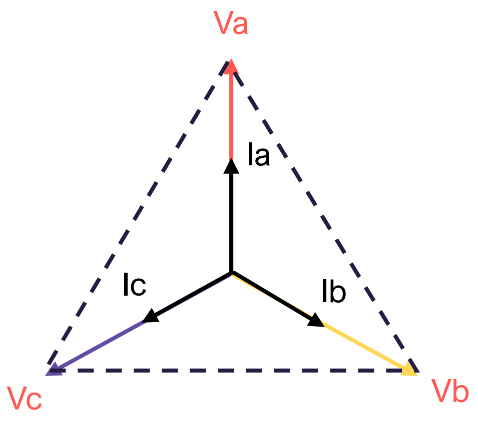



Current polarized directional relay

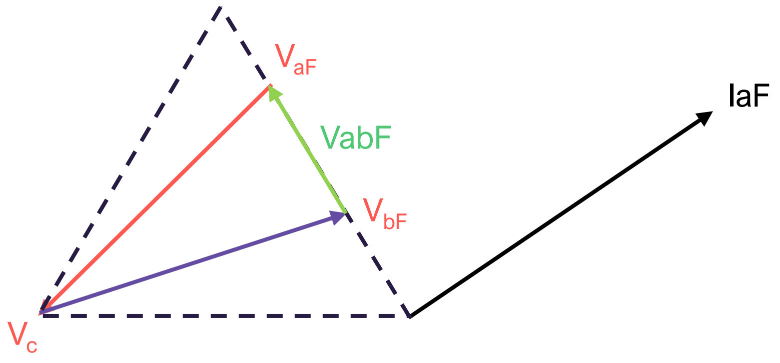
# Directional Relay based on Induction Principle

- Consider an a-b fault with $I_a$ as operating quantity and $V_{ab}$ as polarizing quantity.

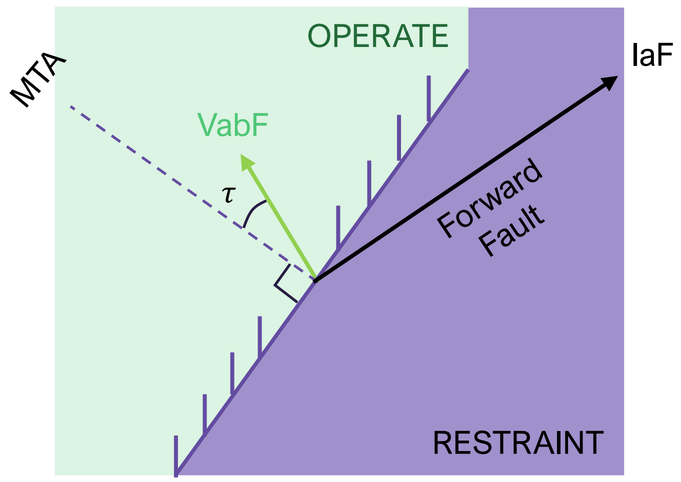



Normal Load Condition
(Unity Power Factor)




Phase-Phase (ab) Fault

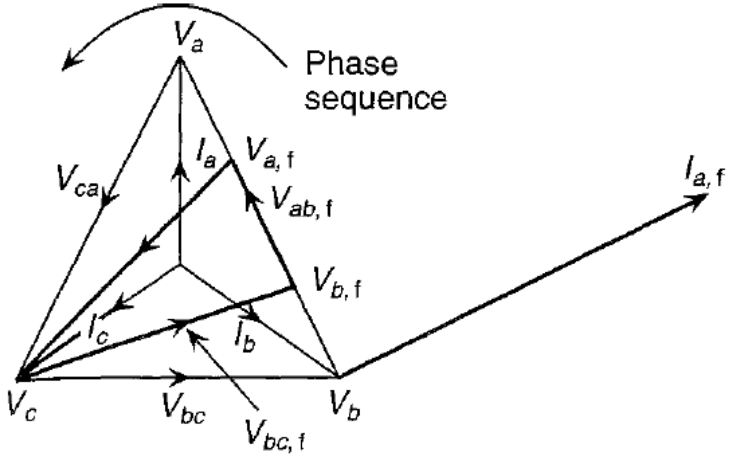



Phasor Relationship and
Operating Region for
$V_{POL} = V_{ab}$ $I_{OP} = I_{aF}$

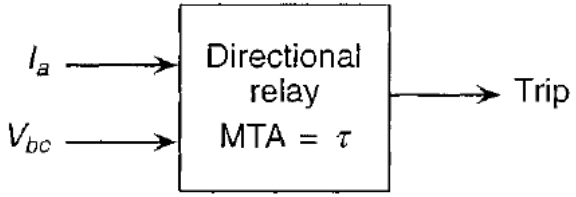
- Vab tends to collapse during a-b fault. The angle between Vab and Ia during fault becomes substantially large. For the MTA angle shown, the relay does not develop positive torque during fault.

# Directional Relay based on Induction Principle

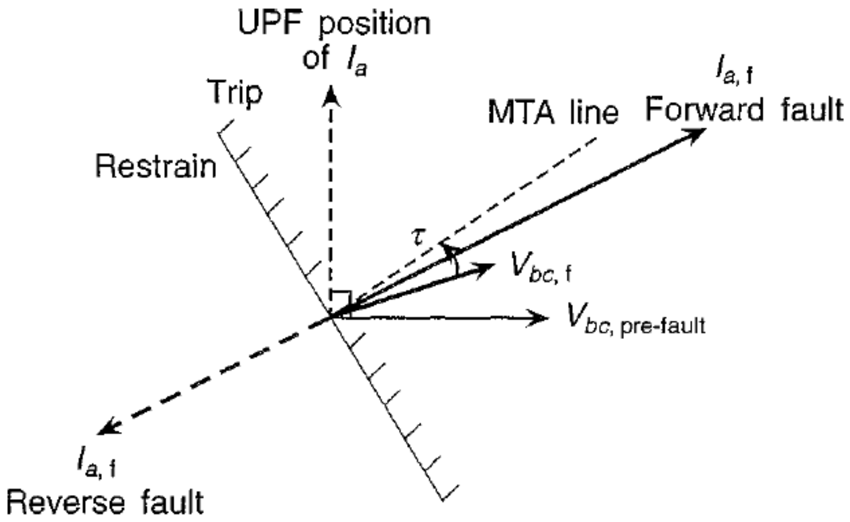
- A suggested solution is cross-polarization, using the quadrature voltage (e.g. Vbc to Ia) to perform direction detection.
- Under normal condition, the unity power factor (UPF) position of Ia is 90$^{o}$ lead Vbc, it is called a 90$^{o}$ connection.




(a) Phasor diagram during *a*-*b* fault



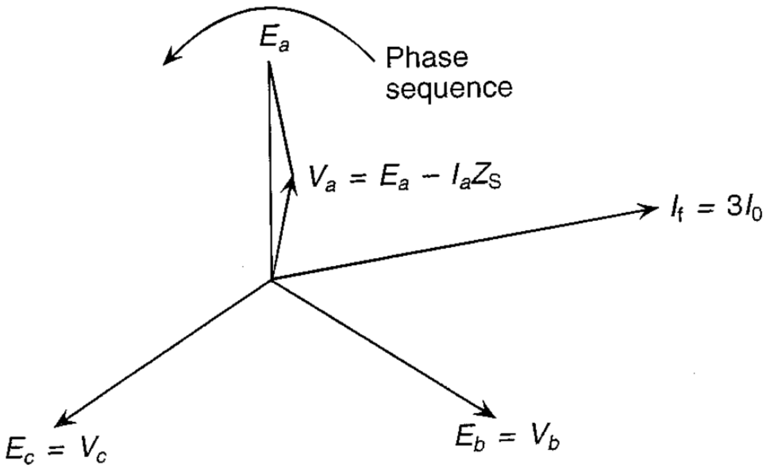

(b) Correct energization of phase *a* directional relay with $I_a$ and $V_{bc}$ resulting in the 90° connection



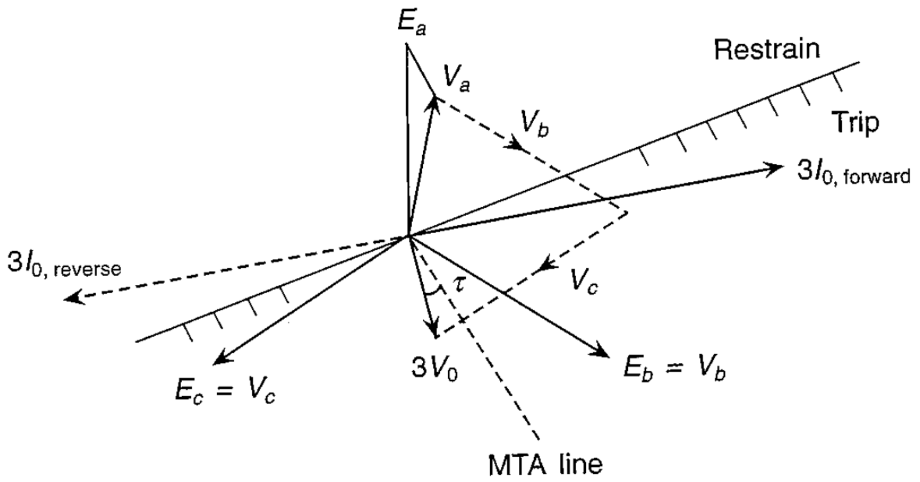

(c) Phasor relationships during UPF load, forward and reverse fault for phase *a* directional relay energized by $I_a$ and $V_{bc}$ (the 90° connection).

# Directional Relay based on Induction Principle

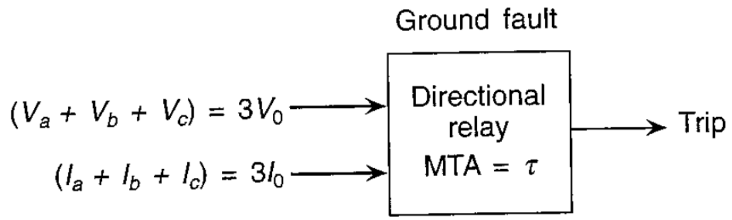
- Directional earth fault (DEF) relays develops correct tripping when fed by the residual current $I_0$ and residual voltage $V_0$.
- It is highly sensitive as normally $I_0$ and $V_0$ is small, and it is large enough to get over the OC / OV detection before activating the direction element. With this principle, it allows to further low set EF with the directional guard.




(a) Phasor diagram for *a-g* fault

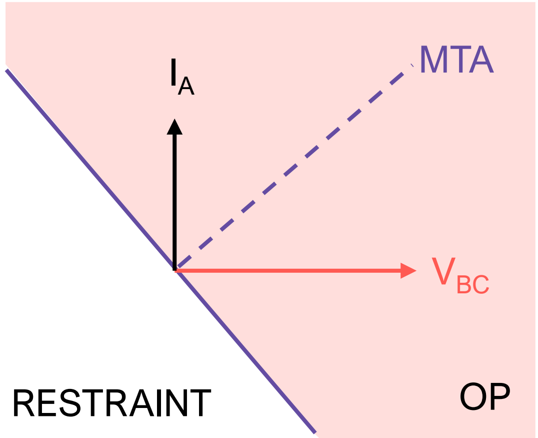



(b) Phasor relationships between actuating quantities during forward and reverse faults



# Effect of Fault Type and Fault Location

- Relay Connection – 90º Connection (45º MTA). Fault Type – A-G Fault
- Close-in Fault ($Z_{1L} = 0; Z_{0L} = 0$)
  - Solidly Earthed Source: $Z_{1S}$ and $Z_{0S}$ are almost pure inductive.
    $\angle Z_D = 270^o + 90^o = 360^o$ i.e. $V_R$ and $I_R$ are in phase (S90º)
  - Resistance Earthed Source: $Z_{0s}$ is almost pure resistive and $Z_{0S} >> Z_{1S}$
    $\angle Z_D = 270^o + 0^o = 270^o$ i.e. $I_R$ leads $V_R$ by 90º (S0º)
- Far-End Fault ($Z_{1L} >> Z_{1S}$, $Z_{0L} >> Z_{0S} \rightarrow Z_{1S} = Z_{0S} = 0$)
  - Line Impedance $Z_{1L}$ and $Z_{0L}$ are almost pure inductive.
    $\angle Z_D = 270^o + 90^o = 360^o$ i.e. $V_R$ and $I_R$ are in phase (S90º)
  - $Z_{0L}$ is mainly resistive with large earthing resistance. $\angle Z_{0L} = 0^o$ and $Z_{0L} >> Z_{1L}$.
    $\angle Z_D = 270^o + 0^o = 270^o$ i.e. $I_R$ leads $V_R$ by 90º (S0º)




$$I_1 = I_2 = I_0 = \frac{E}{2Z_{1T} + Z_{0T}}$$

$$I_A = \frac{3E}{2Z_{1T} + Z_{0T}}$$

$$V_1 = E - I_1 Z_{1S} = E\left(\frac{2Z_{1T} + Z_{0T} - Z_{1S}}{2Z_{1T} + Z_{0T}}\right)$$

$$V_2 = -I_2 Z_{2S} = -E\left(\frac{Z_{1S}}{2Z_{1T} + Z_{0T}}\right)$$

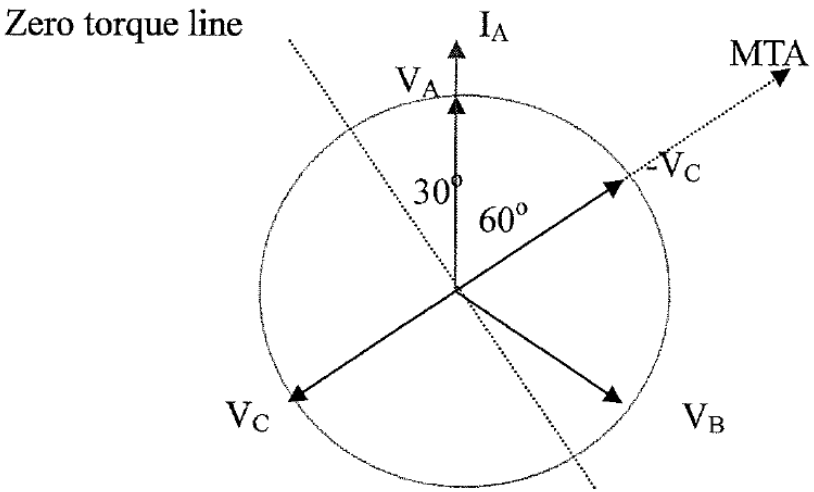
$$V_0 = -I_0 Z_{0S} = -E\left(\frac{Z_{0S}}{2Z_{1T} + Z_{0T}}\right)$$

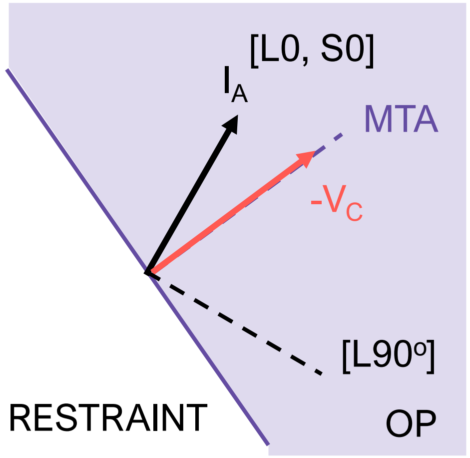
$$V_{BC} = V_B - V_C = (a^2 V_1 + aV_2) - (aV_1 + a^2 V_2)$$
$$= (a^2 - a)(V_1 - V_2) = \sqrt{3}(V_1 - V_2)\angle 270^o = \sqrt{3}E\angle 270^o$$

$$\boxed{Z_D = \frac{V_{BC}}{I_A} = \frac{1}{\sqrt{3}}(2Z_{1S} + Z_{0S} + 2Z_{1L} + Z_{0L})\angle 270^o}$$

# Effect of Fault Type and Fault Location

- Relay Connection – 60º Connection (0º MTA). Fault Type – A-G Fault
- Close-in Fault
  - Solidly Earthed Source: – $Z_{0S}$ are almost pure inductive.
    $\angle Z_D = 330^o + 90^o = +30^o$ (S90º)
  - Resistance Earthed Source: $Z_{0s}$ is almost pure resistive and $Z_{0S} >> Z_{1S}$
    $\angle Z_D = 330^o + 0^o = -30^o$ (S0º)
- Far-End Fault ($Z_{1L} >> Z_{1S}$, $Z_{0L} >> Z_{0S}$ → $Z_{1S} = Z_{0S} = 0$)
  - If the fault resistance is zero and $Z_{L1}$ and $Z_{L0}$ are reactive, $\angle Z_D = 60^o$ (L90º)
  - If the fault is mainly resistive, $Z_{0L} >> Z_{1L}$, $\angle Z_D$ is mainly dominated by $Z_{0S}$, hence $\angle Z_D = 330^o$ (L0º)




$$I_B=0, \quad I_A - I_B = I_A$$

$$I_1 = I_2 = I_0 = \frac{E}{2Z_{1T}+Z_{0T}}$$

$$I_A = \frac{3E}{2Z_{1T}+Z_{0T}}$$

$$V_1 = E - I_1 Z_{1S} = E\left(\frac{2Z_{1T}+Z_{0T}-Z_{1S}}{2Z_{1T}+Z_{0T}}\right)$$

$$V_2 = -I_2 Z_{2S} = -E\left(\frac{Z_{1S}}{2Z_{1T}+Z_{0T}}\right)$$

$$V_0 = -I_0 Z_{0S} = -E\left(\frac{Z_{0S}}{2Z_{1T}+Z_{0T}}\right)$$

$$V_{AC} = V_A - V_C = V_1 + V_2 + V_0 - (aV_1 + a^2V_2 + V_0)$$
$$= (a^2-1)(aV_1 - V_2)$$
$$= (a^2-1)[(Z_{1S}+Z_{0S}+2Z_{1L}+Z_{0L})\angle 120^o + Z_{1S}]\left(\frac{E}{2Z_{1T}+Z_{0T}}\right)$$
$$= (a^2-1)[Z_{1S}\angle 60^o + (Z_{0S}+2Z_{1L}+Z_{0L})\angle 120^o]\left(\frac{E}{2Z_{1T}+Z_{0T}}\right)$$
$$= \sqrt{3}[Z_{1S}\angle 270^o + (Z_{0S}+2Z_{1L}+Z_{0L})\angle 330^o]\left(\frac{E}{2Z_{1T}+Z_{0T}}\right)$$

$$\boxed{Z_D = \frac{V_{AC}}{I_A - I_B} = \frac{1}{\sqrt{3}}[Z_{1S}\angle 270^o + (Z_{0S}+2Z_{1L}+Z_{0L})\angle 330^o]}$$

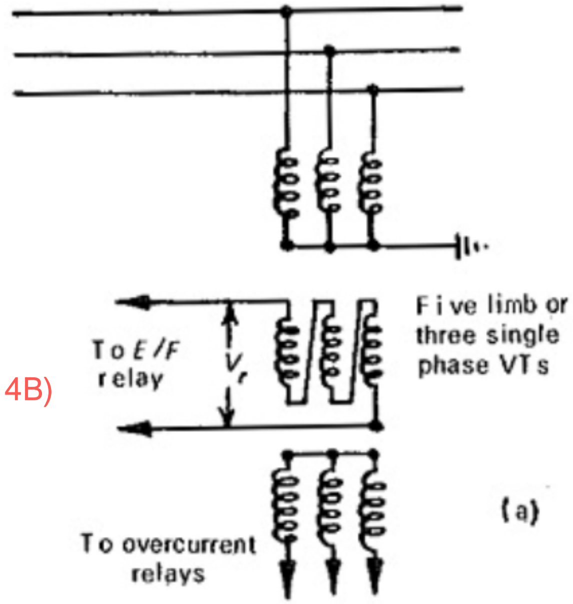
# Directional Relay based on Induction Principle

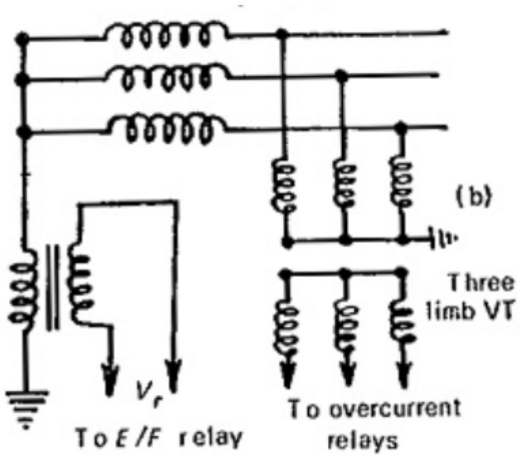
- In case of DEF, the angular relationship between residual current Ir and residual voltage Vr is independent of faulted phase and is governed by only the R/X ratio of fault path.

$$T_r = K\, I_r V_r \cos(\phi - \theta)$$

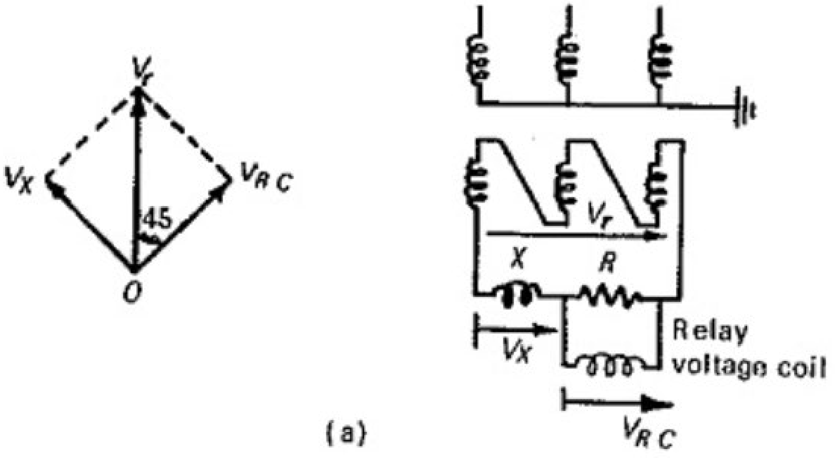
- The magnitude of Vr when a fault occurs depends on earthing method and fault resistance.
- Another consideration with solidly earthed system is low fault power factor. Phase angle compensation can be applied to increases torque even at low fault power factors (X >> R).

Open Delta
(e.g. DCD814B)



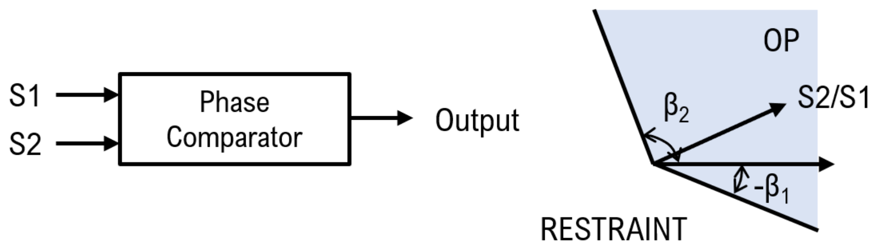

Arc Suppression Coil

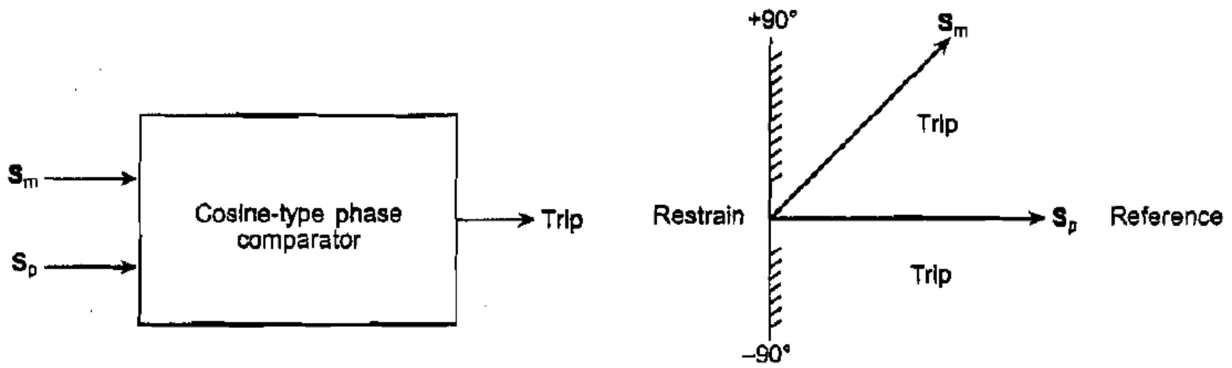


# Directional Relay based on Static Comparator

- Induction type directional relay relies on torque calculation and hence the operating region is often a 180° fan shape.
- Cosine-type phase comparator, for static relay, has two phasor $S_p$ (polarizing input) and $S_m$ (measured input) at its input with a trip output. Trip law for the comparator:

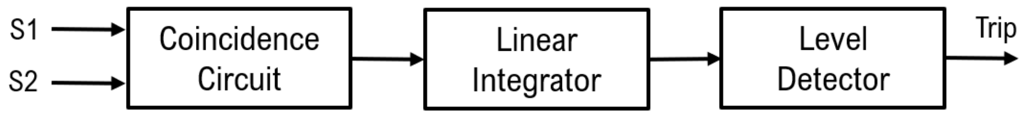
$$\boxed{\text{If } -90^{\circ} < \text{Arg}\,(S_m / S_p) < +90^{\circ} \text{ then trip; else restrain.}}$$

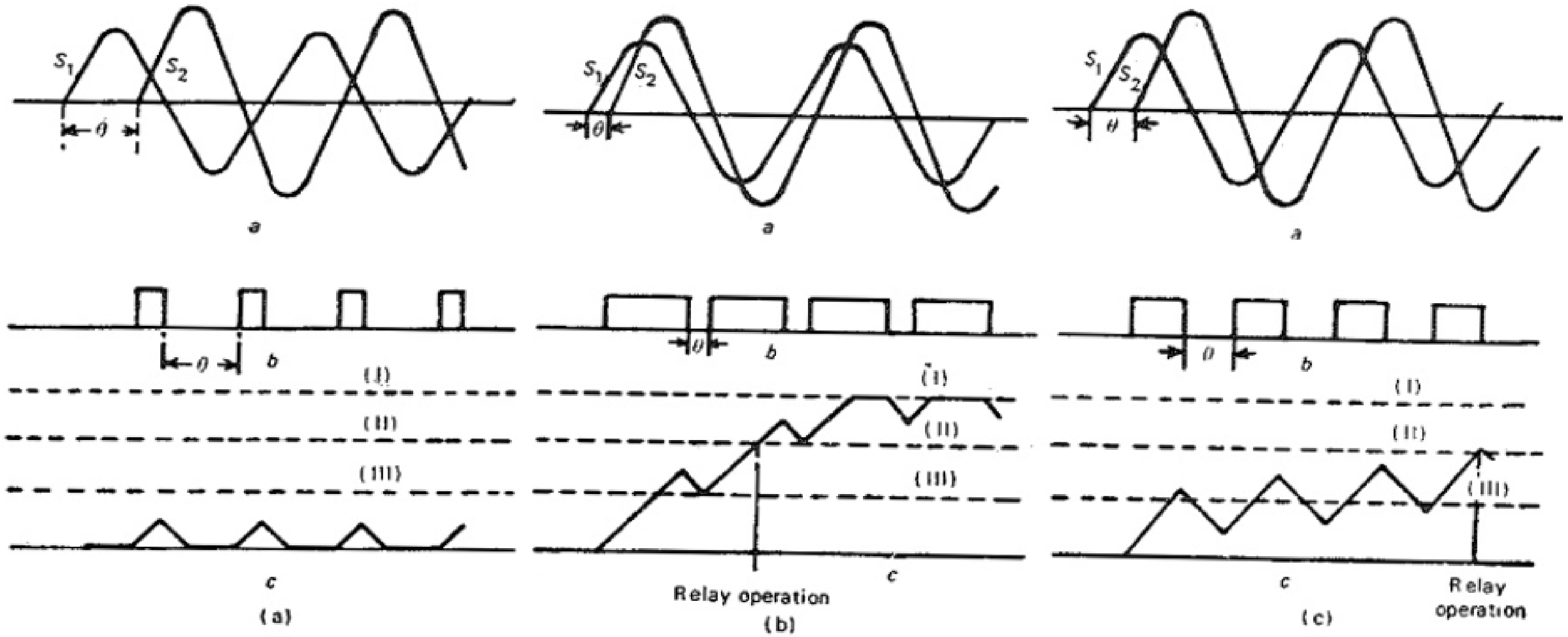



- The input quantities S1 and S2 are compared in a coincidence circuit producing standard output pulses, which are positive with S1 and S2 in same polarity and negative with opposite polarity. The pulses are applied to an integrating circuit whose output increases linearly during the time when the pulse is positive and falls at the same rate when the polarity reverses. The level detector switches when the integrator output exceeds some preset value, and resets when the output falls below some second value.
- The rise and fall rates in the integrator are at the designer's disposal, so that the critical phase angle may be set to any desired value. Both the level detector set and reset levels are critical in relation to the total excursion limits of integrator linearity and to the slope of the output.

# Directional Relay based on Static Comparator

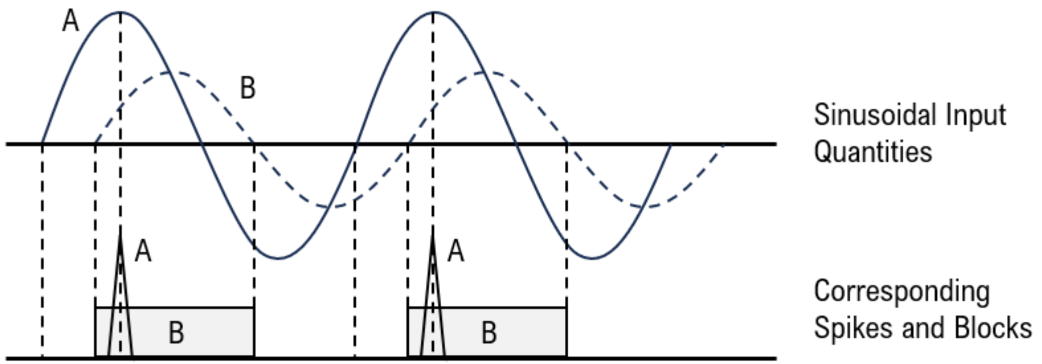


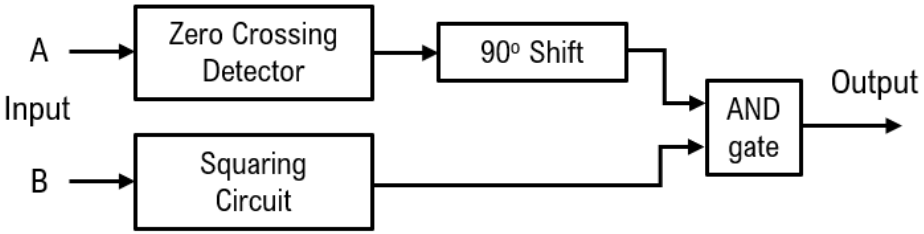




(a) θ > π/2 (b) θ < π/2 (c) θ = π/2
(a) Input signals to coincidence circuit, (b) output from coincidence circuit, (c) integrator output
(i) upper limit, (ii) set level, (iii) reset level

Karl (2024), Detector and Comparator Circuits in Protection Relaying

# Directional Relay based on Static Comparator

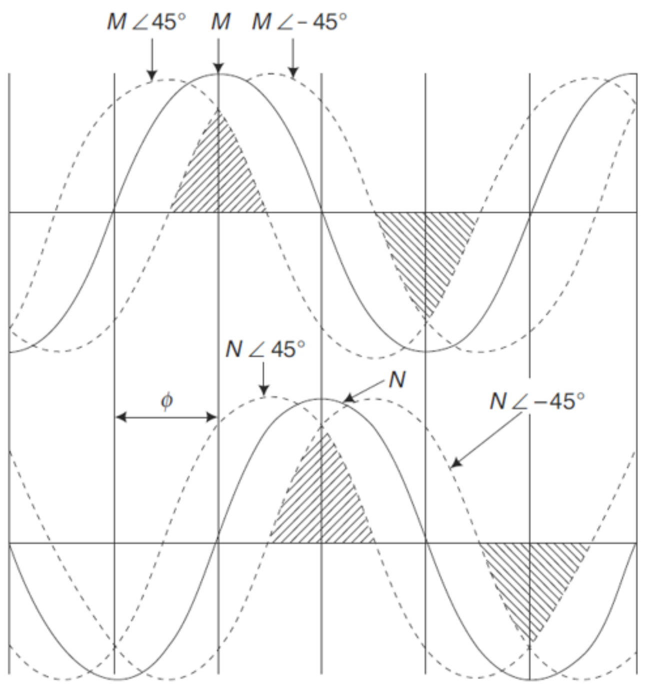


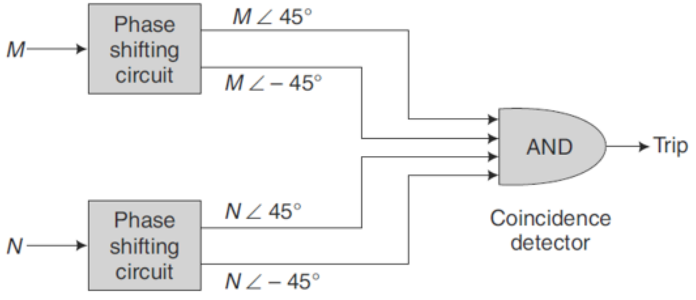




## Block Spike method:

Input B is squared, and input A is turned into a spike preferably at the instant of its peak value; the spike and block signals are then fed through an AND gate. The phase comparator has input signals only for -90° ≤ θ ≤ +90°.

## Phase Split Input method -



# Directional Relay based on Static Comparator

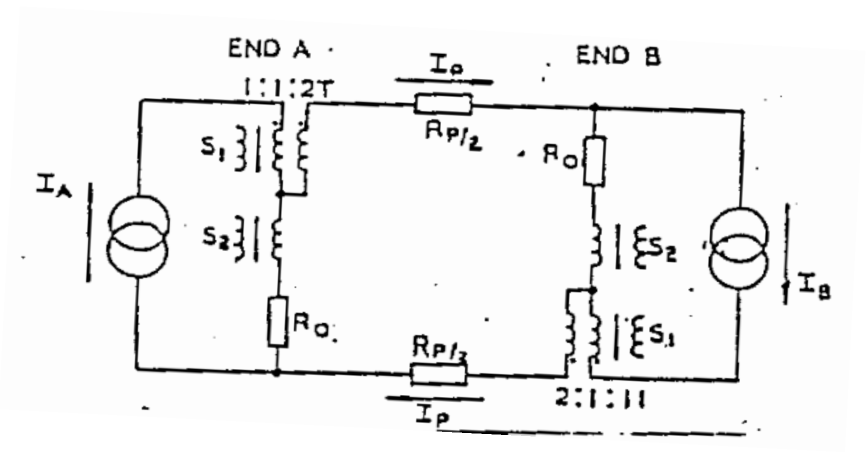
- Translay S (Pilot Wire Scheme) employs coincidence circuits to perform phase comparison between two quantities, namely

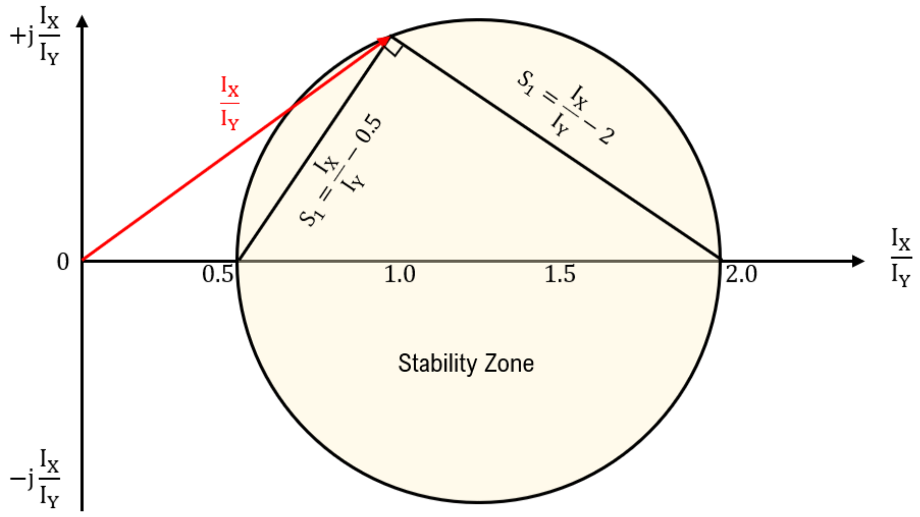
$$S1 = I_A - 2I_B \quad S2 = 2I_A - I_B$$

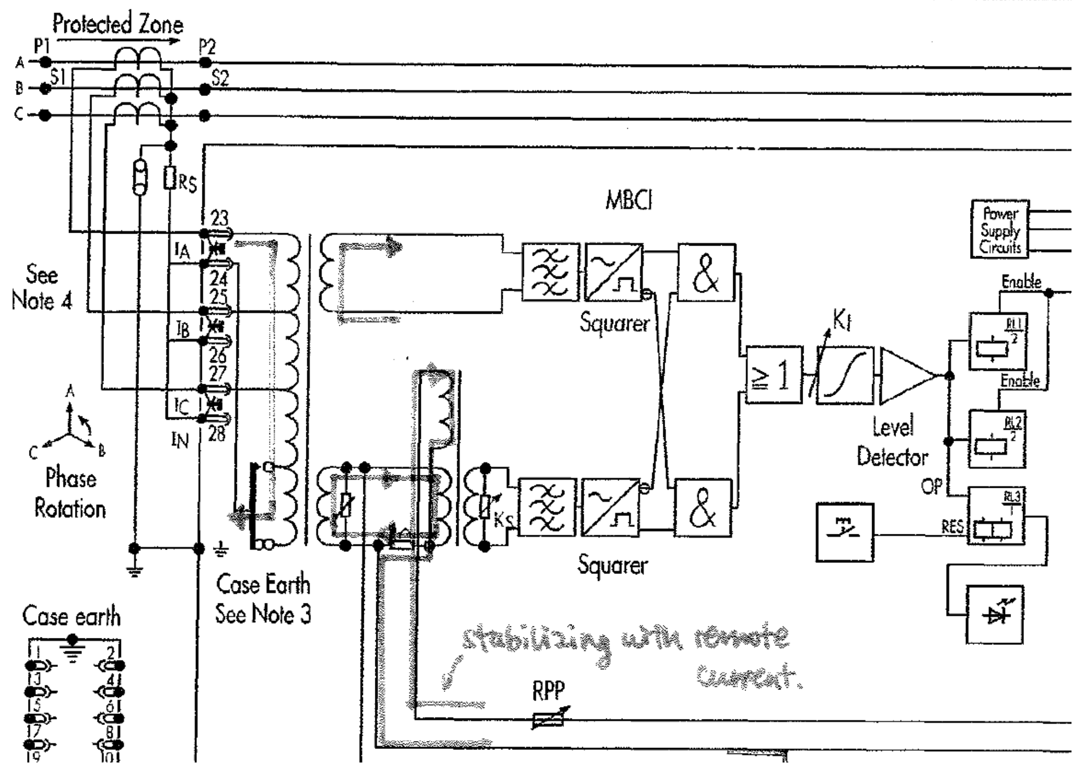
- The feeder protection remain stable with $0.5\, I_B < I_A < 2.0\, I_B$ with

$$\angle S_1 - \angle S_2 > 90^o \text{ (by phase comparison)}$$

- The earliest design of 400kV first main protection includes power line carrier (PLC) phase-comparison scheme, other than pilot wire protection, to modulate at positive cycles and send to remote end for phase comparison.

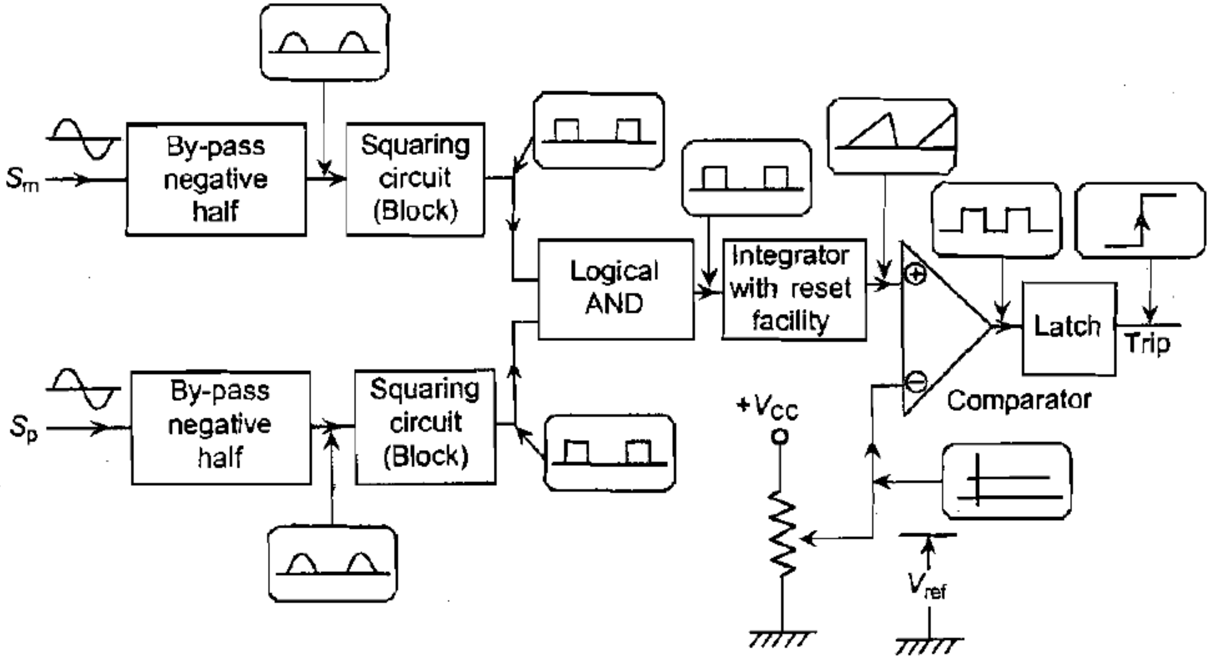


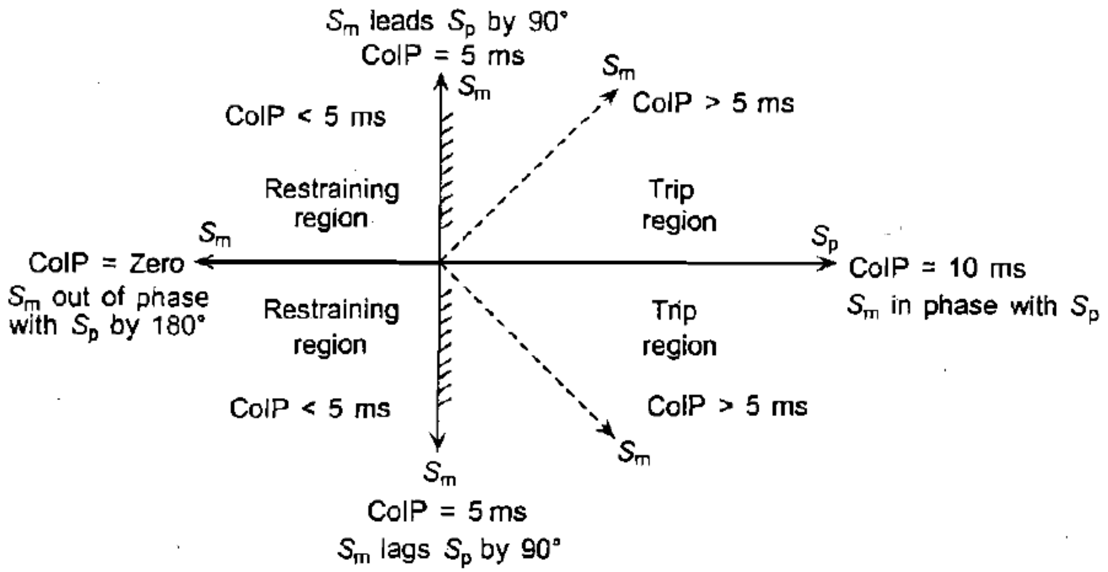



# Directional Relay based on Static Comparator

- Tripping Condition: Coincidence Period > 5ms
  Restraining Condition: Coincidence Period < 5ms
- Components required: rectifier (to remove negative excursion), squarer (make sine wave into block), AND gate, integrator, comparator, latch

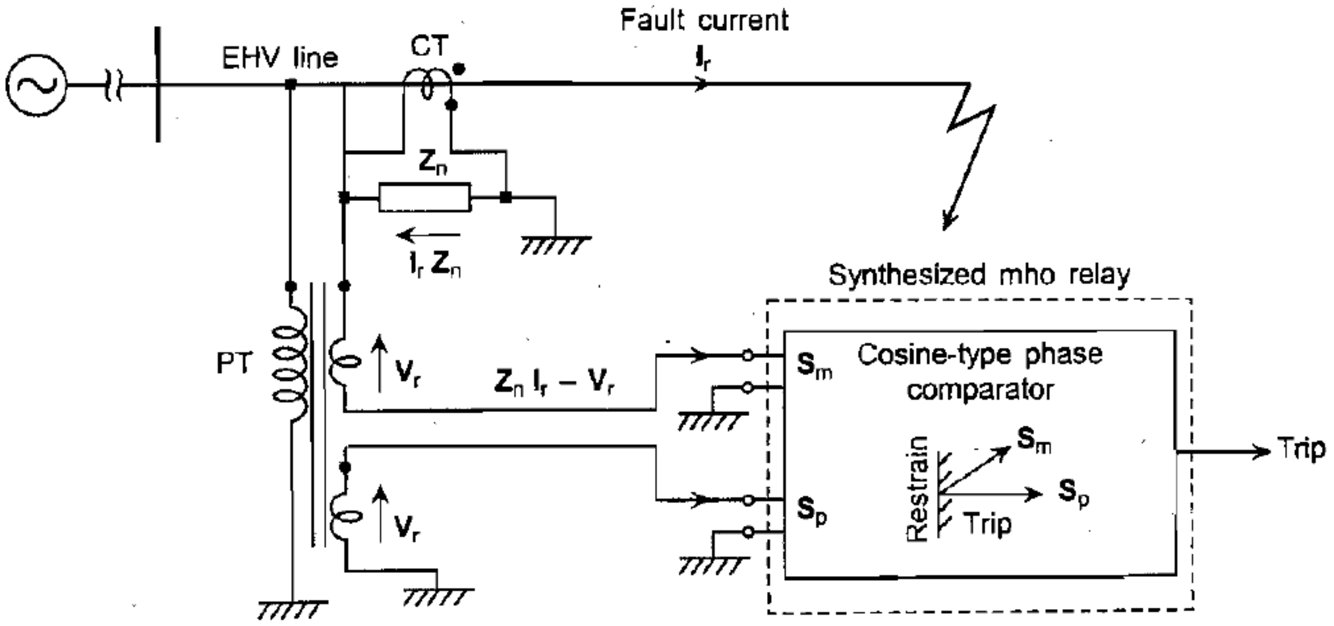


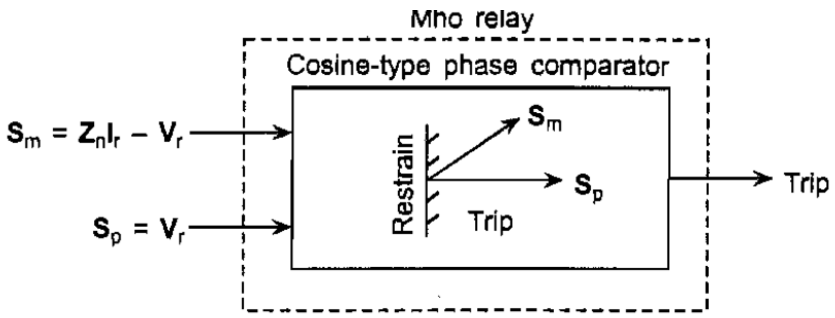




- Application: Translay S, Distance (MHO)

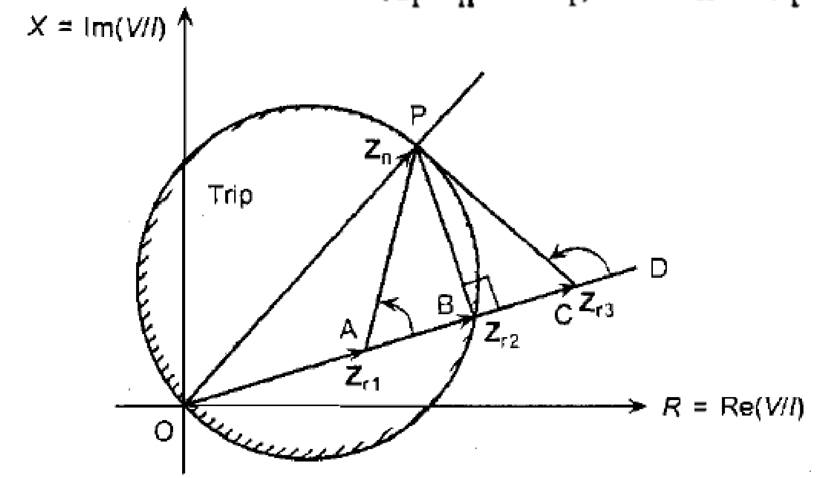
# Directional Relay based on Static Comparator

- MHO relay synthesis using cosine-type phase comparator.




$(\mathbf{I}_r\mathbf{Z}_n - \mathbf{V}_r)$ and $\mathbf{V}_r$




$OA = |Z_{r1}| \rightarrow$ Trip

$OB = |Z_{r2}| \rightarrow$ Threshold

$OC = |Z_{r3}| \rightarrow$ Restrain

$AP = |Z_n - Z_{r1}|$

$BP = |Z_n - Z_{r2}|$

$CP = |Z_n - Z_{r3}|$

$$\mathrm{Arg}\ \frac{|Z_n - Z_{r1}|}{|Z_{r1}|} = \angle BAP < 90^\circ \quad \Rightarrow \quad \text{Trip}$$

$$\mathrm{Arg}\ \frac{|Z_n - Z_{r2}|}{|Z_{r2}|} = \angle CBP = 90^\circ \quad \Rightarrow \quad \text{Threshold}$$

$$\mathrm{Arg}\ \frac{|Z_n - Z_{r3}|}{|Z_{r3}|} = \angle DCP > 90^\circ \quad \Rightarrow \quad \text{Restrain}$$

**Trip law:**

$$\text{If} \quad \mathrm{Arg}\ \frac{|Z_n - Z_r|}{|Z_r|} < 90^\circ; \quad \text{then trip}$$

# Phase Directional Element Design – Quadrature Torque

- Sonnemann (1950) describes the popular 90º connected phase directional elements with the following operating and polarizing quantities of these elements.

| Phase | Operating Quantity ($I_{OP}$) | Polarizing Quantity ($V_{POL}$) |
|---|---|---|
| A | $I_A$ | $V_{POLA} = V_{BC}$ |
| B | $I_B$ | $V_{POLB} = V_{CA}$ |
| C | $I_C$ | $V_{POLC} = V_{AB}$ |
| EF | $3I_0$ (meas) | $V_{POL0} = 3U_0$ |

- The following equations represents the torque ($T_{PH}$) calculations for each 90º connected phase directional elements.

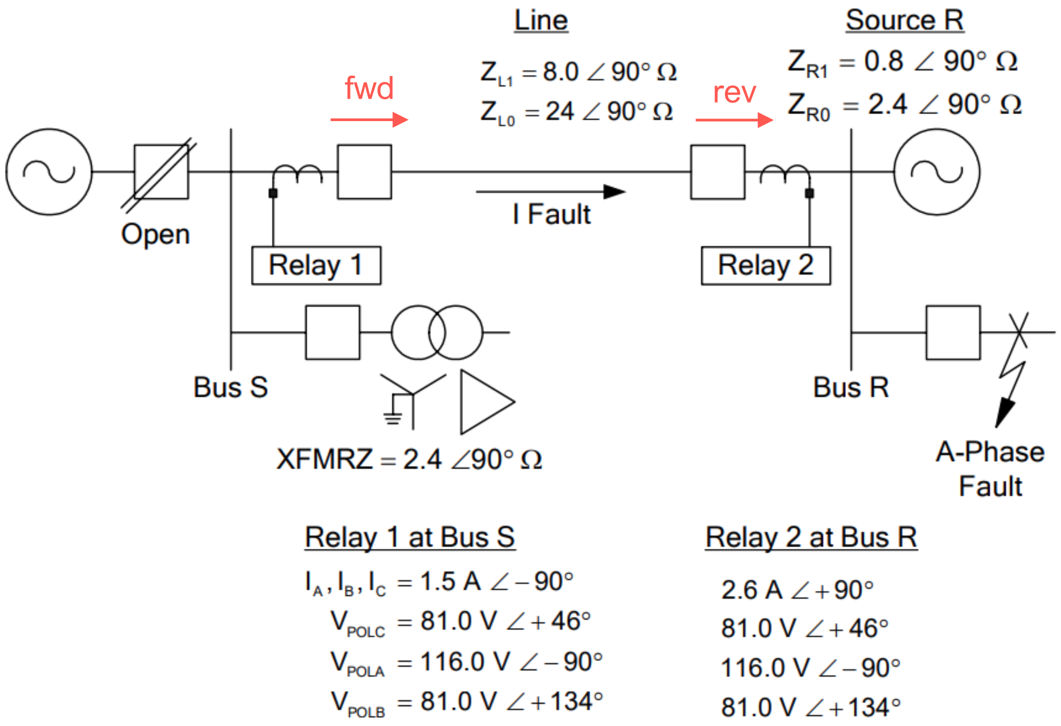
$$T_A = |V_{BC}| \bullet |I_A| \bullet \cos(\angle V_{BC} - \angle I_A)$$
$$T_B = |V_{CA}| \bullet |I_B| \bullet \cos(\angle V_{CA} - \angle I_B)$$
$$T_C = |V_{AB}| \bullet |I_C| \bullet \cos(\angle V_{AB} - \angle I_C)$$

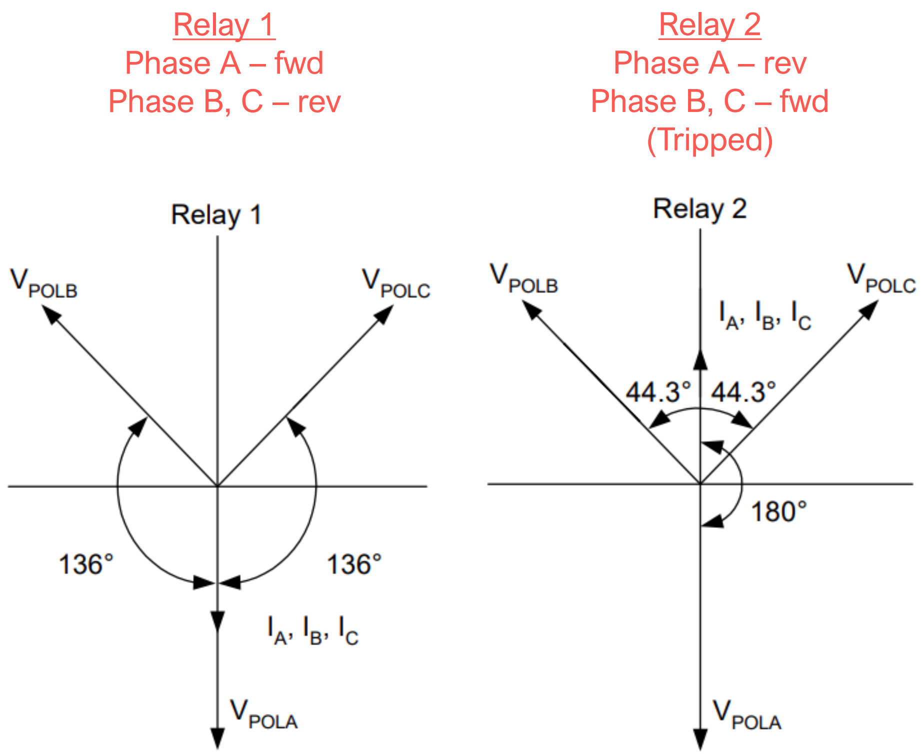
Dot Product - $< V_{POL}, I_{OP} >$
Can be implemented by integration of a cycle.

- Each directional element declares a forward fault condition if the torque sign is positive and a reverse fault condition if the torque sign is negative.

W. K. Sonnemann, "A Study of Directional Element Connections for Phase Relays," AIEE Transactions, 1950, Volume 69, pp 1438–1451.

# Phase Directional Element Design – System Dependence



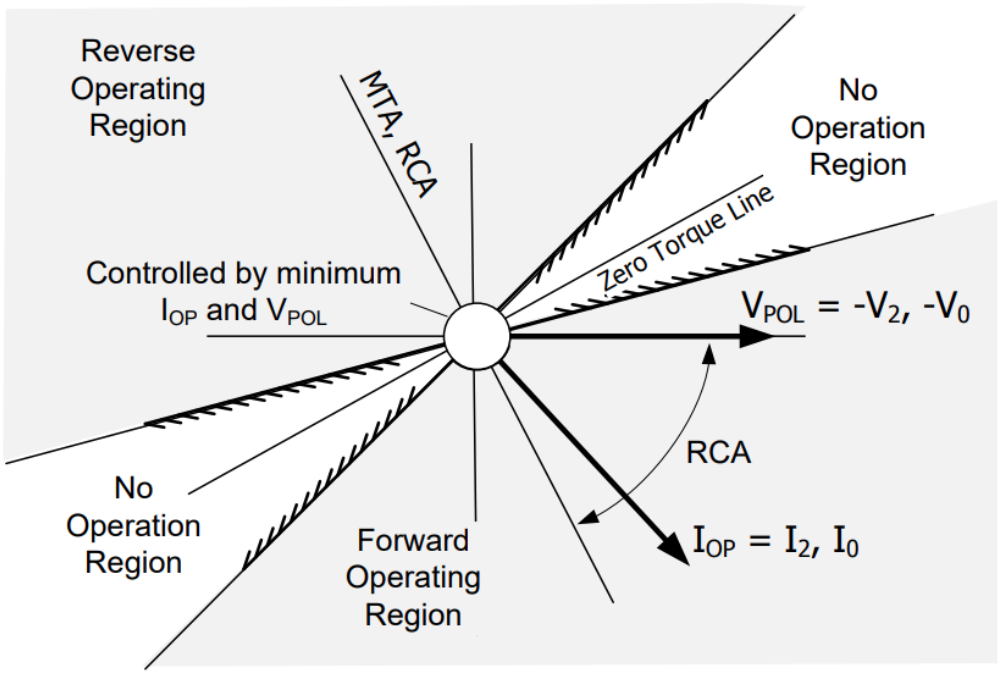




- Warrington (1969) identifies a system-dependent fault condition that produces a misoperation for 90° connected phase directional elements. This condition is a reverse single-line-ground (SLG) fault where the remote infeed current from Bus S is predominantly zero-sequence.
- This disagreement is due to the large angular separation of the polarizing quantities.

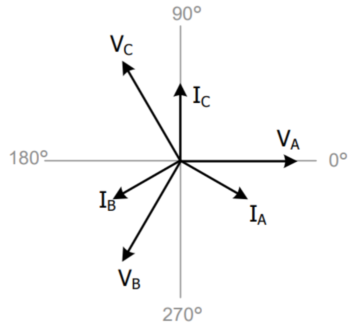
A. R. Van C. Warrington, Protective Relays: Their Theory and Practice, Chapman and Hall, 1969, Volumes I and II.

# Phase Directional Element Design

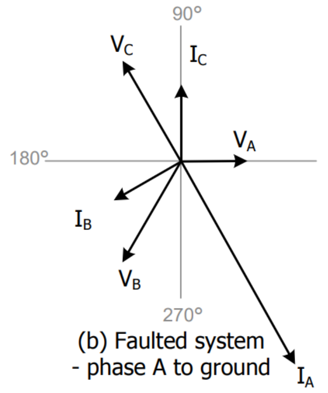
- Due to possible fault characteristics (more reactive or resistive), a maximum torque angle (MTA) or a relay characteristics angle (RCA) is added to the polarizing voltage to allow maximum torque at fault condition.
- To avoid insecure operation due to voltage angle fluctuation, possibly due to CCVT transient overreach or VT fuse blown, a minimum torque requirement may be applied.



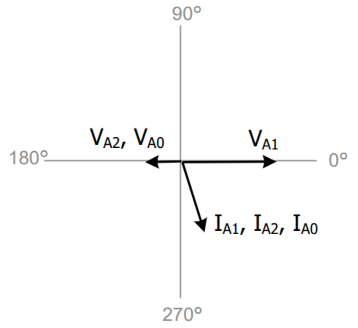

Forward and Reverse Directional Operating Characteristic for Greater Security



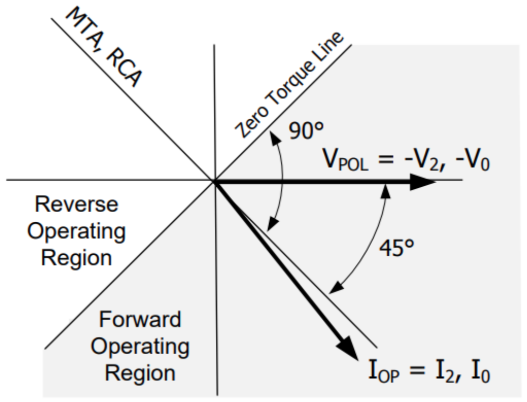

(a) Balanced system



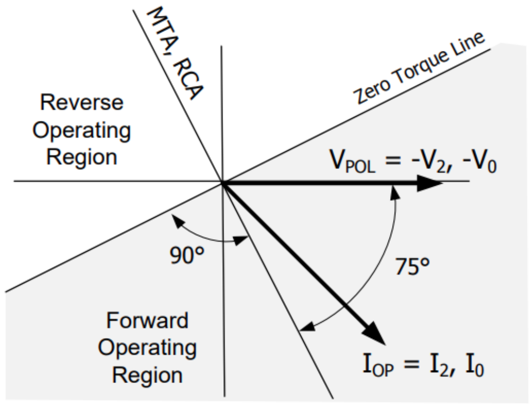

(b) Faulted system - phase A to ground




(c) Faulted system phase A sequence quantities




(a) 45° Relay Characteristic Angle (maximum torque)




(a) 75° Relay Characteristic Angle (maximum torque)

# Phase Directional Element Design – Positive Sequence DIR

Possible Solutions

1. Require agreement of ALL phase directional elements before declaring phase fault direction.
   [higher security for the SLG fault but block phase directional elements from operating for phase-phase faults; requires a separate directional element to discriminate phase-phase fault direction. ]

2. Positive-Sequence Directional Element (Reduced number of elements)

| Phase | Operating Quantity ($I_{1OP}$) | Polarizing Quantity ($V_{1POL}$) |
|---|---|---|
| 3φ | $3I_1 \cdot 1\angle Z_{L1}$ | $3V_1$ |

Positive-Sequence Directional Torque (T32P) –

$$T32P = |3V_1| \bullet |3I_1| \bullet \cos[\angle 3V_1 - (\angle 3I_1 + \angle Z_{L1})]$$

where:

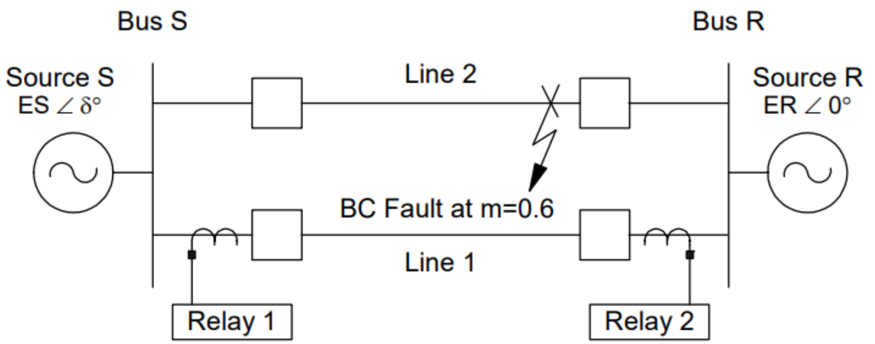
| | |
|---|---|
| $3I_1$ | = Positive-sequence current: $3I_1 = (I_A + a \bullet I_B + a^2 \bullet I_C)$. |
| $3V_1$ | = Positive-sequence voltage: $3V_1 = (V_A + a \bullet V_B + a^2 \bullet V_C)$. |
| a | = $1\angle 120°$. |
| $\angle Z_{L1}$ | = Positive-sequence line angle. |

- As an additional security step, the magnitude of T32P should exceed a minimum threshold to avoid erroneous directional decisions when either $|V_{1POL}|$ or $|I_{1OP}|$ is so small to make their angles unreliable.

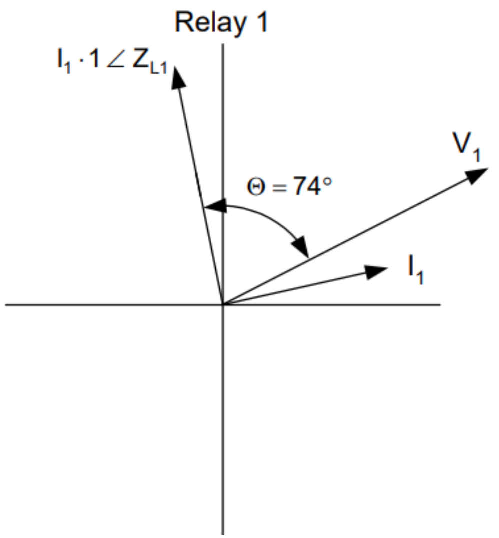
# Phase Directional Element Design – Load Dependence

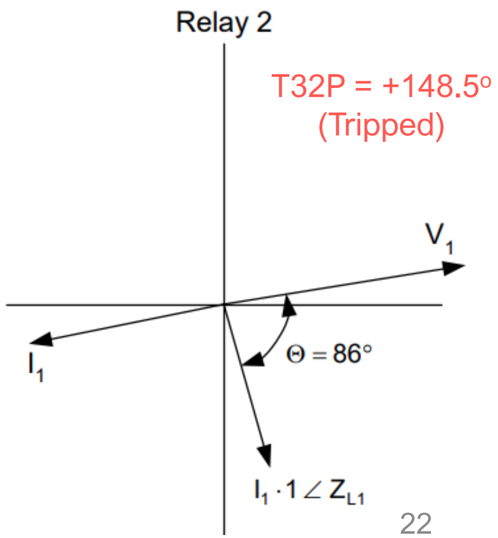
- T32P Response to SLG Fault –
  Recall that the magnitude of T32P must exceed a minimum torque threshold. Because $I_{1OP}$ is zero for this reverse SLG fault, the positive-sequence directional element would not give an output.
- T32P Response to Bolted Three Phase Fault –
  If the polarizing quantity of the positive-sequence directional element does not have memory, T32P cannot operate for a three-phase fault where the magnitudes of all three phase voltages are almost zero (neither could the 90° connected phase directional elements). Using positive-sequence memory voltage ($V_{1MEM}$) for $V_{1POL}$ overcomes a failure to operate for a close-in three phase fault.
- T32P Response to Out-of-Section Phase-Phase Fault with Heavy Load –
  The T32P element may need some additional supervision if the fault does not involve all three phases and the fault current magnitudes approach that of load.

$\delta = 30°$
Left to Right




| | Relay 1 at Bus S | Relay 2 at Bus R |
|---|---|---|
| Positive – Sequence V : $V_1$ | 57.0 V $\angle +25°$ | 55.0 V $\angle +5°$ |
| Positive – Sequence I : $I_1$ | 4.8 A $\angle +9°$ | 4.8 A $\angle -171°$ |
| Negative – Sequence V : $V_2$ | 8.4 V $\angle +13°$ | 10.5 V $\angle +13°$ |
| Negative – Sequence I : $I_2$ | 0.5 A $\angle +103°$ | 0.5 A $\angle -77°$ |



# Phase Directional Element Design – Negative Sequence DIR

- Phase Directional Elements for Unbalanced Faults
  We need a separate directional element to determine unbalanced fault direction. The decision of this element must overrule the T32P element for unbalanced faults.
- Only positive- and negative-sequence quantities are available for both unbalanced phase fault types. As positive-sequence load quantities mislead a directional element for unbalanced faults, only negative-sequence quantities remain as viable inputs to an unbalanced fault directional element.
- Negative Sequence Directional Elements (1980s)

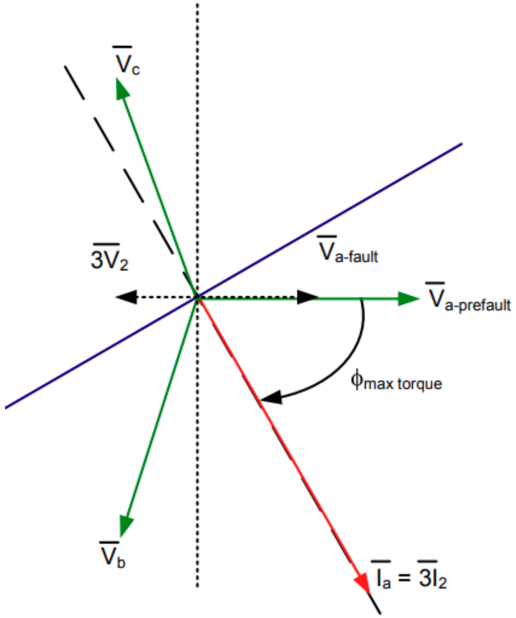
| Phase | Operating Quantity ($I_{1OP}$) | Polarizing Quantity ($V_{1POL}$) |
|---|---|---|
| $3\varphi$ | $3I_2 \cdot 1\angle Z_{L1}$ | $-3V_2$ |

$$T32Q = |V_2| \bullet |I_2| \bullet \cos\left[\angle -V_2 - \left(\angle I_2 + \angle MTA\right)\right]$$

$$T32Q = |3V_2| \bullet |3I_2| \bullet \cos[\angle -3V_2 - (\angle 3I_2 + \angle Z_{L1})]$$

where:

$3I_2$ = Negative-sequence current: $3I_2 = (I_A + a^2 \bullet I_B + a \bullet I_C)$.
$-3V_2$ = Negative-sequence voltage: $-3V_2 = (V_A + a^2 + V_B + a \bullet V_C) \bullet (1\angle 180°)$.




- T32Q is positive for forward faults and negative for reverse faults. As with the T32P element, the magnitude of T32Q must exceed a minimum threshold. Using V2 and I2, T32Q = – 50.13 for Relay 2.

# Phase Directional Element Design – Zero Sequence DIR

- Ground directional elements supervise sensitive residual overcurrent and ground distance elements. The pickup threshold of a ground overcurrent element is typically set low to detect high-resistance faults. Because the ground protection element is sensitive, the directional element must be secure.
- Zero-Sequence Voltage Polarized Ground Directional Elements
  A zero-sequence voltage polarized ground directional element uses $V_0$ or $3V_0$ as the polarizing reference.

$$T32V = |3V_0| \cdot |3I_0| \cdot \cos[\angle -3V_0 - (\angle 3I_0 + \angle Z_{L0})]$$

where:

$3V_0$ = Zero-sequence voltage: $3V_0 = (V_A + V_B + V_C)$.
$3I_0$ = Zero-sequence current: $3I_0 = (I_A + I_B + I_C)$.
$\angle Z_{L0}$ = Zero-sequence line angle.

If the polarizing voltage magnitude becomes too small, its angle becomes unreliable. Remote ground faults present the ground directional relay with the lowest polarizing voltage magnitude.

- Zero-Sequence Current Polarized Ground Directional Elements
  A zero-sequence current polarized ground directional element measures the phase angle difference between the line residual current ($3I_0$) and an external polarizing source current ($_{IPOL}$).

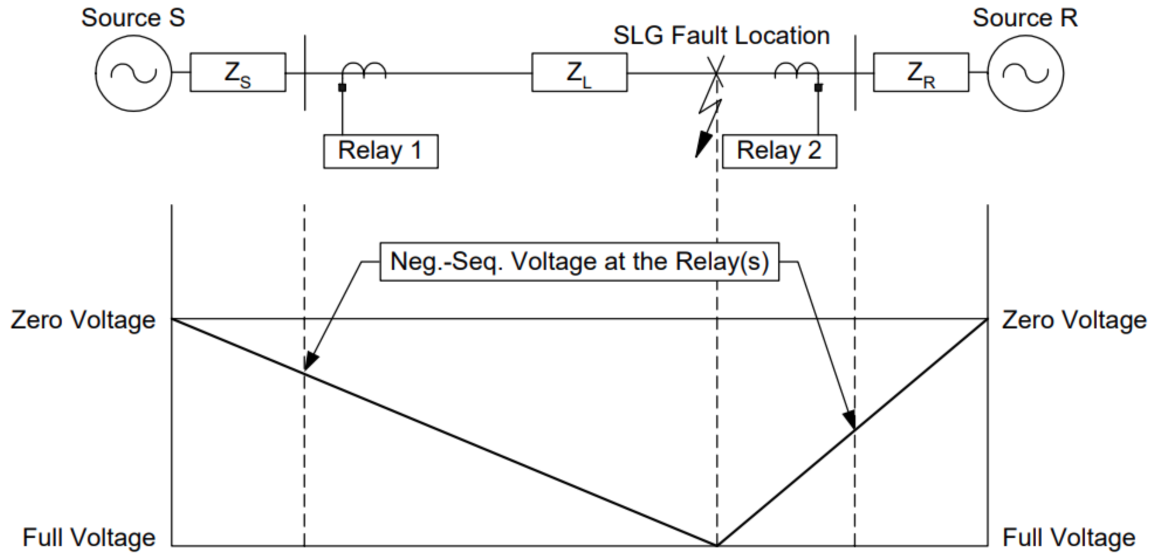
$$T32I = |I_{POL}| \cdot |3I_0| \cdot \cos(\angle I_{POL} - \angle 3I_0)$$

# Phase Directional Element Design – Compensated DIR

Negative-sequence polarized directional elements have the following two major advantages when compared to zero-sequence voltage polarized directional elements:

1. Negative-sequence directional elements are insensitive to zero-sequence mutual coupling associated with parallel transmission line applications. They are suitable for isolated zero-sequence source systems.
2. If the bus behind the relay location is a strong zero-sequence source (i.e. with low impedance), $V_2 > V_0$ available at the relay location. However, for remote fault, $V_2$ could still be small for polarization, and it requires further compensation.

$V_2$ at relay 1 may be small for remote fault




Compensated Negative Sequence Directional Element -

$$T32QC = Re[(V_2 - \boxed{\alpha} \cdot Z_{L1} \cdot I_2) \cdot (Z_{L1} \cdot I_2)^*]$$

Problem –
Large α: make a reverse fault appear as a forward fault.

# Phase Directional Element Design – Compensated DIR

- How large can be set the α?
- Consider a close-in reverse fault on a two-terminal system.
- The maximum α setting with ($V_2 - \alpha Z_{L1} I_2$) = 0.

$$\left[V_2 - \alpha \bullet Z_{L1} \bullet (-I_{R2})\right] = 0$$

$$V_2 = \alpha \bullet Z_{L1} \bullet (-I_{R2})$$

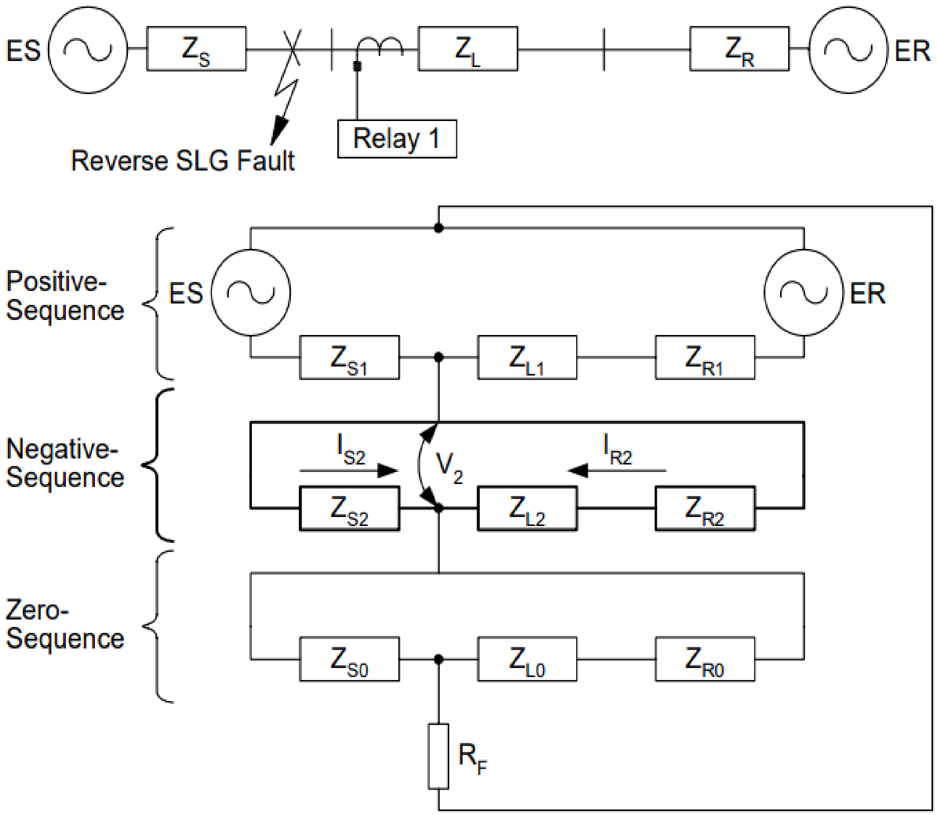
- For this fault, $V_2$ measured equals to $-I_{R2} (Z_{R2} + Z_{L2})$.

$$I_{R2} \bullet (Z_{R2} + Z_{L2}) = \alpha \bullet Z_{L2} \bullet I_{R2}$$

$$(Z_{R2} + Z_{L2}) = \alpha \bullet Z_{L1}$$

$$\alpha = \left( {Z_{R2}}/{Z_{L2}} + 1 \right)$$

- Thus, $\alpha < Z_{R2} / Z_{L2} + 1$ or the amount of forward compensation $\alpha Z_{L2}$ must not be set greater than $Z_{R2} + Z_{L2}$.



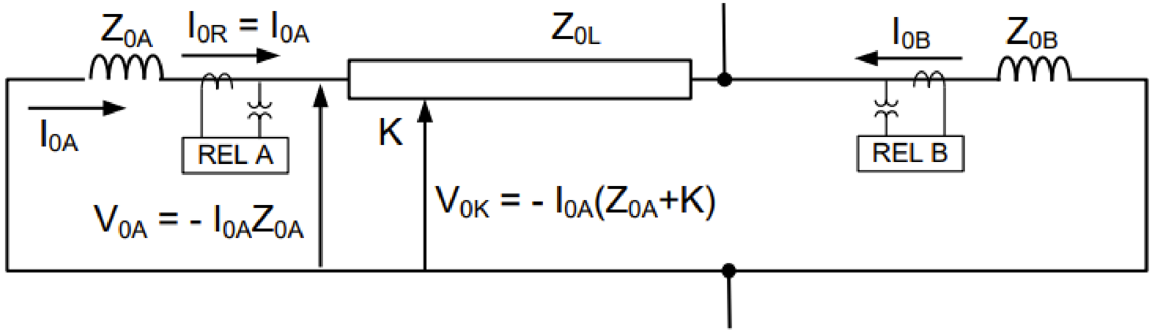
# Phase Directional Element Design – Compensated DIR

- Either negative or zero sequence voltage compensation
- Long line and resistive fault applications; low operating current and strong source with low source impedance

$$\boxed{Vpol = -V_{0A} + I_{0R}\, K\angle RCA}$$

- Care when choosing K (compensation impedance) so that the direction is not forward for a reverse fault.
- For long lines $Z_{0L}$ can be quite high compared to source impedances. If both $Z_{0A}$ and $Z_{0B}$ are much less than $Z_{0L}$, and a remote resistive fault occurred insufficient to provide polarizing voltage at the relay, but the ground current is large enough to give operation.
- Polarizing Voltage: $V_{pol} = -V_{0A} + I_{0R}\, K\angle RCA$ → $V_{POL} = -V_{0A} + K\angle RCA\, V_{0A} / (Z_{0L} + Z_{0B})$

  Restraining Current: $I_{0R} = -I_{0B} = V_{0A} / (Z_{0L} + Z_{0B})$ → $V_{POL} = -V_{0A}\,(1 - K / (Z_{0L} + Z_{0B}))\,\angle RCA$
- To get correct directionality with the compensation factor for a reverse fault, K must be less than $(Z_{0L}+Z_{0B})$, not considering the angle error. The source impedance $Z_{0B}$ might vary so the smallest value provides best reliability. If Z0L is much greater than Z0B then the relation can be simplified into $K < 0.4Z_{0L}$.



# Phase Directional Element Design – Impedance Based DIR

- From $V_2$ and $I_2$, the calculated negative-sequence impedance $Z_{2MEASURED}$ can also tell the direction.

$$\text{Forward SLG Faults:} \quad Z2_{MEASURED} = V_2/I_{S2} = -Z_{S2}$$
$$\text{Reverse SLG Faults:} \quad Z2_{MEASURED} = V_2/(-I_{R2}) = +(Z_{L2} + Z_{R2})$$

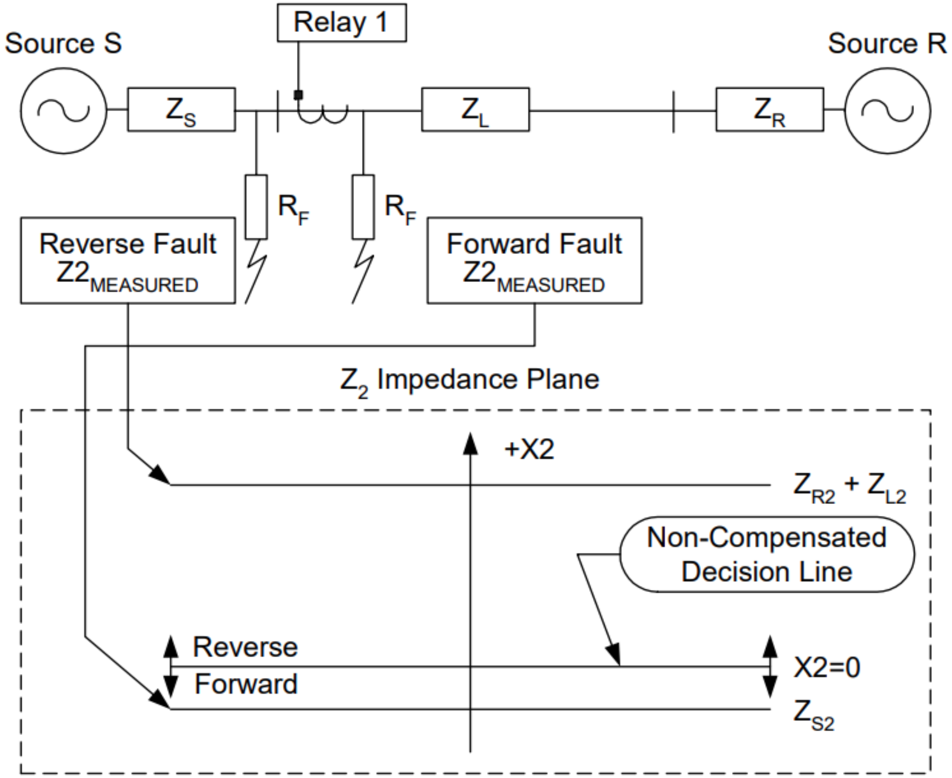
- The equation for this new negative-sequence directional element (1993) is shown below:

$$z2 = \frac{\mathrm{Re}\left[V_2 \bullet (I_2 \bullet 1\angle\Theta)^*\right]}{|I_2|^2}$$

where:

$z2$ = measured negative-sequence impedance.
$\angle\Theta$ = the angle of the negative-sequence line impedance.

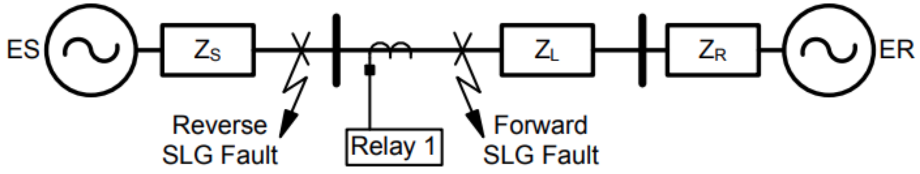
- $z2 <$ Z2F threshold : Forward fault condition
- $z2 >$ Z2R threshold : Reverse fault condition

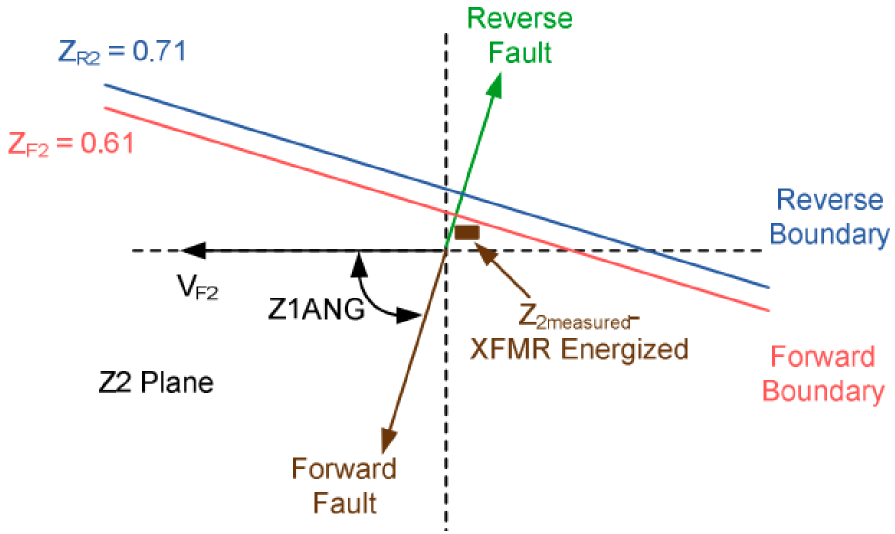


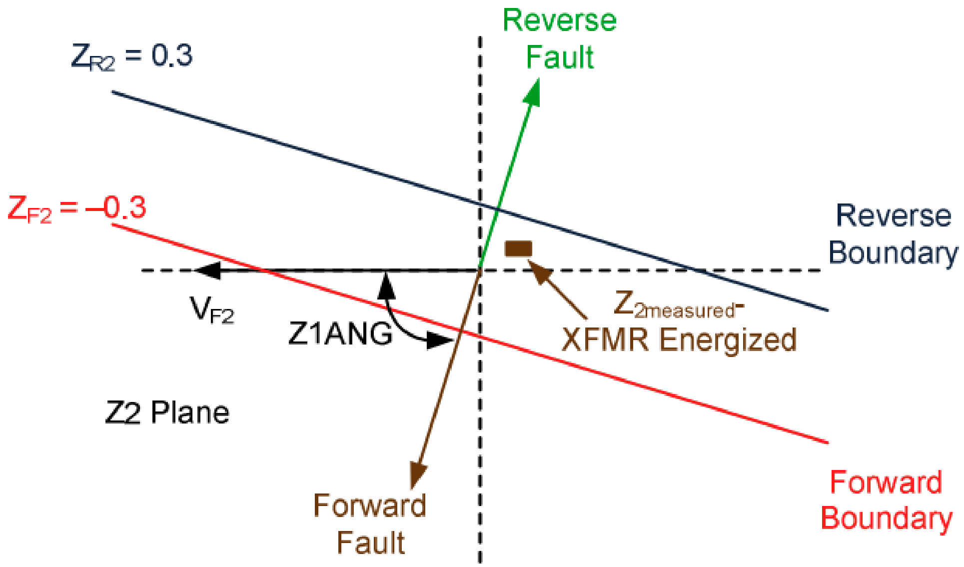

- Z2F must be less than Z2R to avoid any overlap.
- If the magnitude of the measured $V_2$ is so small as to give a $z_2$ result near zero, simply increase the Z2F threshold to gain directional security.

# Phase Directional Element Design – Impedance Based DIR

- Previous directional element designs were limited with low negative-sequence voltage, making the negative sequence $Z_{2measured}$ near zero. In the 1993 design, the threshold ZF2 was increased to improve sensitivity.
- A positive-sequence restraint factor, $|I_{A2}| / |I_{A1}|$, must be exceeded to allow the directional element to operate. This prevents the element from mis-operating during three-phase faults on non-transposed lines
- $|3I_2| > |3I_2|_{F\text{-}SET}$ to ensure that the directional element is disabled for unbalanced power system or load conditions
- Forward Fault: $Z_{2measure} = - Z_{S2}$
  Reverse Fault: $Z_{2measure} = Z_{L2} + Z_{R2}$



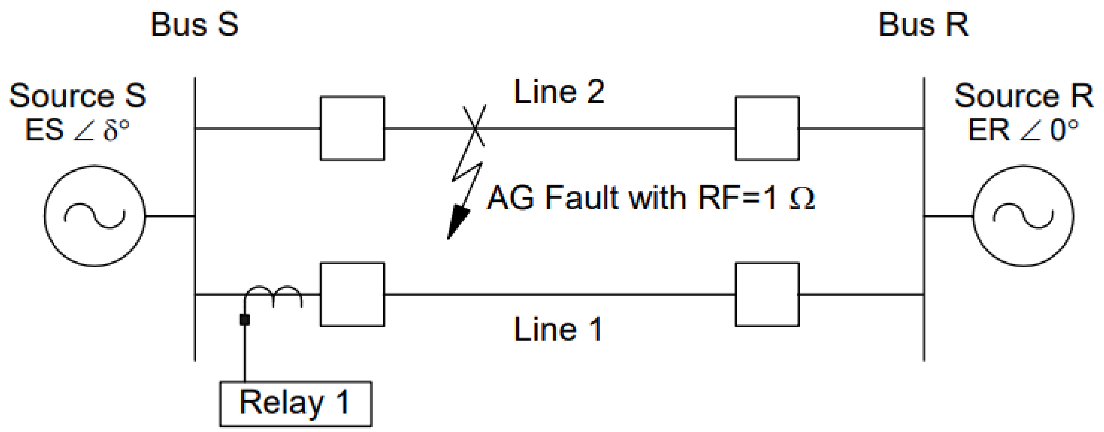



# Phase Directional Element Design

- A ground directional element, which combines phase and residual currents, uses the polarizing and operating quantities below.

| Phase | Operating Quantity ($V_{OP}$) | Polarizing Quantity ($V_{POL}$) |
|---|---|---|
| A | $Z_{L1}$ $(I_A + K_0\ 3I_0)$ | $V_A + jV_{BC}$ |
| B | $Z_{L1}$ $(I_B + K_0\ 3I_0)$ | $V_B + jV_{CA}$ |
| C | $Z_{L1}$ $(I_C + K_0\ 3I_0)$ | $V_C + jV_{AB}$ |

- Short Coming: Residual current is not phase selective, and a directional element for a non-faulted phase can produce errors.



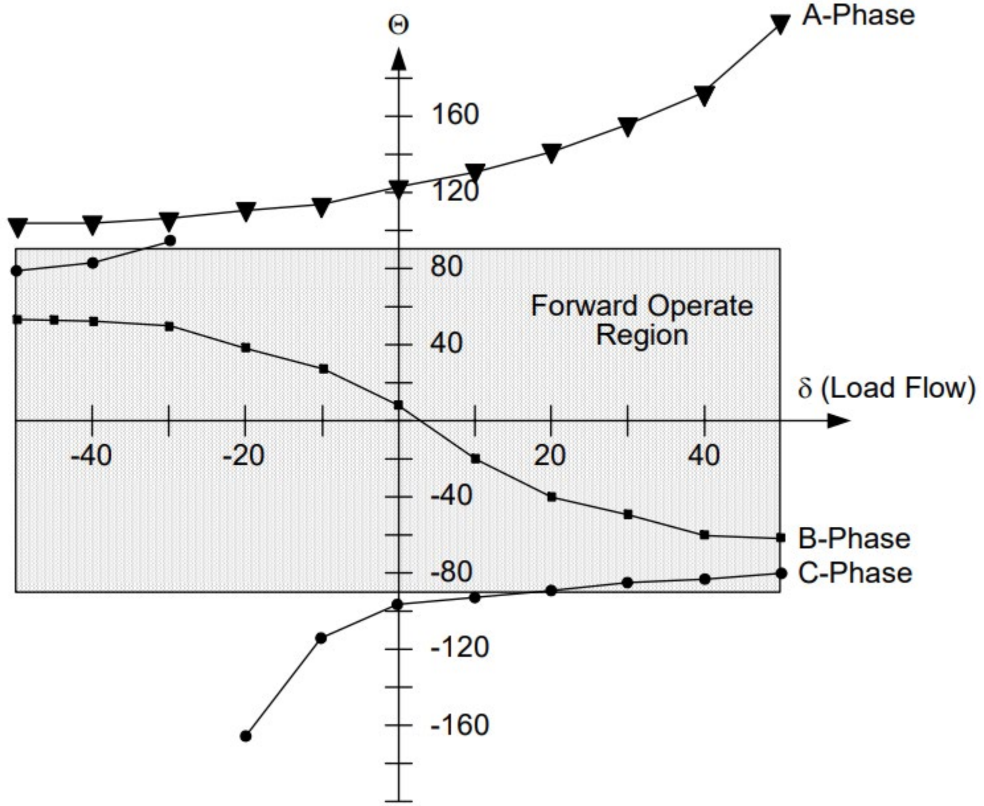

Ideally, Relay 1 should declare the fault direction as reverse.

In the no load case ($\delta = 0$), $I_B$ and $I_C$ are zero and all $V_{OP}$ quantities are in phase. Only the BG directional element declares the fault forward for $\delta = 0$. As load increases into and away from Bus S, the C-phase ground directional element also declares the reverse fault as forward.

# Phase Directional Element Design – Load Flow and Unbalance

Difficulties in Phase Directional Element Design

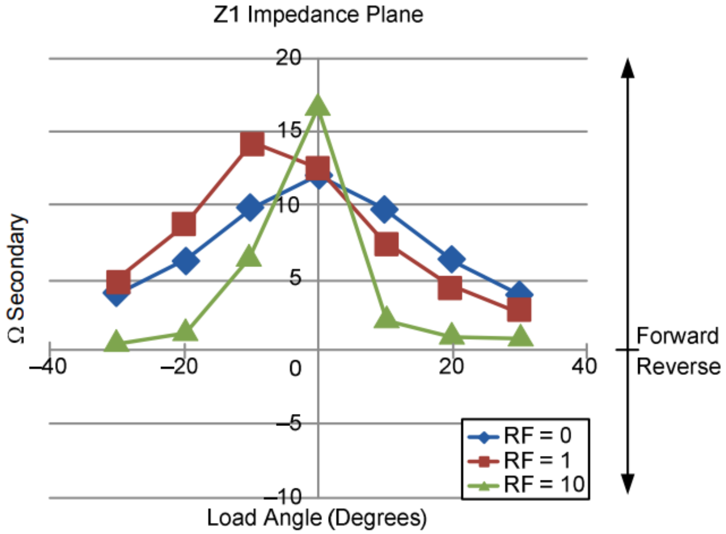
- BG DIR element always declares forward while CG DIR element decision depends upon load flow direction. The indecisive fault direction and their dependence upon load flow make these elements undesirable.
- Consider the case of a ground directional element allowed to run unrestricted during non-fault conditions. This unrestricted directional element can pick up for normal system load unbalance.
- If the load induced direction is opposite that of the fault direction, there is a race between the pickup of the DOC element and the drop off of the load induced DIR.
- By requiring the controlling overcurrent element to pick up before the directional element is enabled, unbalanced load induced directional decisions can be avoided.



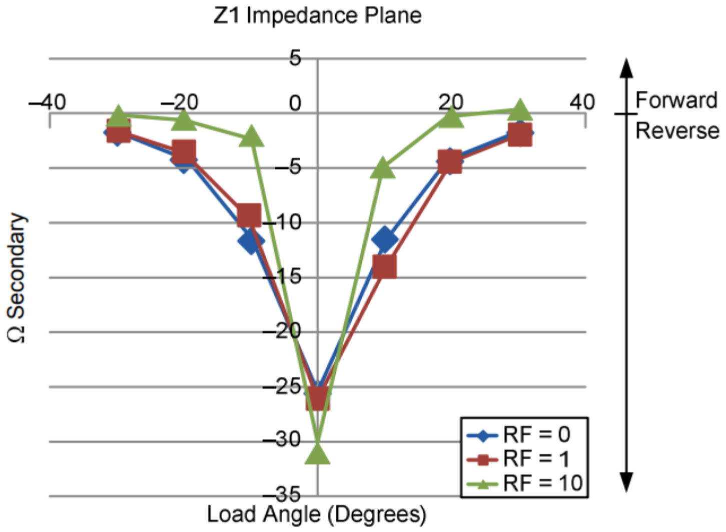

$\Theta_A = \angle V_{POLA} - \angle V_{OPA}$ $\Theta_B = \angle V_{POLB} - \angle V_{OPB}$ $\Theta_C = \angle V_{POLC} - \angle V_{OPC}$

# Phase Directional Element Design – VT Fuse Blown Issue

- During an LOP condition, users should choose to make the relays nondirectional or to disable directional element during the LOP condition.
- This directional element uses the healthy voltage from the remaining voltage inputs to create a positive-sequence impedance element, Z1LOP. Directionality is stable for one or two blown VTs because the V1 angle is stable, regardless of V1 magnitude
- Z1LOP is not recommended when voltages are healthy. The element is active only during LOP conditions. However, it is a viable option for providing protection redundancy during LOP conditions for forward and reverse phase and ground faults, with some known limitations because of load and fault resistance

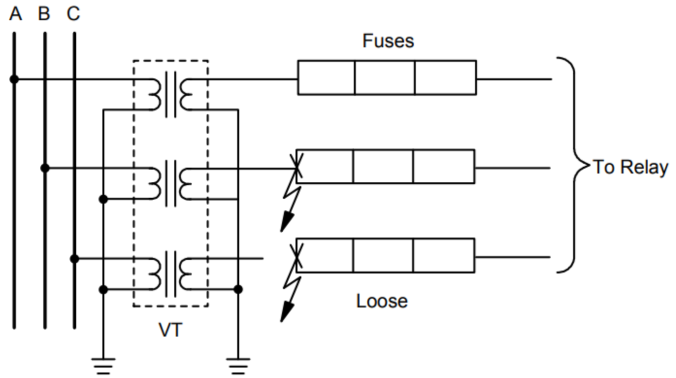



Z1m versus delta load angle with varying fault resistance for a forward midline AG fault with blown A-phase VT fuse



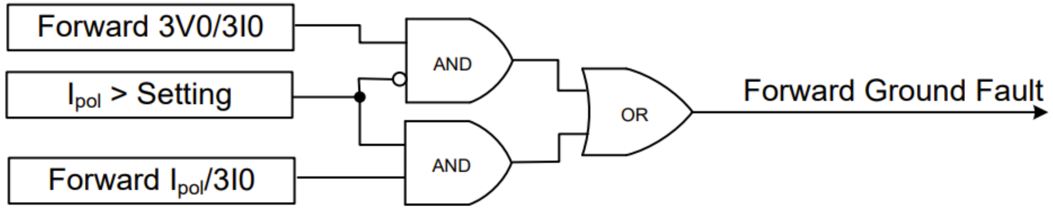

Z1m versus delta load angle with varying fault resistance for a reverse midline AG fault with blown A-phase VT fuse

$$Z_{1\text{measured}} = \frac{\mathrm{Re}\left[(V_1)\bullet(I_1 \bullet \angle Z1ANG)^*\right]}{(|I_1|)^2}$$

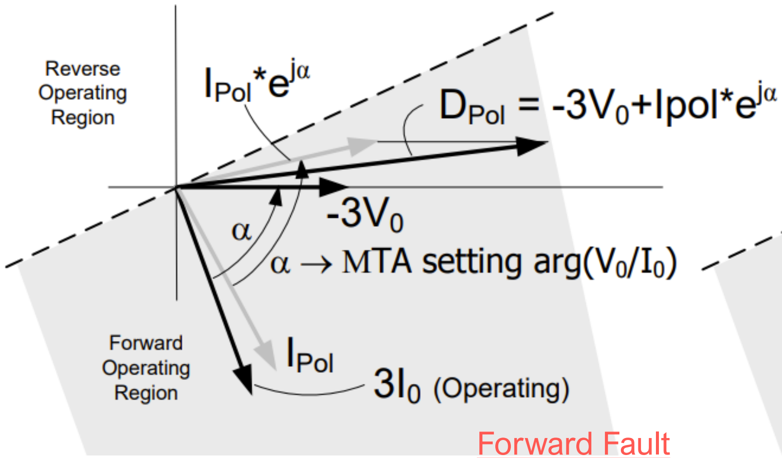


# Phase Directional Element Design – Dual Polarization

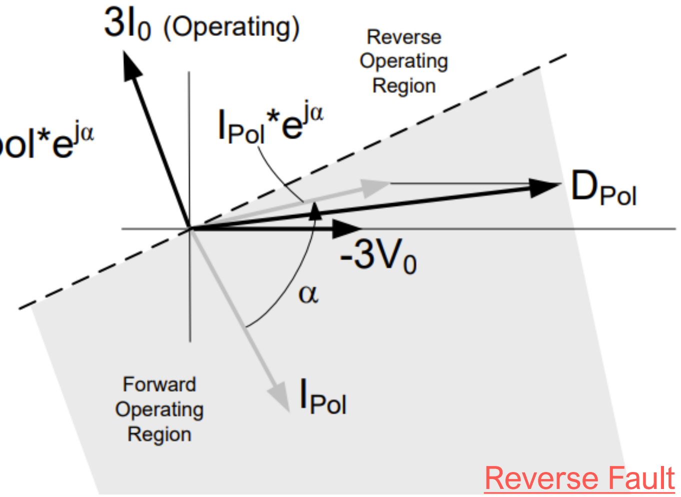
- In EM relay, separate voltage polarized and current polarized units with their forward (closing torque) operating contacts arranged in parallel so that either unit may indicate forward ground fault direction.
- In Static relay, paralleling (OR gate) of the appropriate outputs of the two methods, however, voltage polarizing unit is blocked if polarizing current is available. The voltage unit will only operate if polarizing current is not available.




- Dual polarization with $D_{POL} = -3V_0 + I_{POL}\, e^{j\alpha}$ by summing the polarizing voltage phasor can indicate a strong forward fault with $\alpha = \angle V_0 / I_0$.

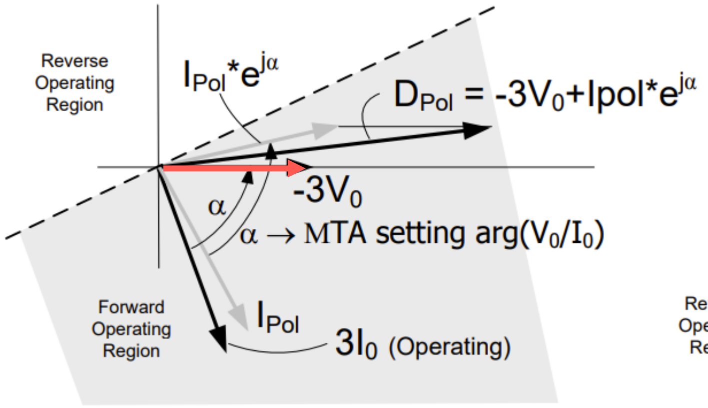



Forward Fault

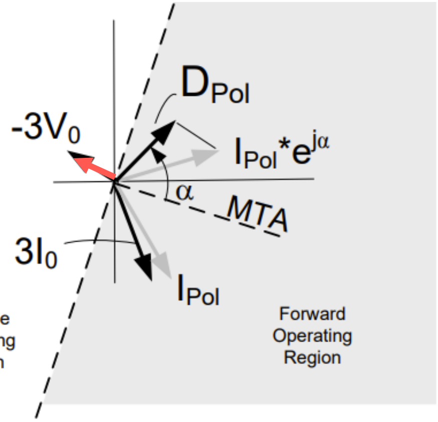



Reverse Fault

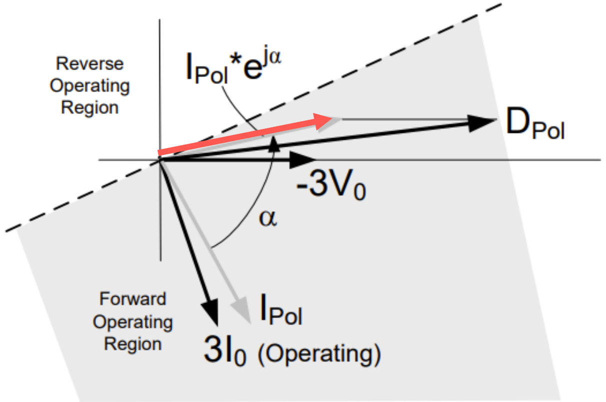
# Phase Directional Element Design – Dual Polarization



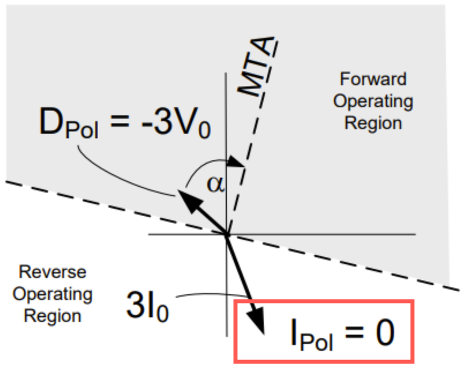

(a) Dual polarization with healthy $3V_0$




(b) Dual polarization with erroneous $3V_0$



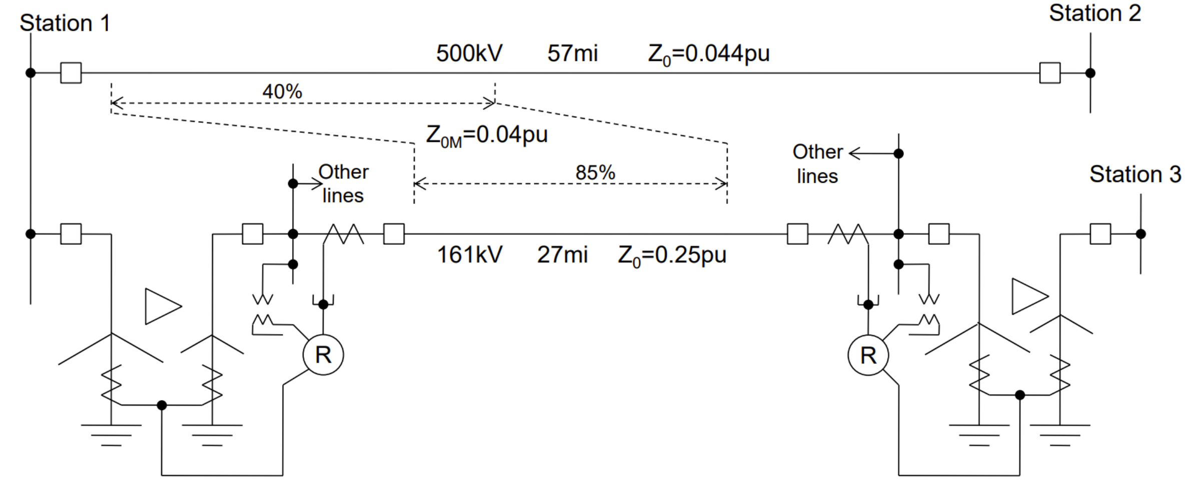

(a) Forward ground fault with $I_{Pol}$

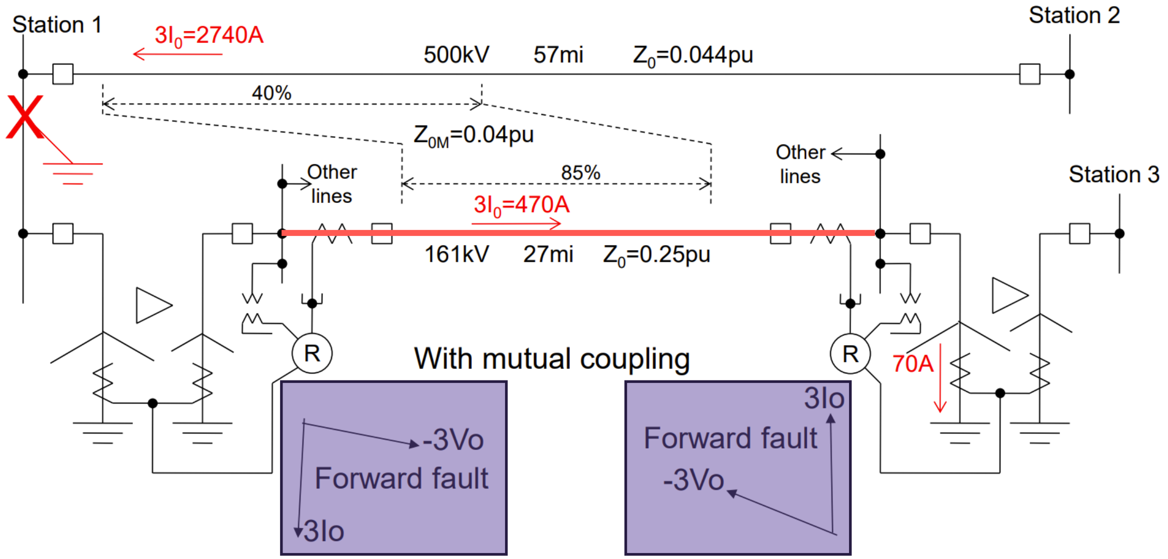



(b) Forward ground fault appearing reverse without $I_{Pol}$ and with erroneous $3V_0$

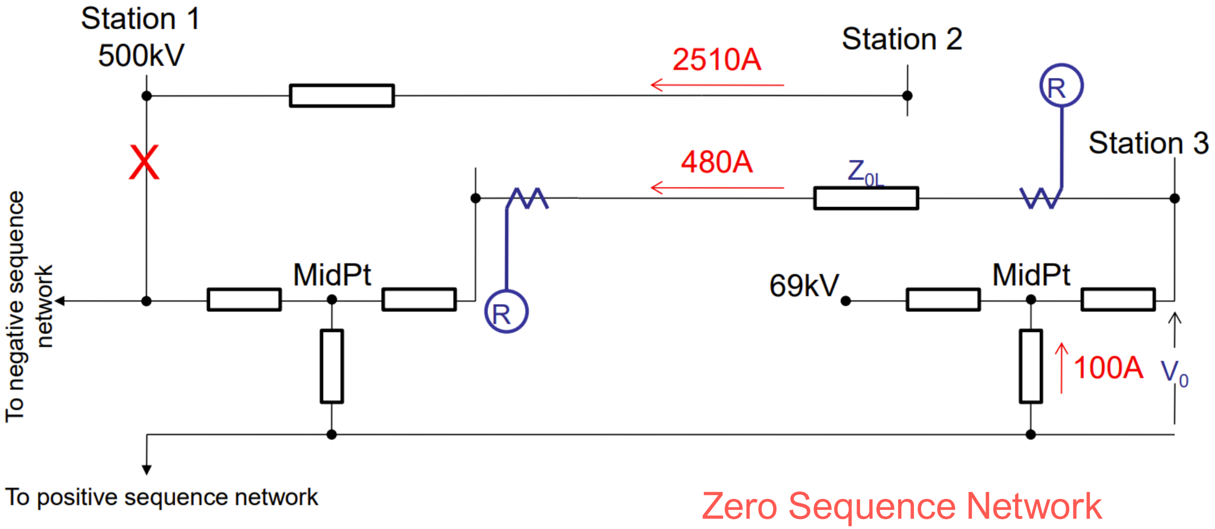
- Sufficient $I_0$ is required to overcome the $-3V_0$ error.
- A remaining issue is CT saturation leading to unreliable phase angle difference.
- The dual polarized quantity is totally dependent on $-3V_0$ for correct polarization. Error to polarized quantities could lead to incorrect directional comparison decisions if *one terminal* is operating with both $I_{Pol}$ and $-3V_0$ while the *other terminal* is operating with $-3V_0$ only.

# Effect of Mutual Coupling to Directional Element

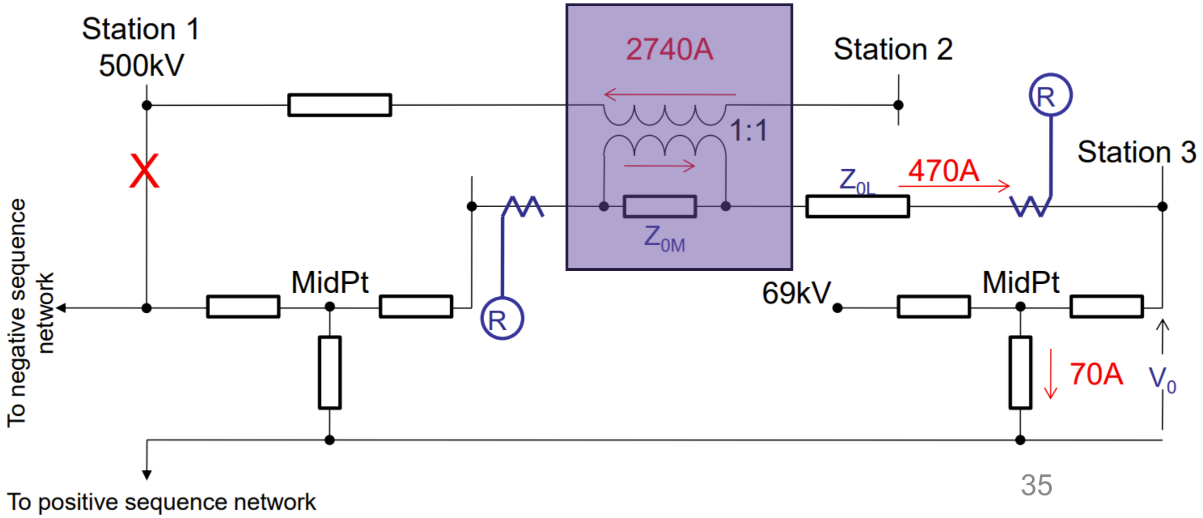


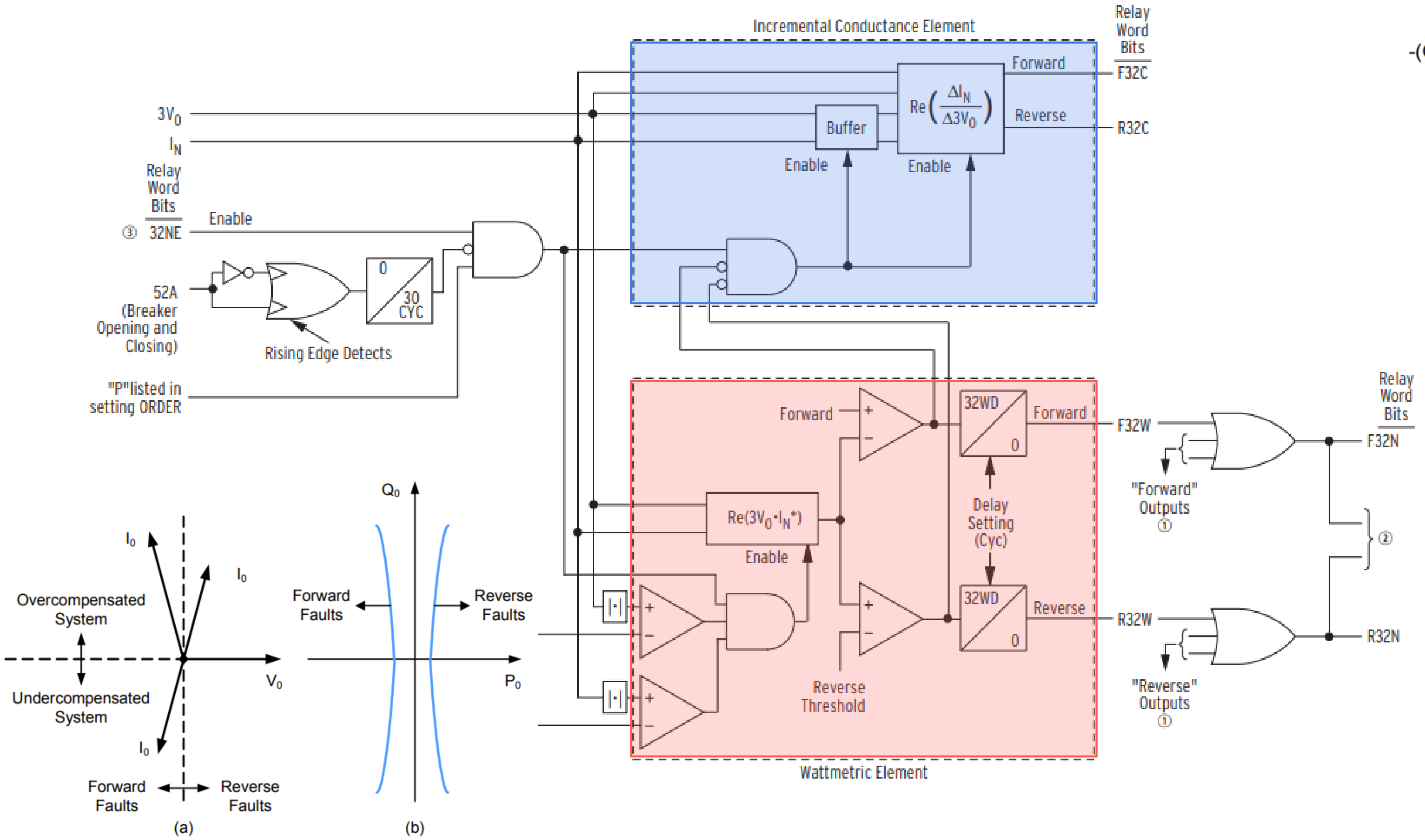

Zero Sequence Network
Neglecting Mutual Coupling



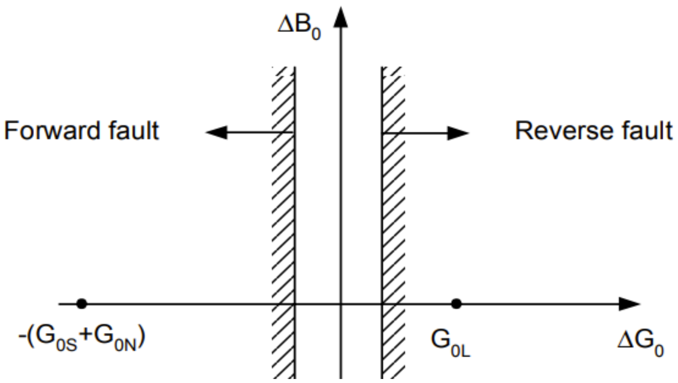

Zero Sequence Network
With Mutual Coupling



# Relay Logic – SEL








## Incremental Conductance Directional (32C)

$$\Delta G_0 = \mathrm{Re}\left[\frac{\Delta \vec{I}_0}{\Delta \vec{V}_0}\right]$$

Forward

$$\Delta G_0 = -\left(\frac{1}{R_{0S}} + \frac{1}{3R_N}\right) = -(G_{0S} + G_{0N})$$

$$\Delta G_0 = \frac{1}{R_{0L}} = G_{0L}$$

Reverse

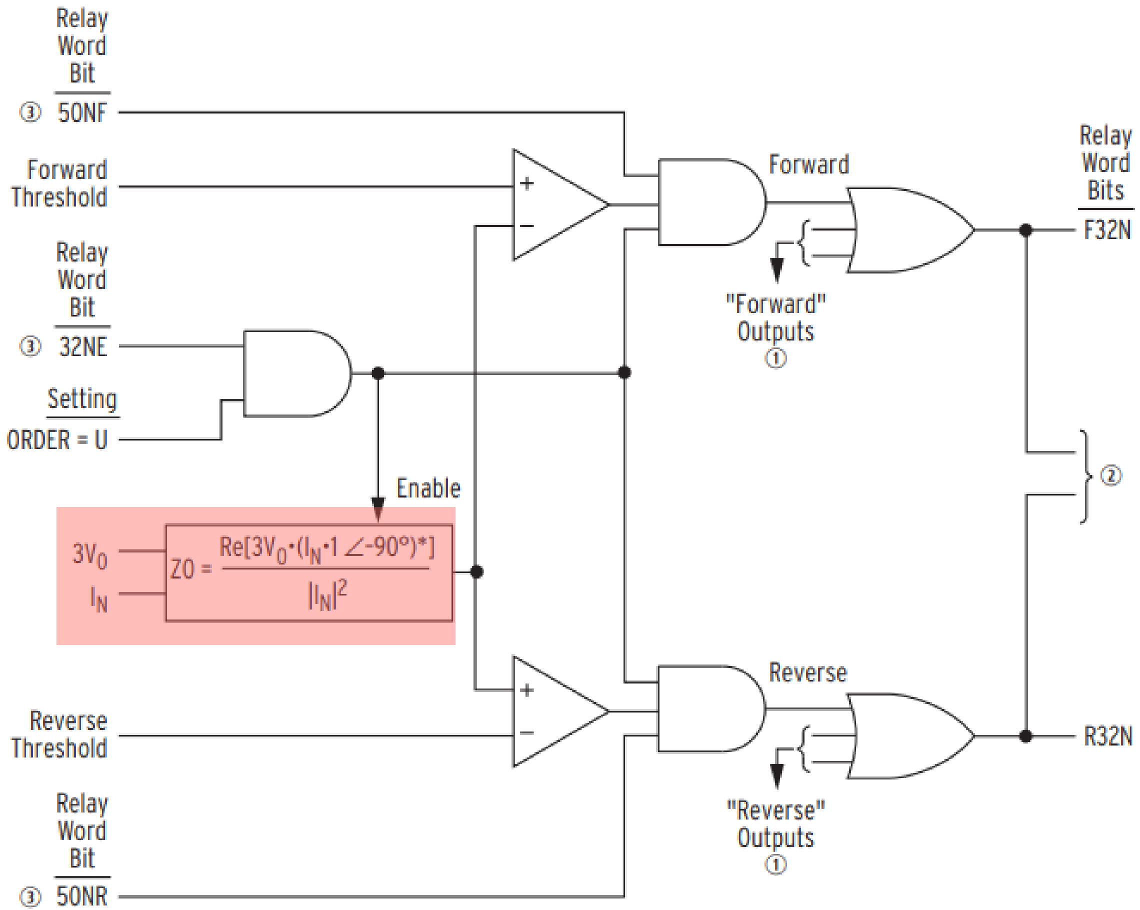
## Wattmetric Directional (32W)

$$Q_{TRAN}(k) = \frac{1}{N}\sum_{k=1}^{N} \hat{u}(k-n+1)\hat{i}(n)$$

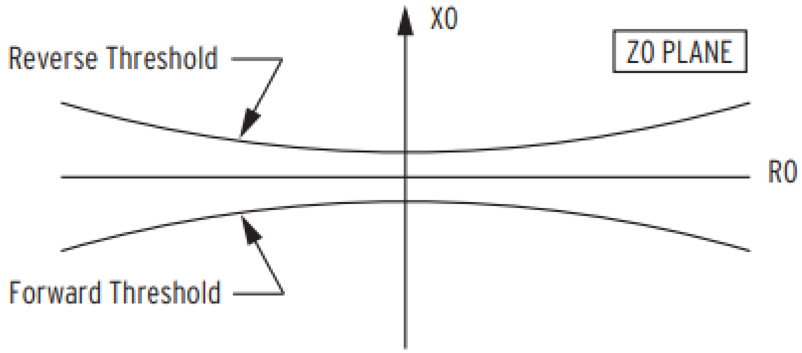
$Q_{TRAN} < -0.1$ Forward

$Q_{TRAN} > 0.1$ Reverse

# Relay Logic – SEL




## Impedance Directional (32Q)

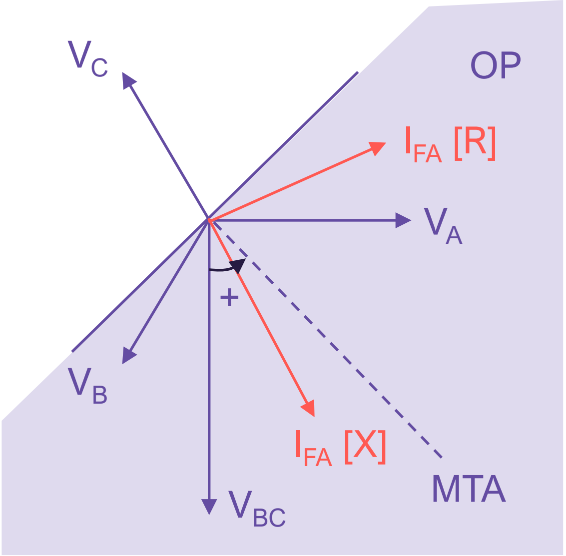



Direction Element Characteristics

| System Grounding Method | Sensitive Current Input Required | Available Directional Elements | Recommended Directional Element |
|---|---|---|---|
| Effective and Low-Impedance Grounding | No | 32I, 32Q, 32V | Best Choice Ground Directional Element |
| Low-Impedance Grounding With High Charging Capacitance | No | 32V, 32I | 32V or 32I |
| High-Resistance Grounding | Yes | 32I, 32V, 32W, 32C | Combination of 32W and 32C |
| Resonant Grounding | Yes | 32W, 32C | Combination of 32W and 32C |
| Isolated Neutral | Yes | 32U, 32W, 32C | 32U |

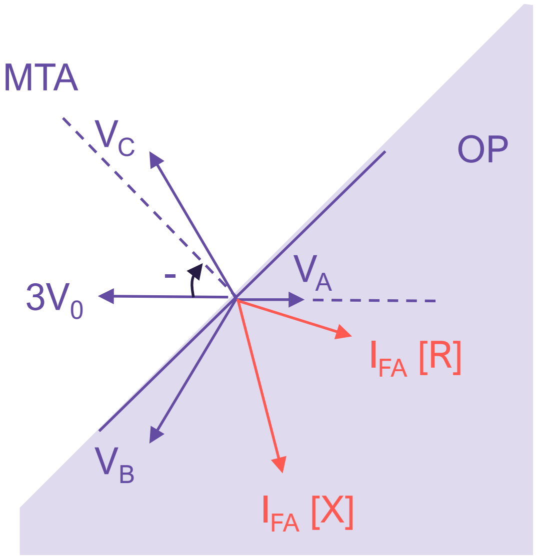
# Relay Logic – DCD814B and DCD914B from Reyrolle

- Cross-Polarized Direction OCEF



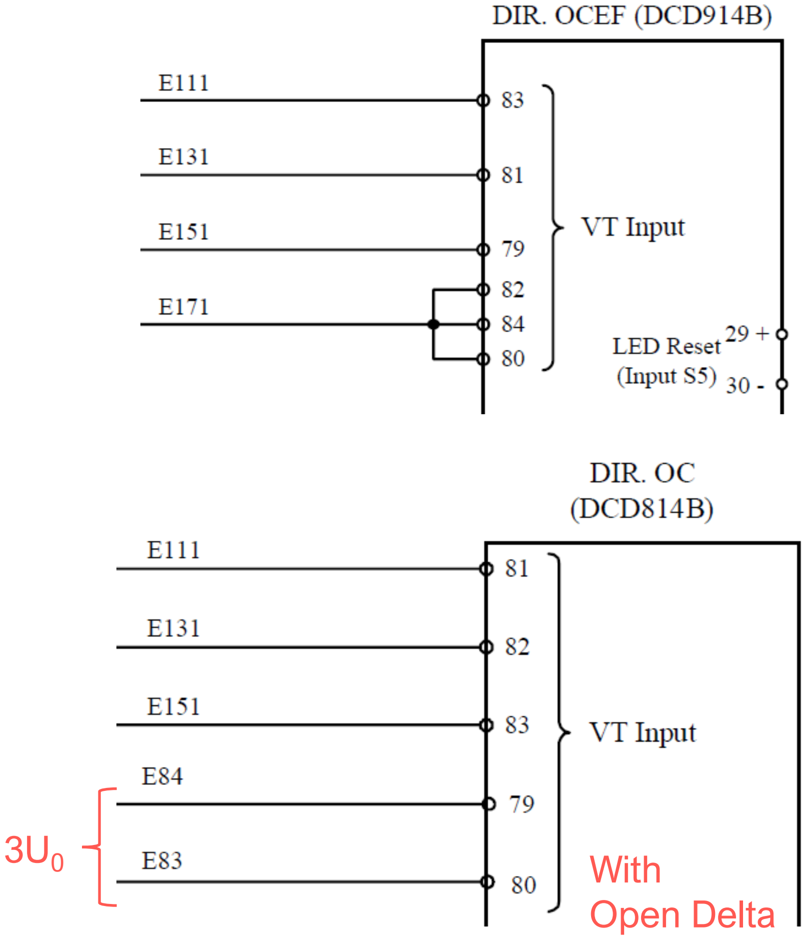

$V_{POL} = V_{BC}$ ; $I_{OP} = I_{FA}$

P/F Char.Angle Setting = +45º




$V_{POL} = 3V_0$ ; $I_{OP} = I_{FA}$

E/F Char.Angle Setting = -45º



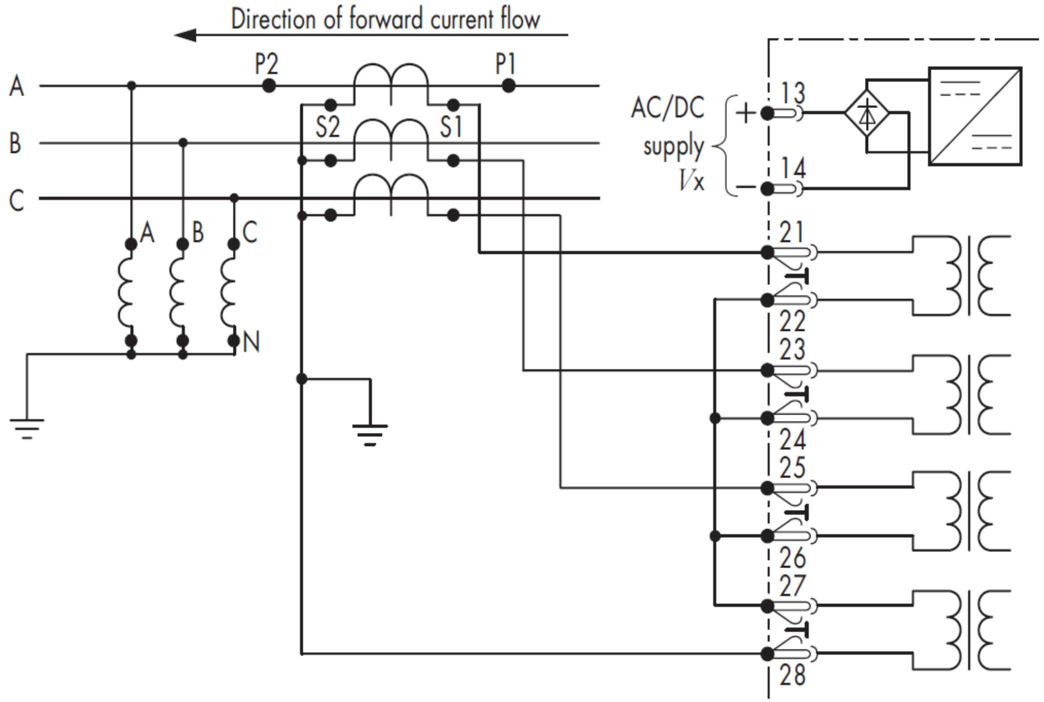

\# In theory EF $V_{POL}$ = - $3V_0$ to align with CA setting

\# Virtual Polarization with $V_{POL} = V_B + V_C$ can be used for earth fault.

\# Earth fault injection requires voltage injected to E83 – E84

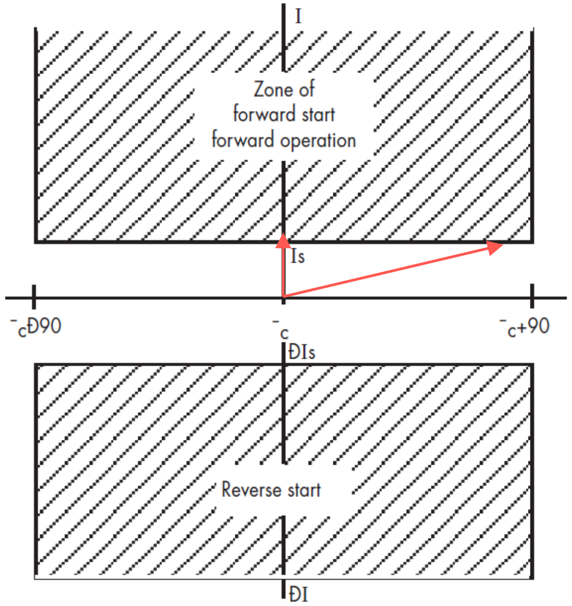
# Relay Logic – KCEG from Alstom

- When DOC protection is used, the elements is polarised. Phase faults are polarised by the quadrature phase voltage.
- For earth faults $3U_0$ is used. The polarising signal also has adjustable threshold value, to allow for any imbalance in the zero-sequence signal due to VT errors.




<u>Application Note</u>

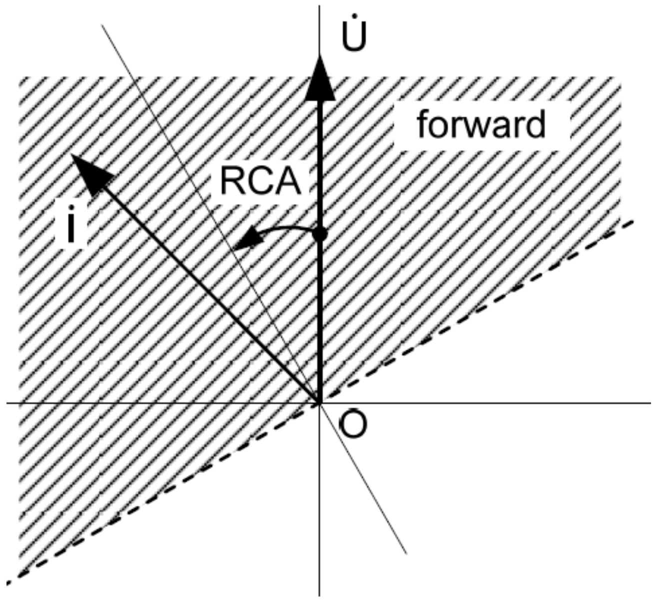
- Injection Set SVERKER 750 does NOT have same source impedance to the two injections (fixed voltage to VT; variable voltage to CT). Hence, voltage angle is distorted.
- KCEG does not include phase detection between 3 phase. It just maps the magnitude to the assumed 120° difference. Phase-Phase injection at VT with fixed voltage often leads to unequal injection at the two phase. It is suggested to have both input at the main injection when testing VTS.
- Additional CB auxiliary contact (N.O.) with $48V_{DC}$ BI is used. VTS is provided with closed CB condition.



# Relay Logic – PCS9611 from NR

- Phase fault element are internally polarized by quadrature phase-to-phase voltage.

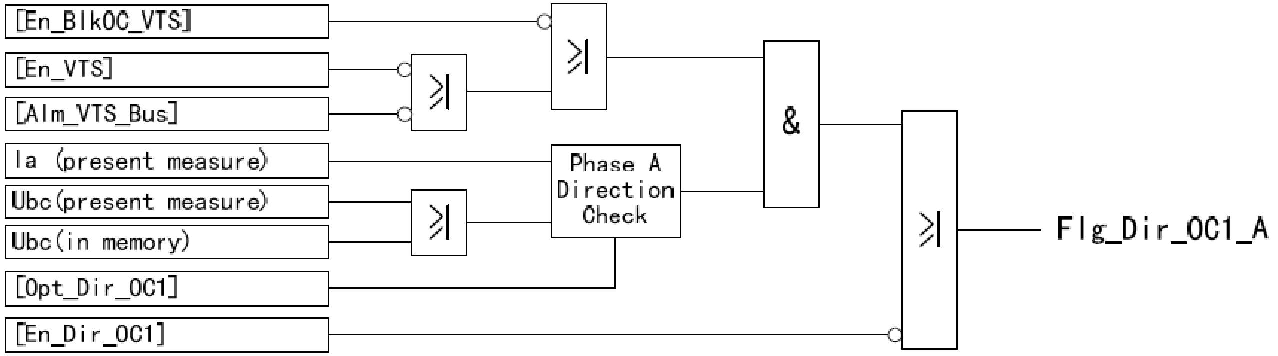
| Phase of Protection | Operate Current (I) | Polarizing Voltage (U) |
|---|---|---|
| A Phase | Ia | Ubc |
| B Phase | Ib | Uca |
| C Phase | Ic | Uab |




- Under system fault conditions, fault current will lag its nominal phase voltage by an angle dependent upon system X/R ratio. Hence an RCA is provided to have maximum sensitivity for current lying in this region.
- For close-in fault with all three-phase voltage collapse to zero, the relay includes a memory polarization feature that stores the pre-fault positive sequence voltage for 0.5s. After 0.5s, it will keep the result of directional element, to ensure that either instantaneous or time delayed DOC will be operative, even with all phase voltage collapse.
- Directionality Check
  - Directional forward

    -90° < (angle(I) - angle(U) - RCA) < 90°
  - Directional reverse

    -90° > (angle(I) - angle(U) - RCA) > 90°



# Relay Logic – PCS9611 from NR

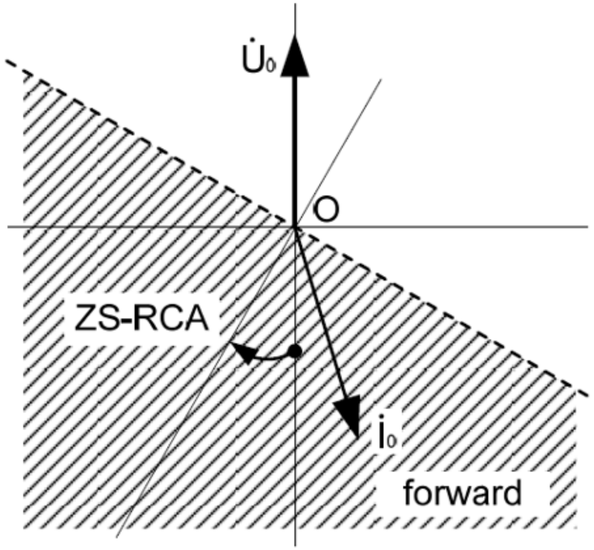
- Zero-Sequence relay characteristics angle (ZS-RCA) is configurable with setting [phi_Char_ROC]. A directional check is performed with

  - Directional forward

    -90° < (angle(I0) - angle(U0+180°) - ZS-RCA) < 90°

  - Directional reverse

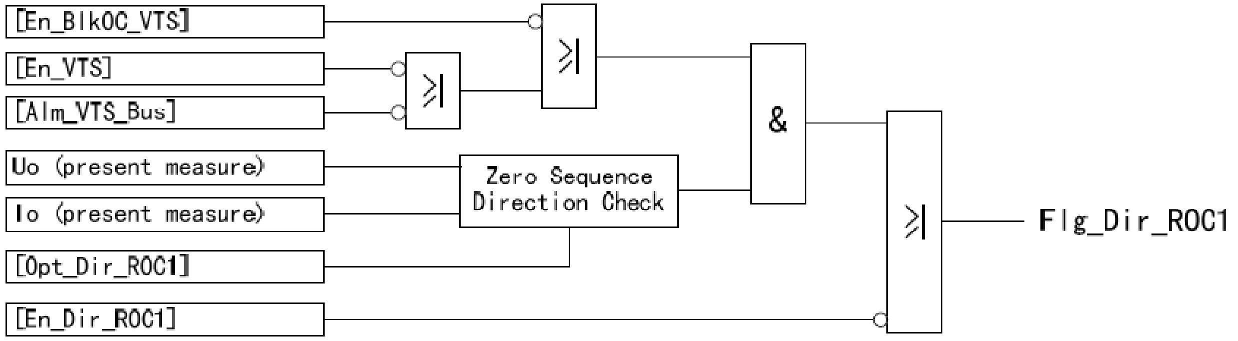
    -90° > (angle(I0) - angle(U0+180°) - ZS-RCA) > 90°




- When the element is selected as directional, a VTS block option is available. When the relevant setting is set to "1", operation of VTS will block the stage if the relevant directional element is in service. When the relevant setting is set to "0", the stage will revert to non-directional upon operation of VTS.

Setting Table P15_V180104

| | | |
|---|---|---|
| 90. En_VTS | ☐ 0 | (VTS/FastVTS: 0=OFF,1=ON) |
| 91. En_BlkOC_VTS | ☐ 0 | (VTS to block OC/ROC) |



# Relay Logic – RCS902H from NR

- Zero-sequence power $P_0$ is calculated by $3U_{0Cal}$ and $3I_{0Cal}$.

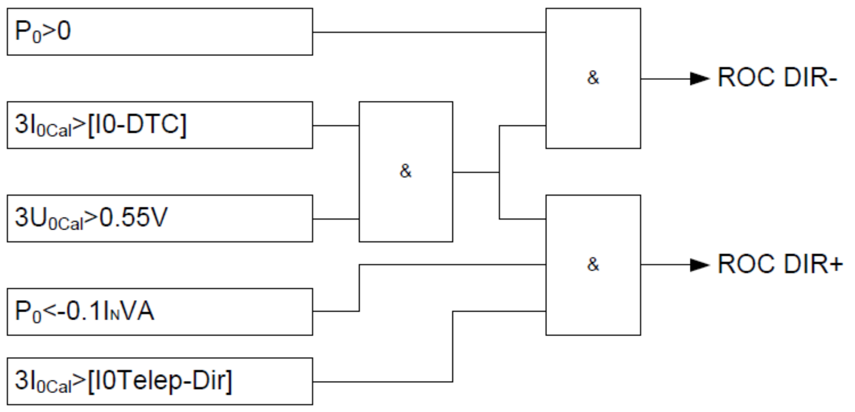
$$P_0 = 3U_{0Cal} \times [3I_{0Cal} \times \cos(\theta - \varphi)]$$

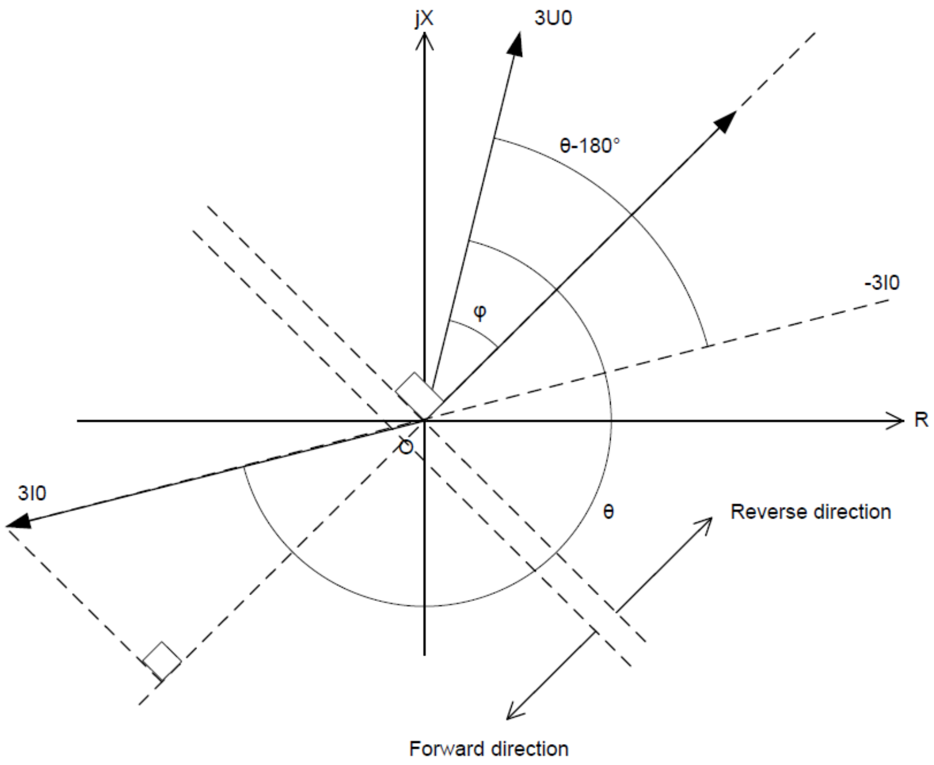
where

$\varphi$ = zero-sequence RCA, to be set according to the sensitive angle of zero-sequence impedance behind the device.

$\theta$ = phase angle between zero-sequence voltage and zero-sequence current.

- Forward zero-sequence element ($F_{0+}$) and Reverse zero-sequence element ($F_{0-}$) are determined by $P_0$.
- When $P_0 > 0$, $F_{0-}$ operates
  When $P_0 < -0.1 I_N VA$ $F_{0+}$ operates
  When $0 < P_0 < -0.1\ I_N$ VA neither $F_{0-}$ nor $F_{0+}$ operates
  If $F_{0-}$ operates, zone 1 and zone 2 phase-to-ground distance element will be blocked.
- ROC DIR+ indicates a forward ground fault derived from output of $F_{0+}$ through an AND gate with directional comparison $3I_{0Cal}$.
- Application –
  Current Reversal Logic in Distance for Parallel Feeder.

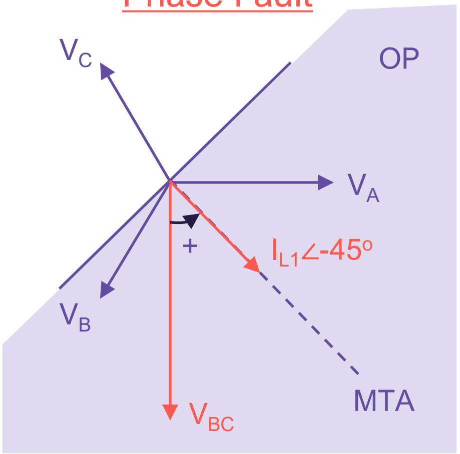


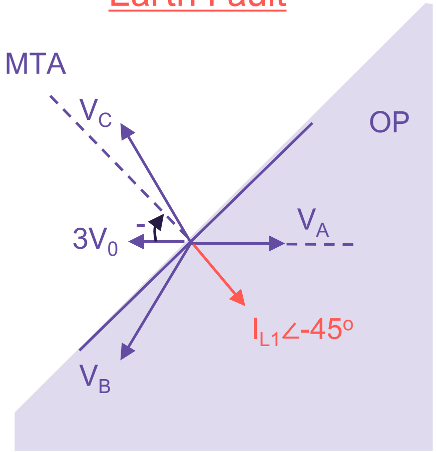
# Injection for Maintenance Test

- Test with Omnicron 356 (or 156) – with three phase injection

Phase Fault




Earth Fault




**1. DOCEF1 (FWD, NI) Operating Time Characteristic Test (☐ Not Applicable)** NR PCS9611

☐ To reset LED & LCD message, press & hold [ADJUST/ESC] and then [MENU/ENT] buttons.

Phase angles of voltages and currents for injection test:

| Phase Faults | | | | | Earth Fault (L1-ph) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Voltage applied | Current applied | | | | Voltage applied | Current applied | | | |
| | ☐ RCA = +45° | | ~~☐ RCA = +30°~~ | | | ☐ RCA = -45° | | ~~☐ RCA = -14°~~ | |
| | FWD | REV | ~~FWD~~ | ~~REV~~ | | FWD | REV | ~~FWD~~ | ~~REV~~ |
| 63.5∠0° | IL1∠-45° | IL1∠135° | ~~IL1∠-60°~~ | ~~IL1∠120°~~ | 50∠0° | IL1∠-45° | IL1∠135° | ~~IL1∠-76°~~ | ~~IL1∠104°~~ |
| 63.5∠-120° | IL2∠-165° | IL2∠15° | ~~IL2∠-180°~~ | ~~IL2∠0°~~ | 63.5∠-120° | IL2= 0 | IL2= 0 | ~~IL2= 0~~ | ~~IL2= 0~~ |
| 63.5∠-240° | IL3∠-285° | IL3∠-105° | ~~IL3∠-300°~~ | ~~IL3∠-120°~~ | 63.5∠-240° | IL3 =0 | IL3 =0 | ~~IL3 =0~~ | ~~IL3 =0~~ |

**6. DOCEF Forward (I> and I0> Elements) Setting Test (☐ Not Applicable)** Alstom KCEG

| Phase under test | Applied Voltages and Currents | | | | | | |
|---|---|---|---|---|---|---|---|
| | VL1 | VL2 | VL3 | Injection current angle at different char. angles | | | |
| | | | | ☐ CA = +45° | ☐ CA = +30° | ☐ CA = -45° | ☐ CA = -14° |
| L1 | 63.5∠0° | 63.5∠-120° | 63.5∠-240° | IL1∠-45° | IL1∠-60° | - | - |
| L2 | 63.5∠0° | 63.5∠-120° | 63.5∠-240° | IL2∠-165° | IL2∠-180° | - | - |
| L3 | 63.5∠0° | 63.5∠-120° | 63.5∠-240° | IL3∠-285° | IL3∠-300° | - | - |
| EF | 0∠0° | 63.5∠-120° | 63.5∠-240° | - | - | IL1∠-45° | IL1∠-14° |

# Injection for Maintenance Test

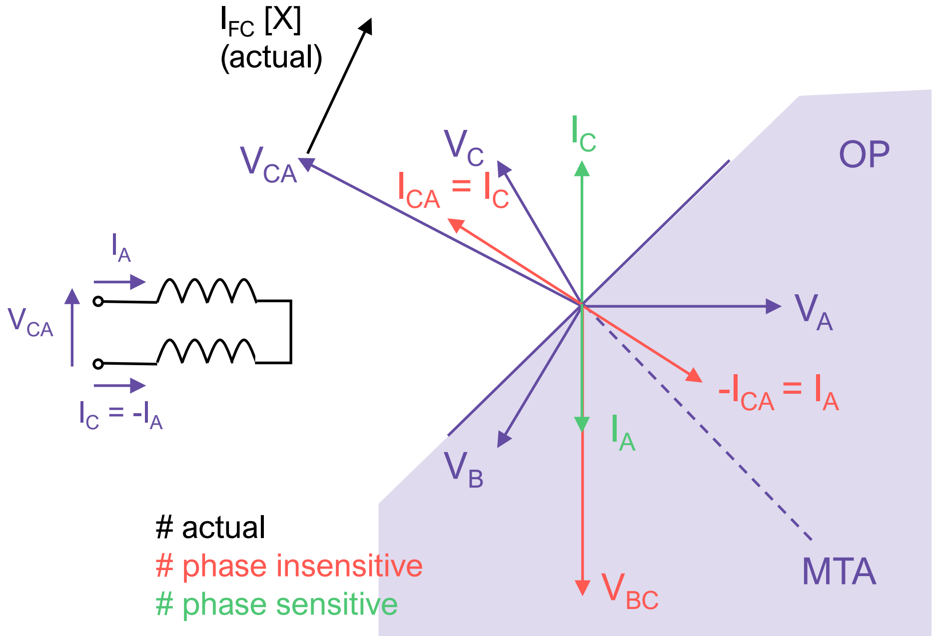
**Remarks** –
With phase insensitive voltage input, flipping voltage input does not trigger negative direction.

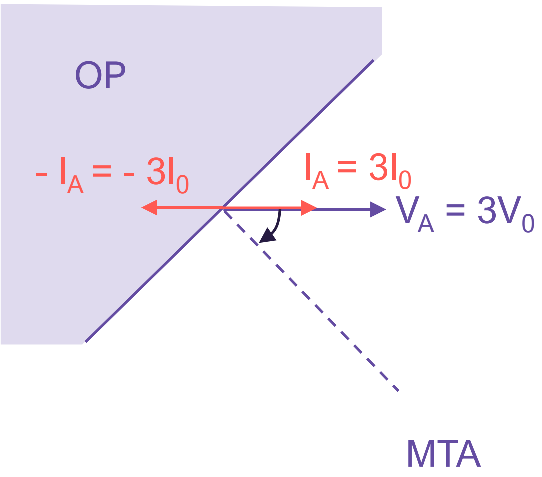
- Injection with SVERKER 750 (Single Phase Injection Set)

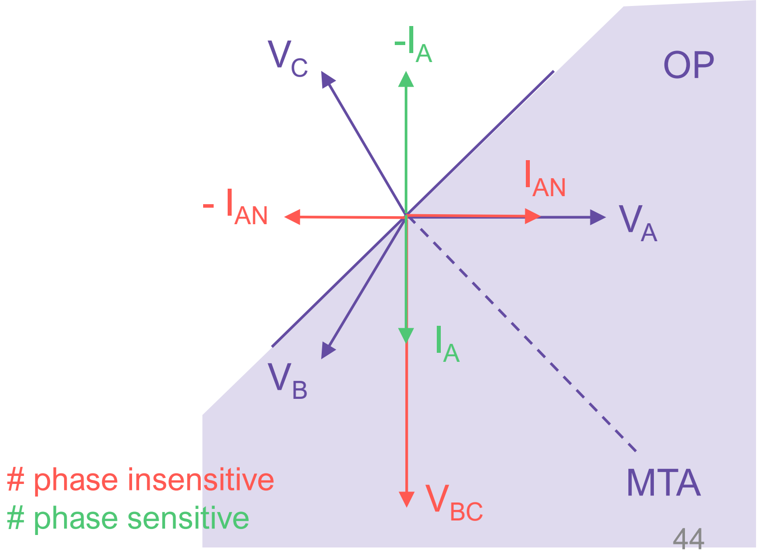
| Voltage Injected | Current Injected |
|---|---|
| AB | BC |
| BC | CA |
| CA | AB |
| AN | AN |

| Voltage Injected | Current Injected |
|---|---|
| AB | CN |
| BC | AN |
| CA | BN |
| AN | AN |

Shorted to 4-short at BBP DOC Test Block

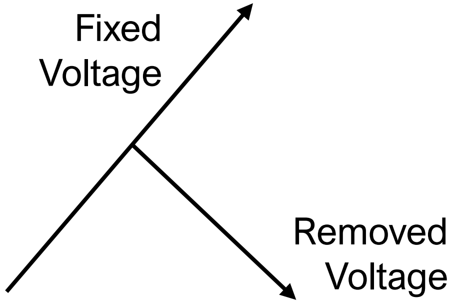


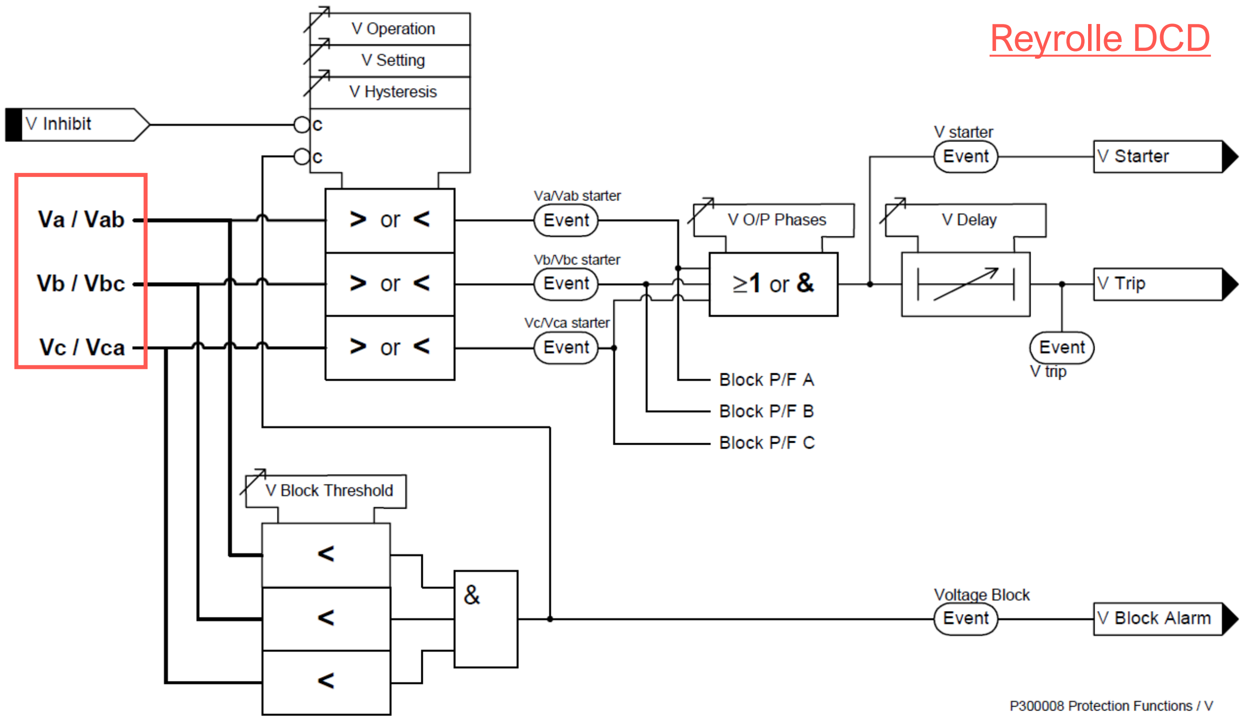



# Undervoltage Element for VTS

Reyrolle DCD




Phase Voltage + Line Voltage Detection




**9. Under-Voltage (U/V) Test (☐ Not Applicable)**

- ☐ Set 3-ph balance voltage =63.5V.
- ☐ Decrease and increate the voltage to check the U/V pickup and drop off va
- ☐ # Turn on Under-Voltage protection.
- ☐ Switch one phase voltage from 63.5V to 0V to check the operating time.

| Phase | Voltage setting | Time Delay | * Pickup Voltage | * Drop Off Voltage | LED | ## LCD | Injected voltage | ** Op. time |
|---|---|---|---|---|---|---|---|---|
| Va | | | V | V | ☐ TRIP = On | ☐ 'date' 'time'<br>☐ TRIP A | Va = 0V<br>Vb = 63.5V<br>Vc = 63.5V | |
| Vb | | | V | V | ☐ TRIP = On | ☐ 'date' 'time'<br>☐ TRIP B | Va = 63.5V<br>Vb = 0V<br>Vc = 63.5V | |
| Vc | | | V | V | ☐ TRIP = On | ☐ 'date' 'time'<br>☐ TRIP C | Va = 63.5V<br>Vb = 63.5V<br>Vc = 0V | |
| Va,b,c | N.A. | N.A. | N.A. | N.A. | ☐ TRIP = Off | ☐ No indication | Va = 0V<br>Vb = 0V<br>Vc = 0V | ☐ No TRIP |
| ☐ Output contacts < 0.5Ω. Record results in Step 9. | | | | | | | | |

Injected Voltage NOT required to have phase difference.
[i.e. short 1ϕ voltage to all 3ϕ]

3 phase VT loss possibly due to MCB trip does not have alarm (DCD)

# Loss of DOCEF due to Parallel Fuse Blown under Faulted Condition

17/10/2023 **Faulted Cable**

- BU DEF/OOC alarm for PCH Tx H2 activated at the same time with FNL-QUH RMU No.1 cable circuit fault. After site investigation, it was found that the VT supply fuses (L1, L2) for 11kV DOCEF relay KCEG was blown.

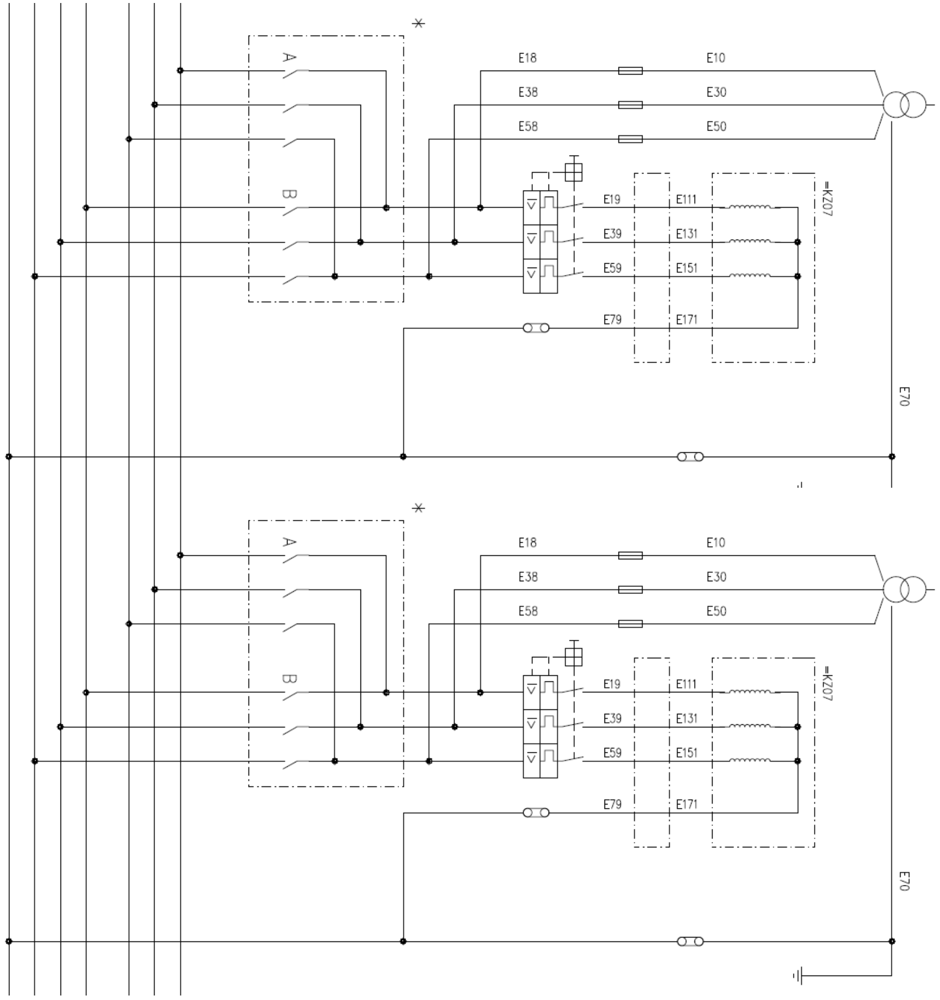
23/10/2023 **Upon Energization**

- PCH011 Tx H1 backup protection defective alarm was activated on 23 October 2023 at 00:25 hours during the circuit energisation. Site investigation revealed that VT secondary fuse (L3) was blown. After replacing the fuse, the alarm was restored to normal.

IPACS substation (e.g. HLY and PCH) includes a ring-loop voltage selection scheme to provide voltage for other panels' measurement. During parallel transformer condition, with any disturbance in grid, e.g. fault at 132kV, the voltage difference across the two paralleled VT on same loop would lead to fuse blown.

As DOCEF, a backup protection for reverse fault or failure in Intertripping facilities, obtains VT voltage from the ring loop, it experiences a VTS condition.

Suggestion – Separate DOCEF and IPACS Bay Module Fuse.



# Commissioning Test for Directional Element (DOCEF)

## COMMISSION TEST – DIRECTIONAL OC/EF

S834B (4/87)

| | |
|---|---|
| SUBSTATION | CLP S/S NO. |
| CIRCUIT | |

| SYSTEM VOLTAGE | SW. GR. PANEL NO. & CB NO. | RELAY PANEL NO. | SW. GR. MAKE & TYPE |
|---|---|---|---|
| 132 kV | 23 1 | 3U | FUJI/VCB |
| PRIMARY CURRENT | LOAD CONDITIONS | C. T. RATIO | V. T. RATIO |
| 630 A | ☑ IMPORT ☐ EXPORT<br>POWER FACTOR = | 2000/5 | 11000/110 |

| | TEST CONDITIONS | RELAY CURRENT (A) | | | RELAY VOLT (V) | | | DIRECTIONAL ELEMENT OPERATION * | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | R | W/EF | B | R | W/EF | B | R | W/EF | B |
| ON LOAD TEST – DOC | ALL CTs & VTs NORMAL | 0-7A | 2-3mA | 0-705A | 113 | 0-95 | 113-5 | Res | Res | Res |
| ON LOAD TEST – DOC | ONLY RCT REVERSED | 0-7A | 2-3mA | 0-705A | 113 | 0-095 | 113-5 | Op | Res | Res |
| ON LOAD TEST – DOC | ONLY WCT REVERSED | — | — | — | — | — | — | — | — | — |
| ON LOAD TEST – DOC | ONLY BCT REVERSED | 0-7A | 2-3mA | 0-705A | 113-0 | 0-095 | 113-5 | Res | Res | Op. |
| ON LOAD TEST – DEF ** | ALL CTs NORMAL | 2-35A | 9.5mA | 2-35A | 110-6 | 76.5 | 52-1 | Res | Res | Res |
| ON LOAD TEST – DEF | W Ø & B Ø CTs S/C<br>R Ø CT NORMAL | 2-3A | 2-3A | Trace | 110-6 | 76.5 | 52-1 | Res | Res | Res |
| ON LOAD TEST – DEF | W Ø & B Ø CT S/C<br>R Ø CT REVERSED | 2-3A | 2-3A | Trace | 110-6 | 76.5 | 52-1 | Op | Op | Res |
| FINAL STABILITY | | | | | | | | | | |
| | RESTORE VT FUSE, REMOVE TEMPORARY SHORT LINK & ALL CT TO NORMAL | 1.57A | 4mA | 1-57A | 113 | 0-09 | 113-5 | Res | Res | Res |

Reverse CT to trigger DIR + OC trip is required.

* For Directional Element Operation :

RES = RESTRAIN

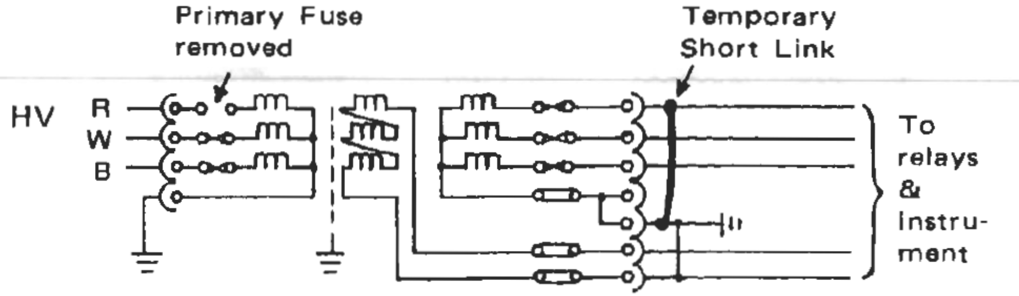
OP = OPERATION

** The procedure for checking the DEF relay are as follows :

a) Remove VT R Ø primary (HV) fuse.

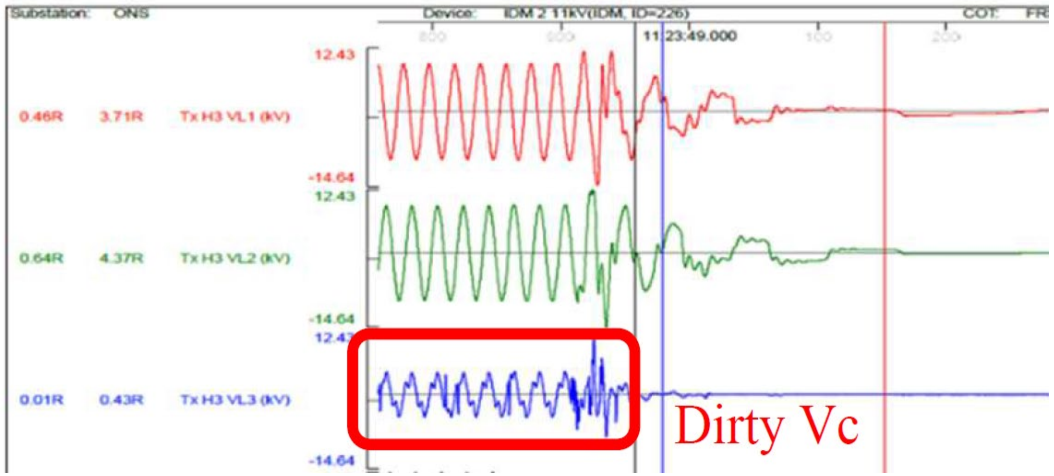
b) Short-circuit the VT R Ø main secondary winding on the load side of the secondary fuse.

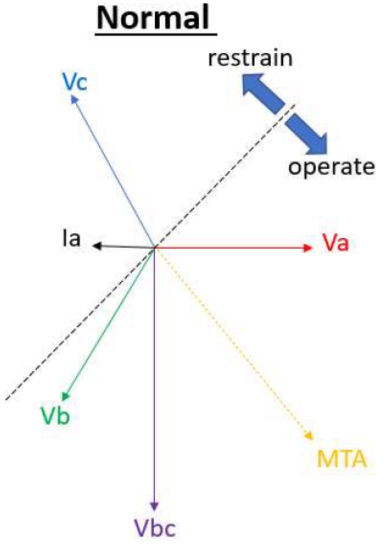
c) Carry out relay test with a primary current of 10% or more of the relay rating



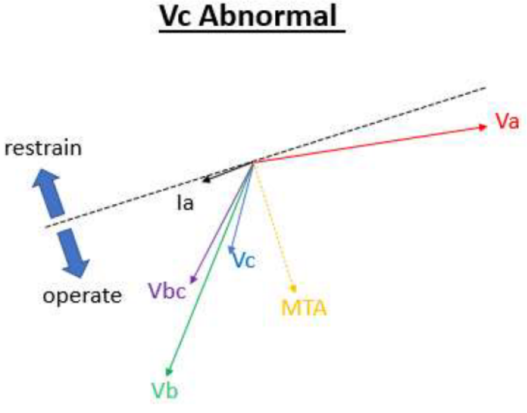
# ONS DOCEF due to VT Fuse Blown (POS385)

- Prior to the incident, HV VT fuse at ONS011 for Tx H3 was blown out and *to be* replaced under outage at midnight. At 19:24hrs, ONS 132/11kV Tx H3 tripped on DOCEF protection.
- From the event log, backup protection defective alarm, which was triggered by VTS, activated and resumed intermittently. It was verified that the relay detected dirty voltage with the L3 VT fuses nearly blown out.
  [Note – VTS does NOT block directional element]
- Owing to the abnormality in L3 voltage, the forward region of directional element would be shifted accordingly. With load current of around 1500A and forward direction detected, the DOC element would therefore operate as designed.
- Recommendation - DOCEF relay should be <u>defeated</u> if voltage signal in dirty with significant magnitude.




$I_a$ in restrain region.
**Remain stable** under normal condition




$I_a$ marginally in operate region.
**Operate** under abnormal L3 voltage