Locating Multiphase, Multisection Faults in Capacitor Banks

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Outline

- Introduction
- SCB configuration
- SCB protection
- SCB fault location
  - Single-phase SCB fault location
  - Multiphase, multisection fault location (MMFL) for SCBs
  - Simulation results

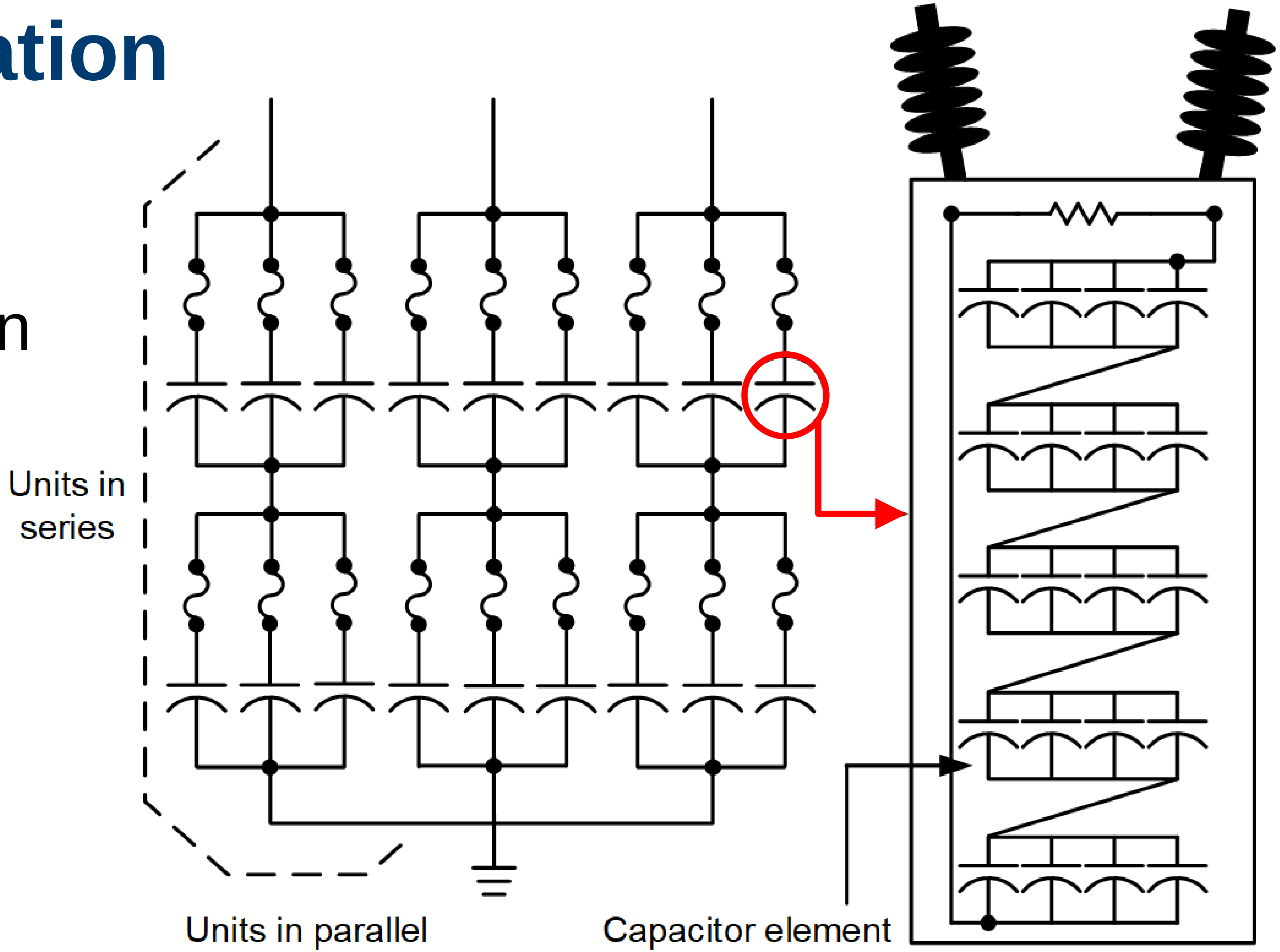
Introduction

Why SCB?

- Delivery of efficient power
- Availability near load
- Economic benefits

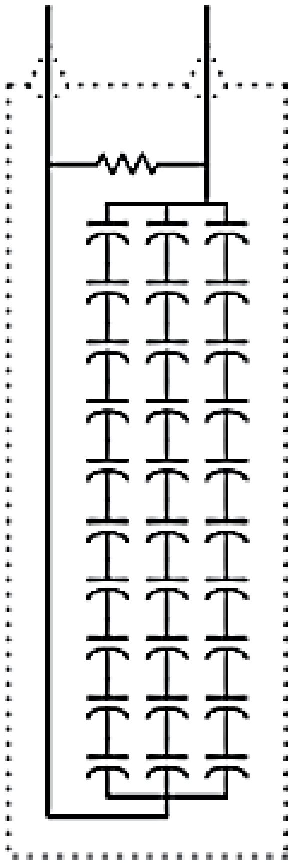
SCB configuration

- SCB design
- SCB configuration
- Fusing

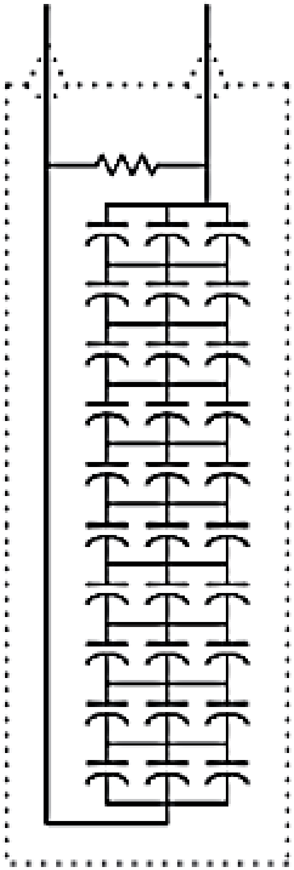


SCB configuration

Series connection

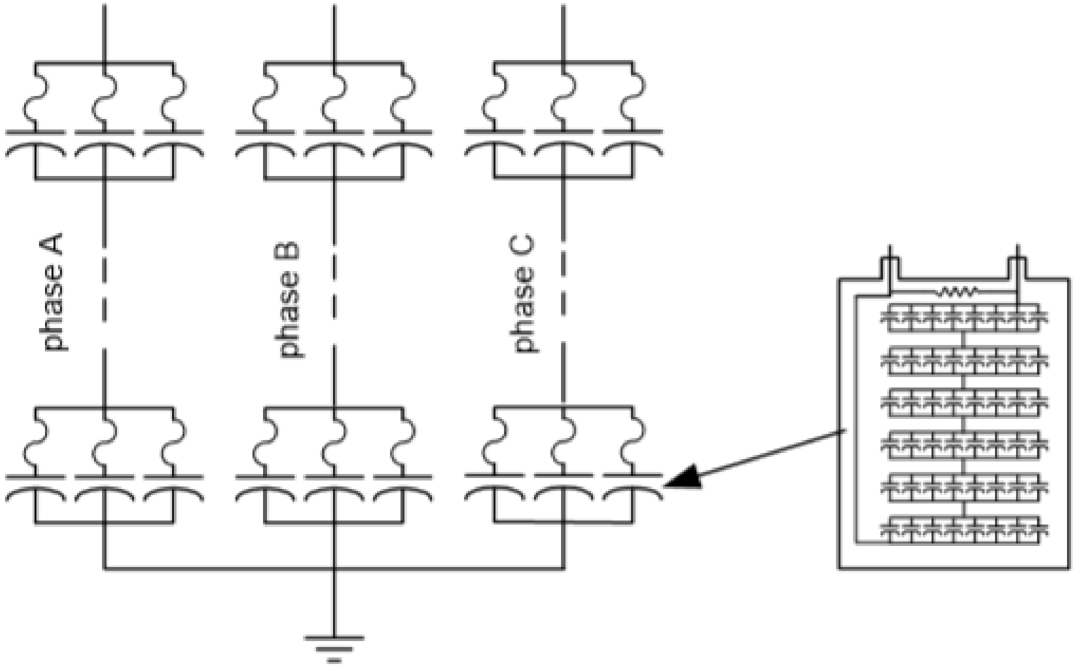


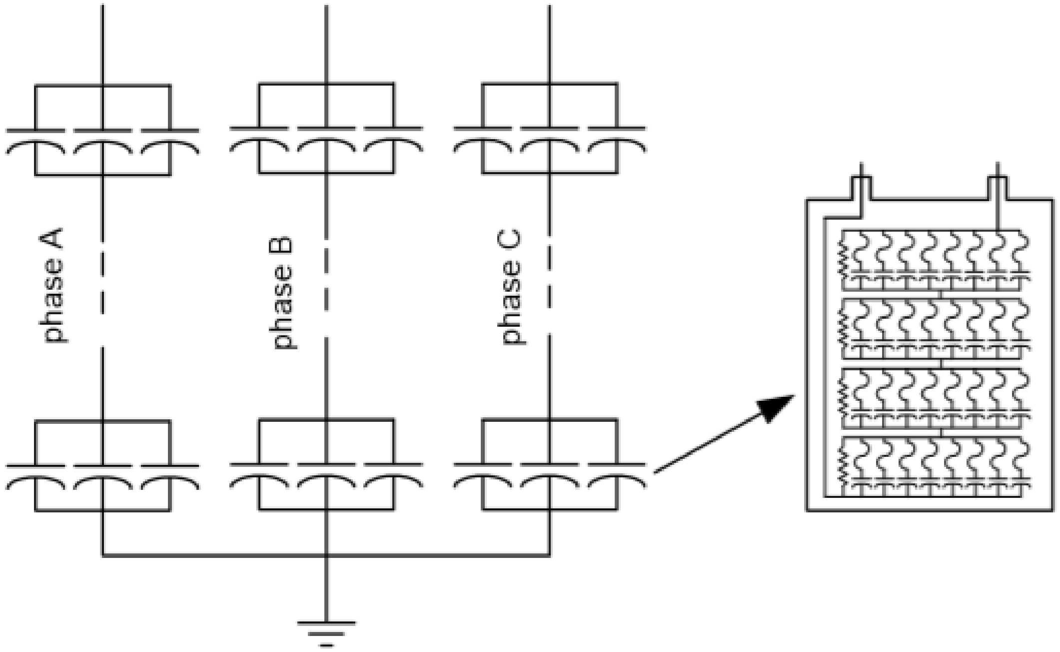
Parallel connection



SCB configuration

- Fused
  - Externally fused
  - Internally fused
- Fuseless



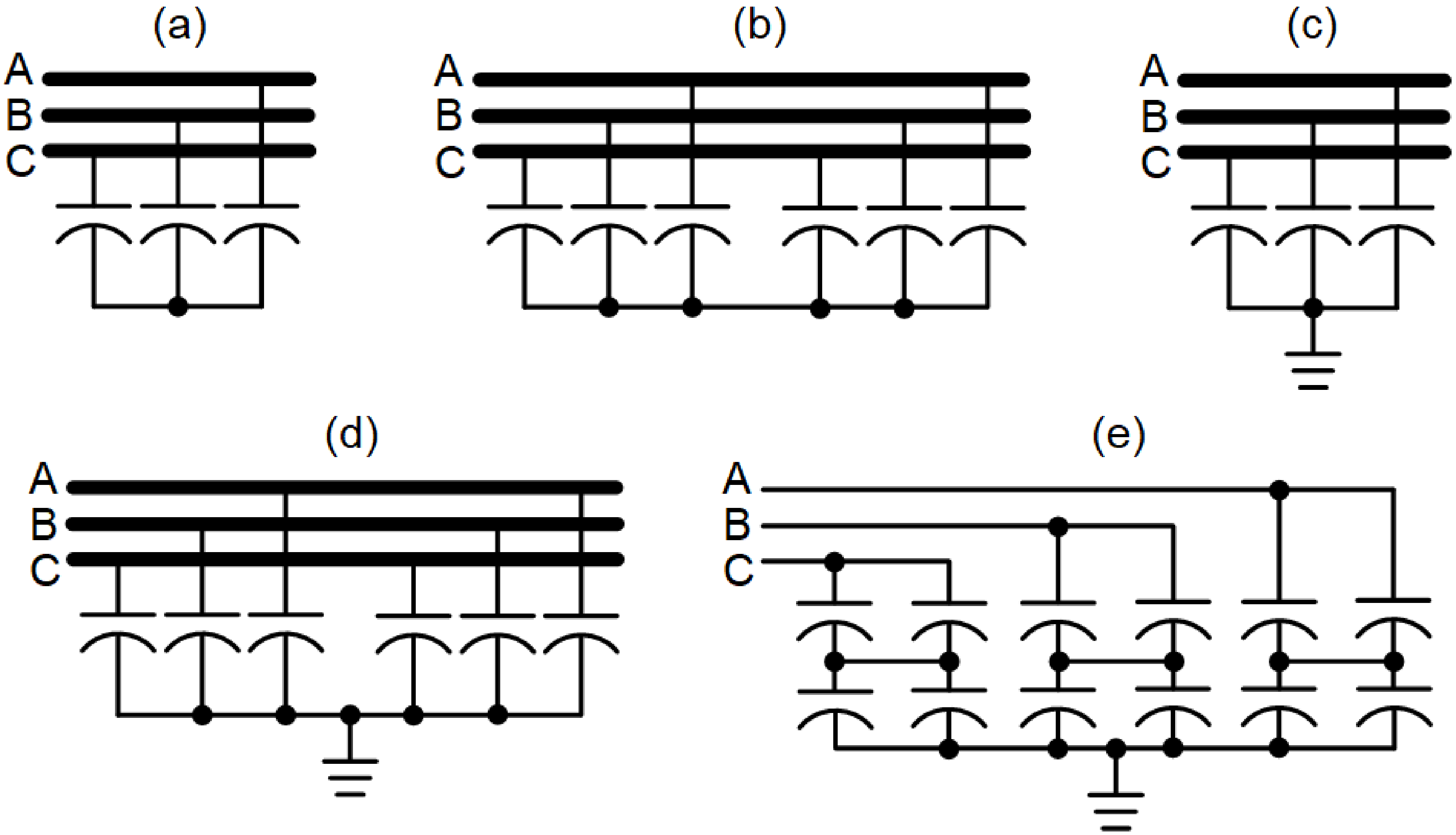


SCB protection

- Capacitor bank protection connections
- Bank protection
  - Protection through fuse
  - Protection through SCB unbalance conditions

SCB protection

Protection connections



SCB protection

Bank protection

- Protection through fuse
- Protection through SCB unbalance conditions
  - Phase voltage unbalance
  - Neutral voltage unbalance
  - Phase current unbalance
  - Neutral current unbalance

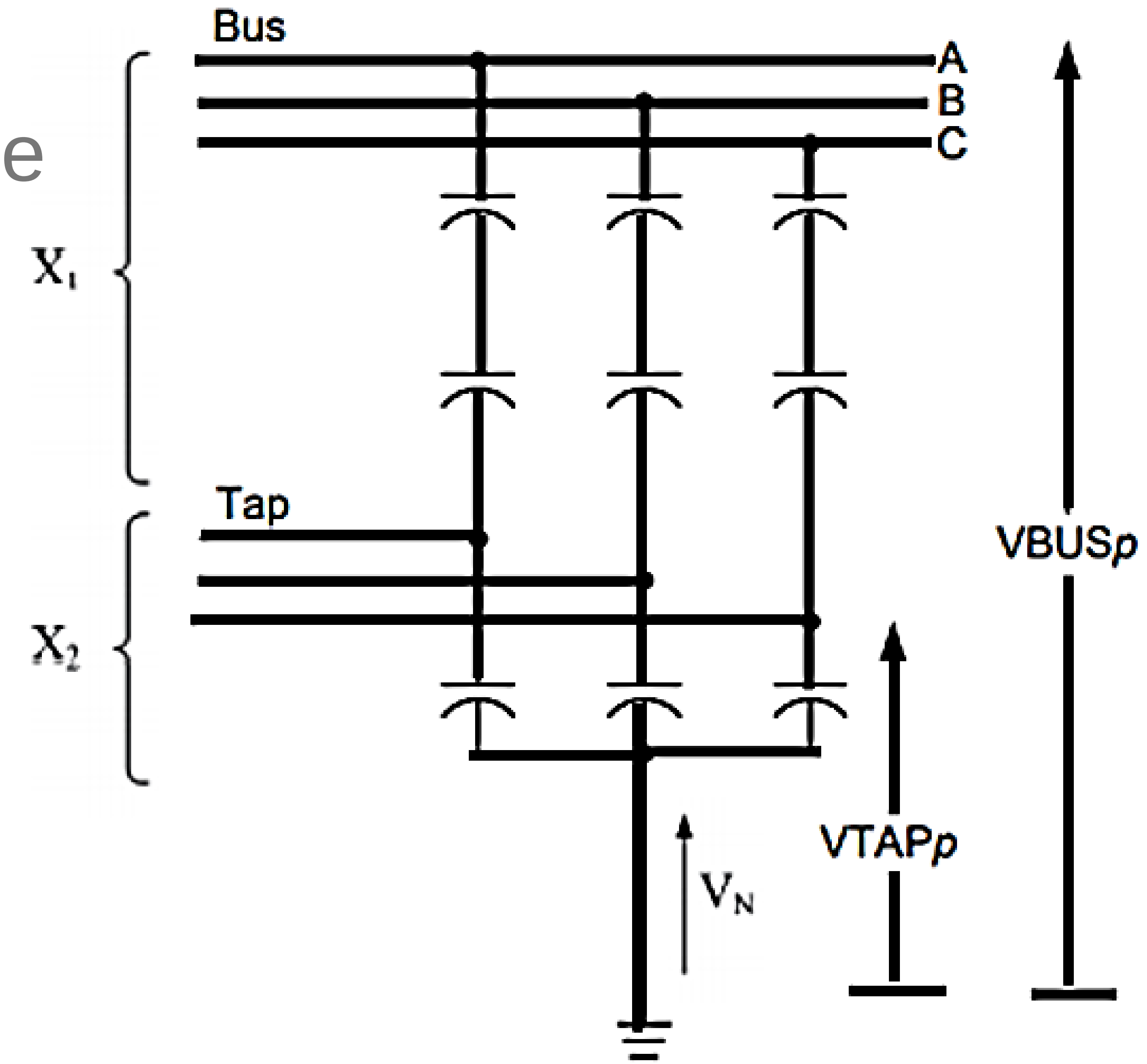
SCB protection

Phase voltage unbalance

$$\frac{V_{TAP} - V_N}{V_{BUS} - V_N} = \frac{X_2}{X_1 + X_2}$$

$$K = \frac{X_2}{X_1 + X_2}$$

$$DV = \left| V_{TAP} - K \bullet V_{BUS} \right|$$



SCB protection

Neutral voltage unbalance

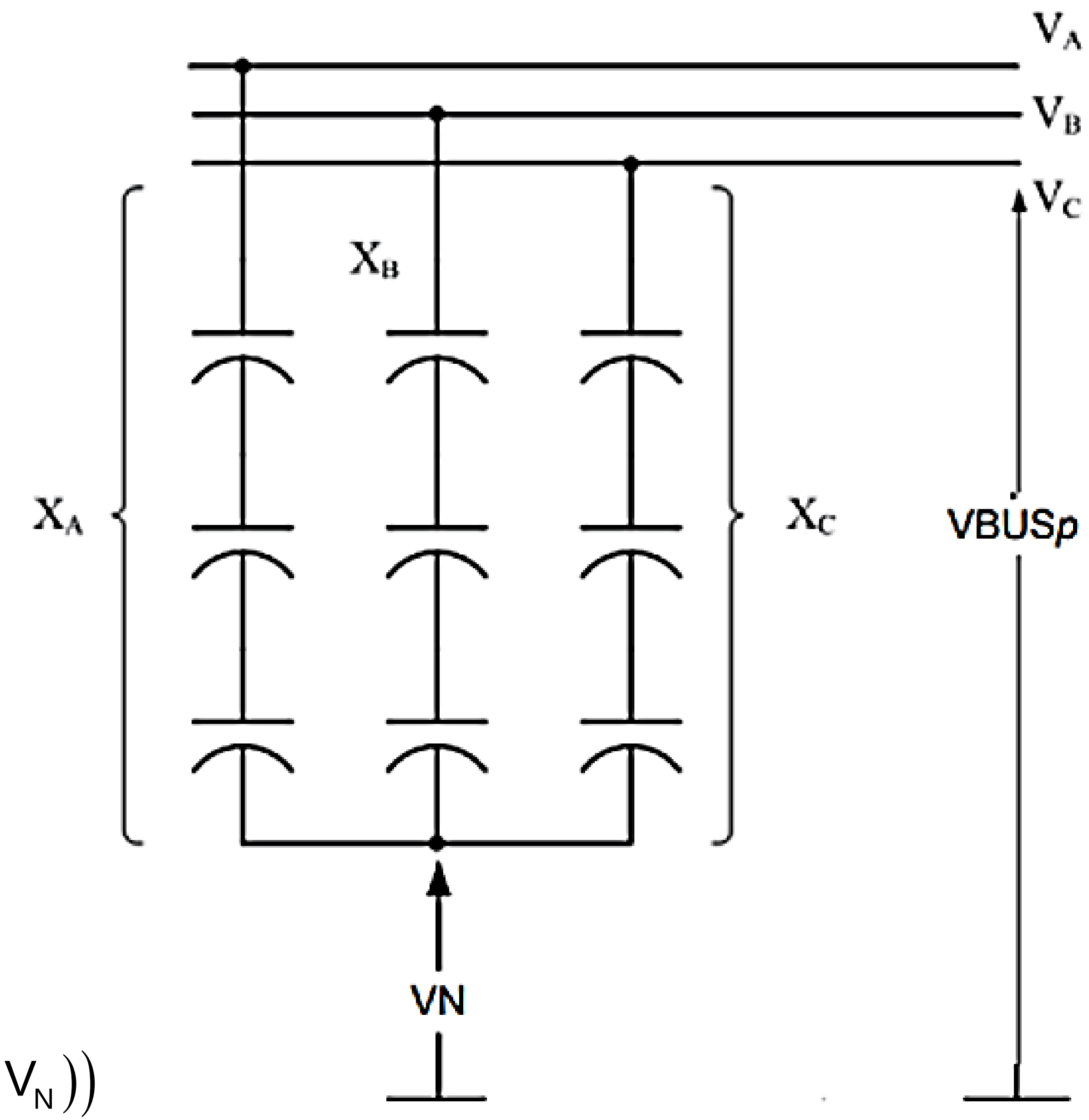
$$\frac{V_A - V_N}{-j_X \bullet X_A} - \frac{V_B - V_N}{-j_X \bullet X_B} - \frac{V_C - V_N}{-j_X \bullet X_C} = 0$$

$$\frac{V_A}{X_A} + \frac{V_B}{X_B} + \frac{V_C}{X_C} - V_N \bullet \left(\frac{1}{X_A} + \frac{1}{X_B} + \frac{1}{X_C} \right) = 0$$

$$\left(\frac{1}{X_A} + \frac{1}{X_B} + \frac{1}{X_C} \right) = \frac{3}{X_A}$$

$$3 \bullet V_0 - 3 \bullet V_N = 0$$

$$DVG = -3 \bullet V_0 - 3 \bullet V_N - \left(K1 \bullet \left(V_B - V_N \right) + K2 \bullet \left(V_C - V_N \right) \right)$$



SCB protection

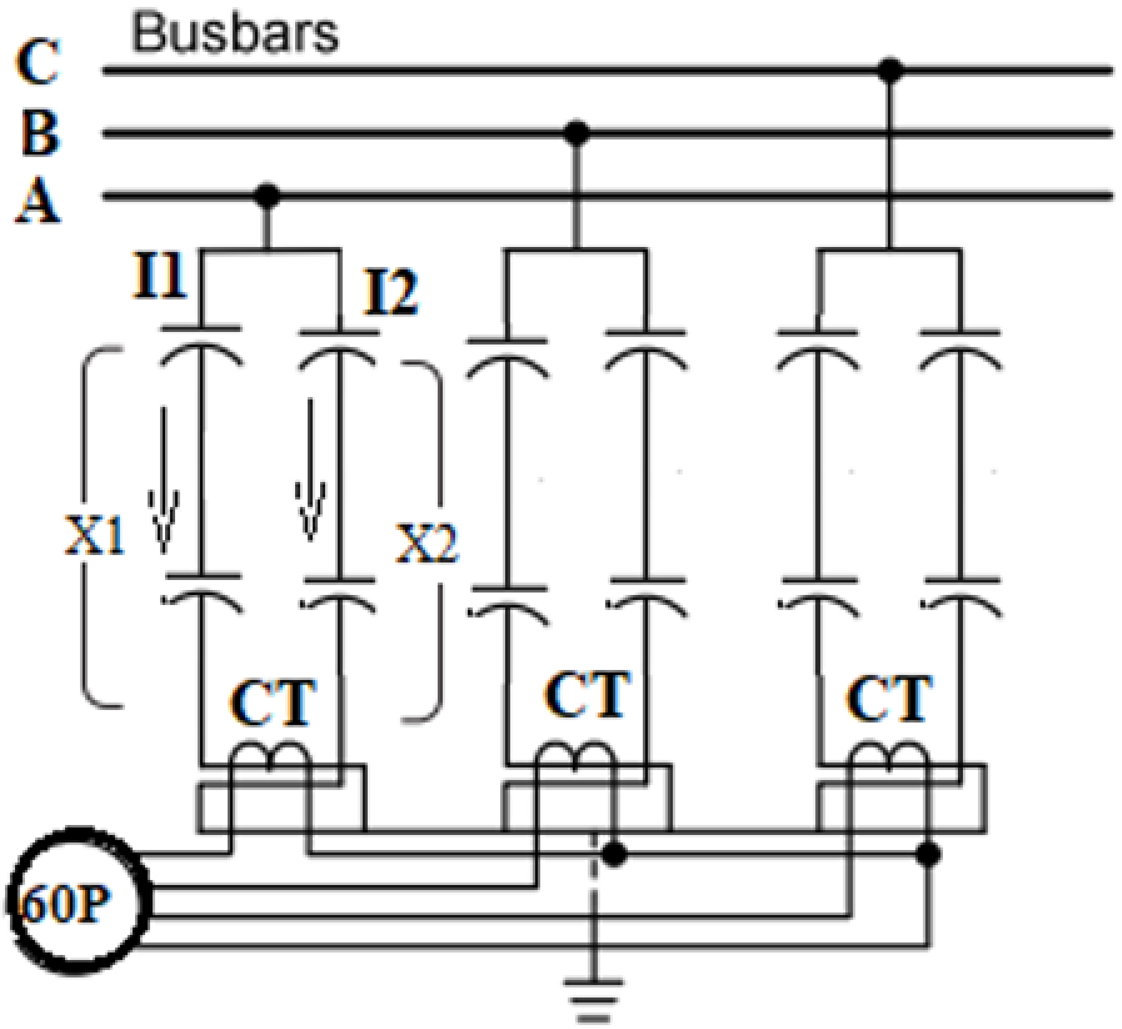
Phase current unbalance

$$I_1 = \frac{V_{BANK}}{-j_X \bullet X_1} \quad \text{and} \quad I_2 = \frac{V_{BANK}}{-j_X \bullet X_2}$$

$$I_{DIF} = \frac{V_{BANK}}{-j_X \bullet X_1} - \frac{V_{BANK}}{-j_X \bullet X_2}$$

$$\text{If we let } K = \frac{X_2 - X_1}{X_2 + X_1}$$

$$60P = \left| I_{DIF} - K \bullet I_{BANK} \right|$$

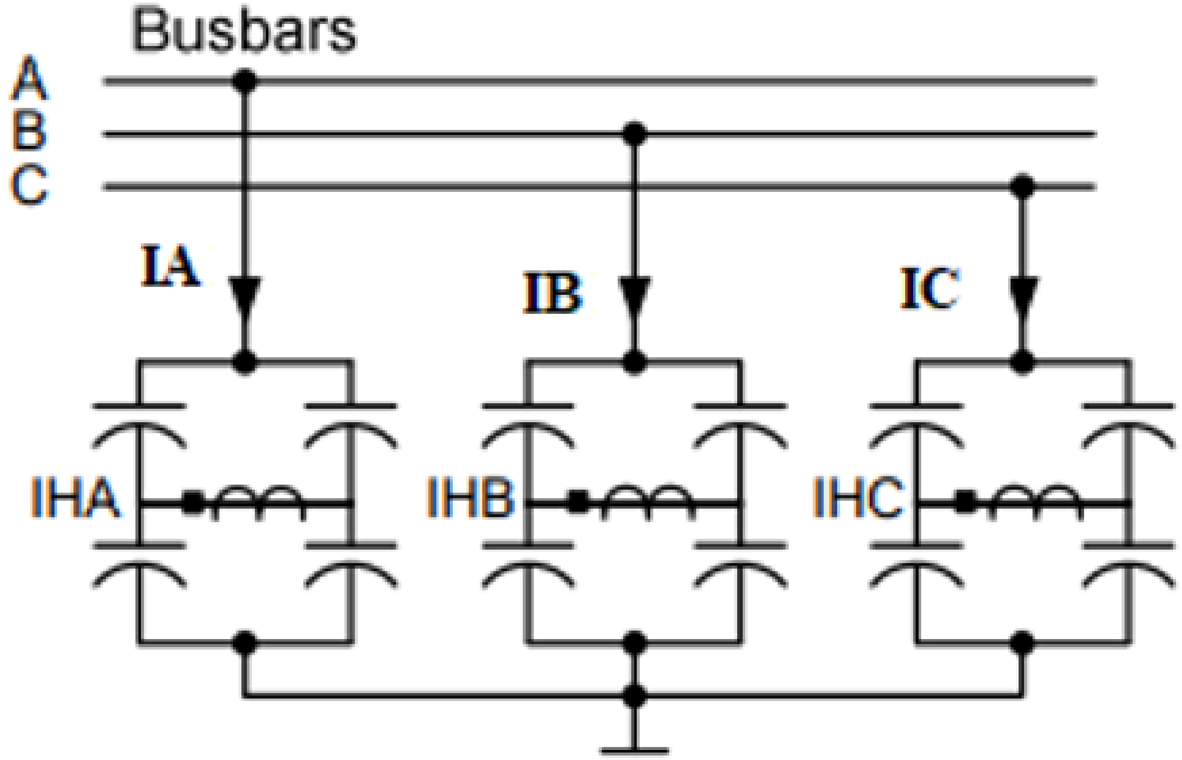


SCB protection

Phase current unbalance

H-bridge bank using phase current unbalance protection

$$60P = \left| I_{HA} - K_A \bullet I_A \right|$$



SCB protection

Neutral current unbalance

$$I_{DIFA} = K_a \bullet I_a$$

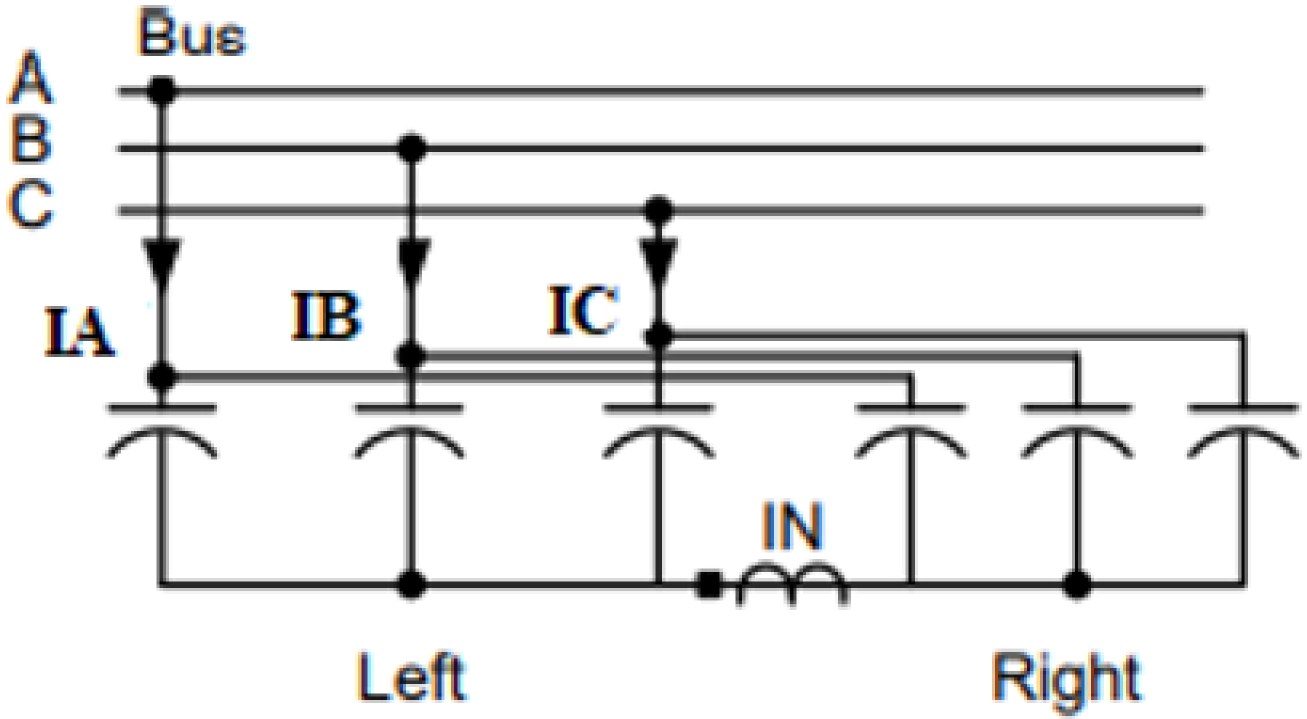
$$I_{DIFB} = K_b \bullet I_b$$

$$I_{DIFC} = K_c \bullet I_c$$

$$I_a + I_b + I_c = 0$$

$$I_a = -\left(I_b + I_c\right)$$

$$60_N = I_N - \left(K_1 \bullet I_B + K_2 \bullet I_C\right)$$



SCB fault location

Steps to put bank back in service

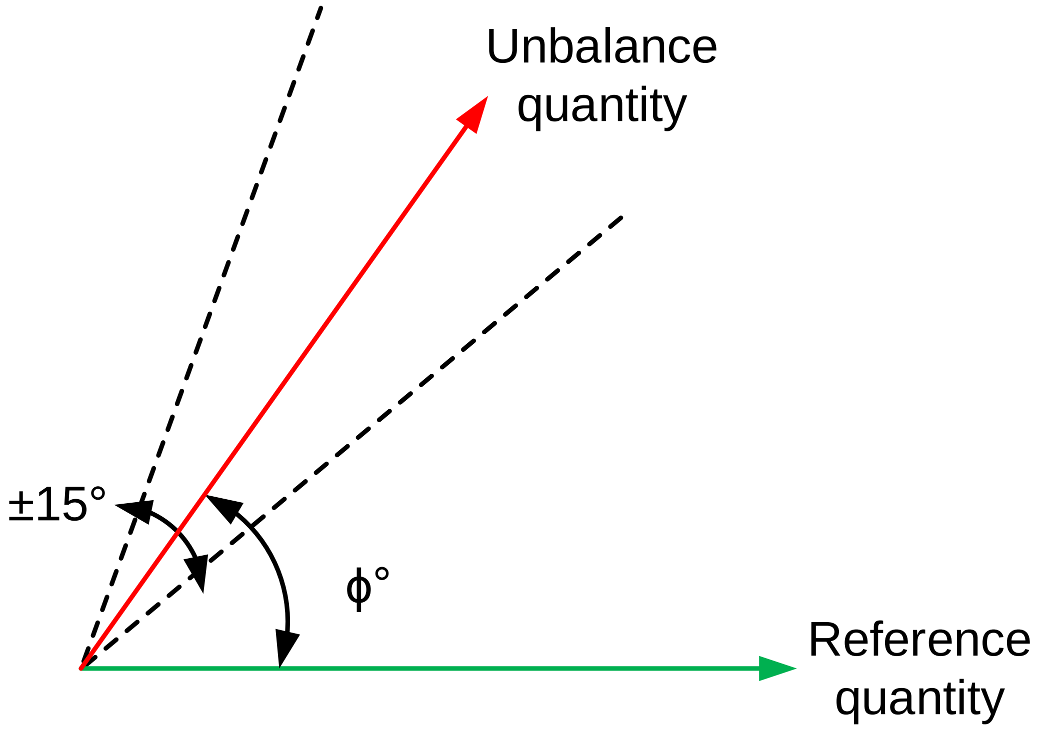
- Take bank out of service
- Isolate and ground bank
- Disconnect each unit
- Measure capacitance across each unit
- Replace faulty unit
- Balance bank
- Energize bank

Advantages of fault location technique

- Has minimal outage time – by identifying phase and section
- Is economical – embedded in protection
- Is versatile – can be applied to wide range of bank configurations

Fault location technique

- Unbalance protection uses measured quantities from instrument transformers to calculate unbalance quantity
- Unbalance quantity is phasor
  - Magnitude
  - Phase angle



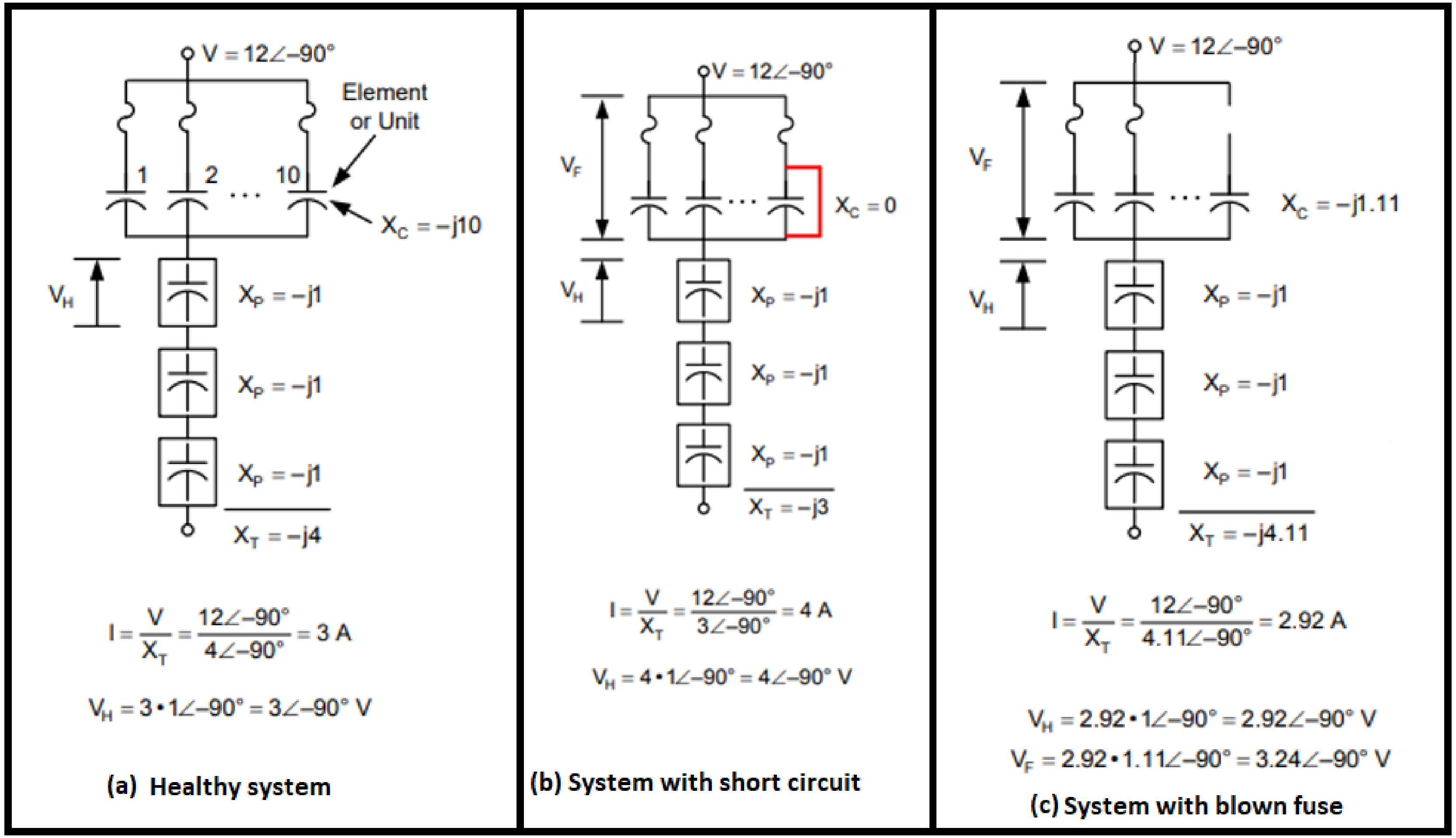
Fault location technique

- Is supervised by alarm or trip for sensitivity
- Has ±15° blinder applied for security
- Is immune to inherent unbalance
- Is affected by fusing method

Fault location method and impact of fusing

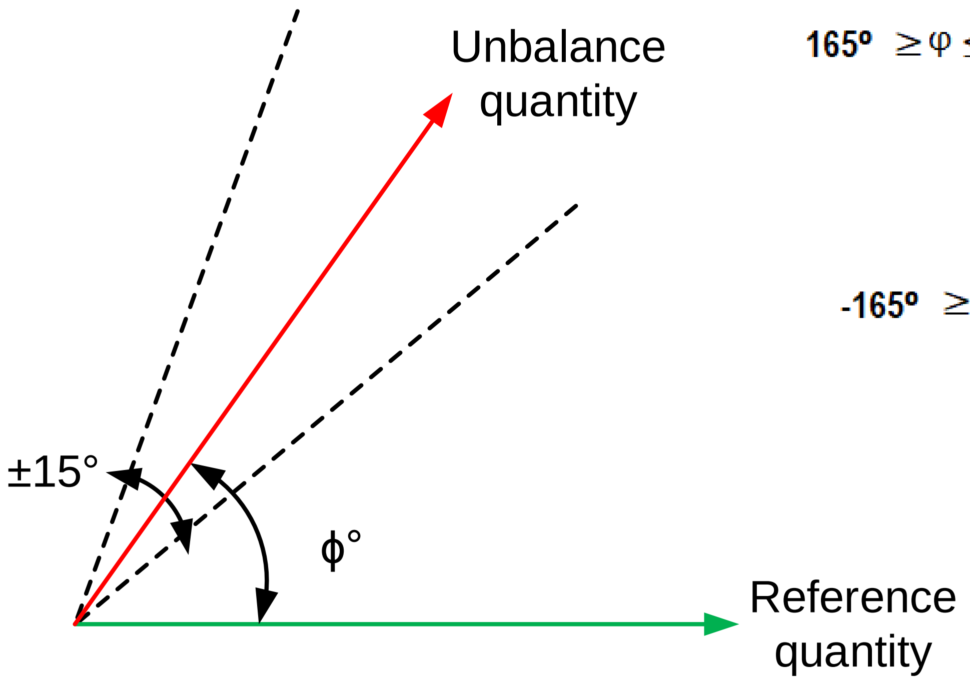
Fusing method affects fault location technique

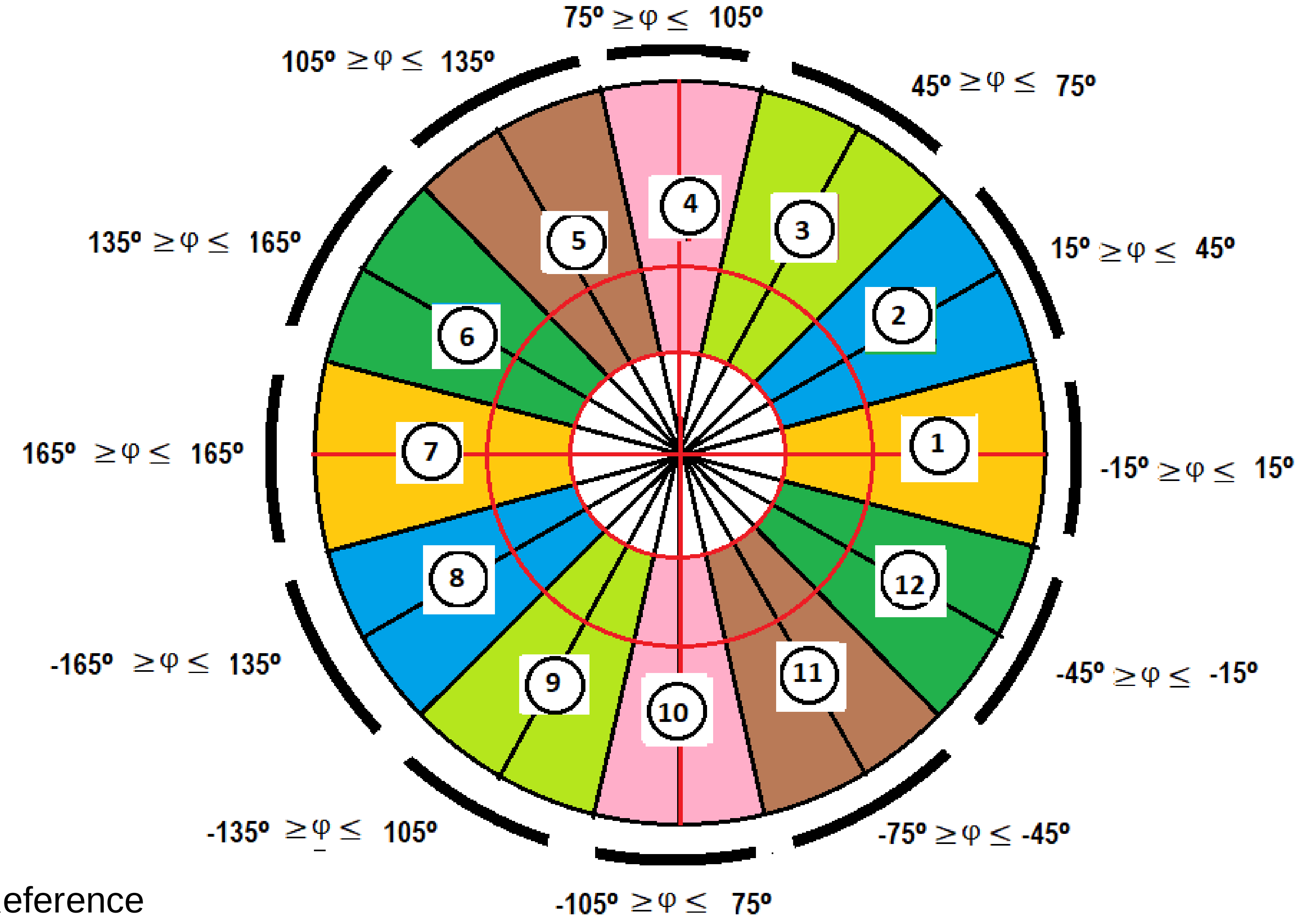
- Impedance
- Voltage
- Current



Fault location technique

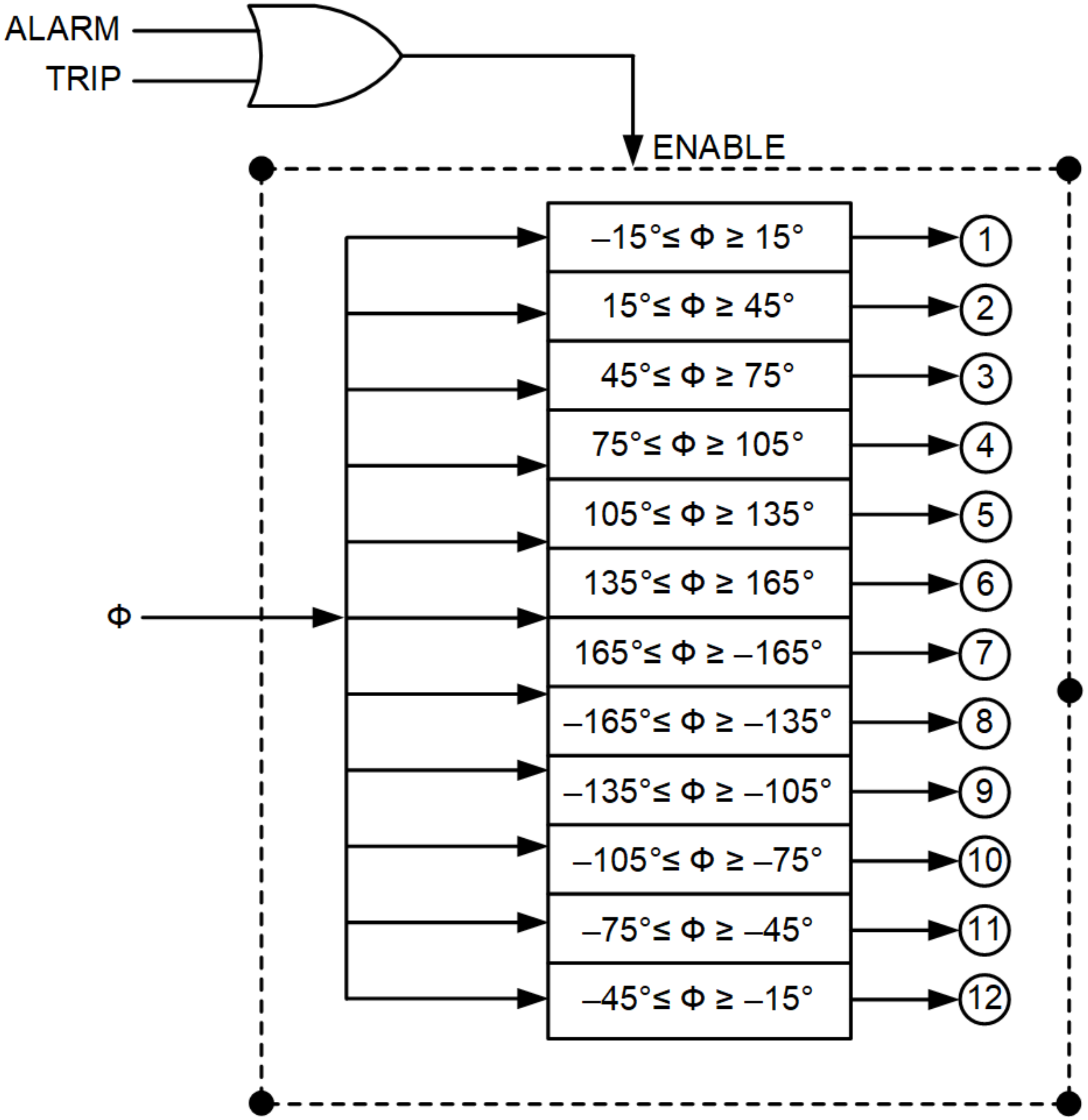
MMFL sectors





Fault location technique

MMFL sectors



Fault location technique

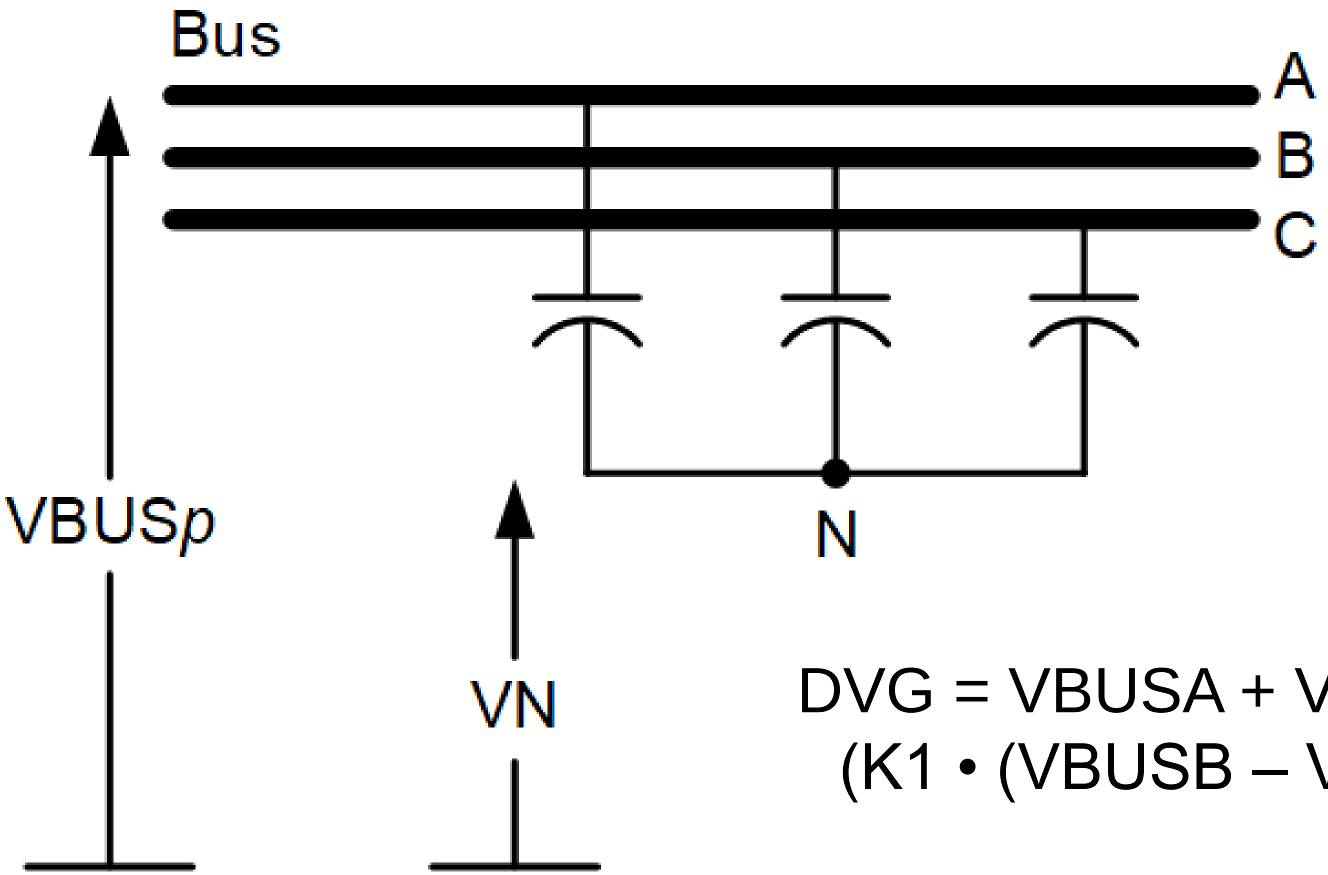
Existing

Single-phase SCB fault location

- Banks using neutral voltage unbalance protection
- Banks using neutral current unbalance protection

Neutral voltage unbalance protection

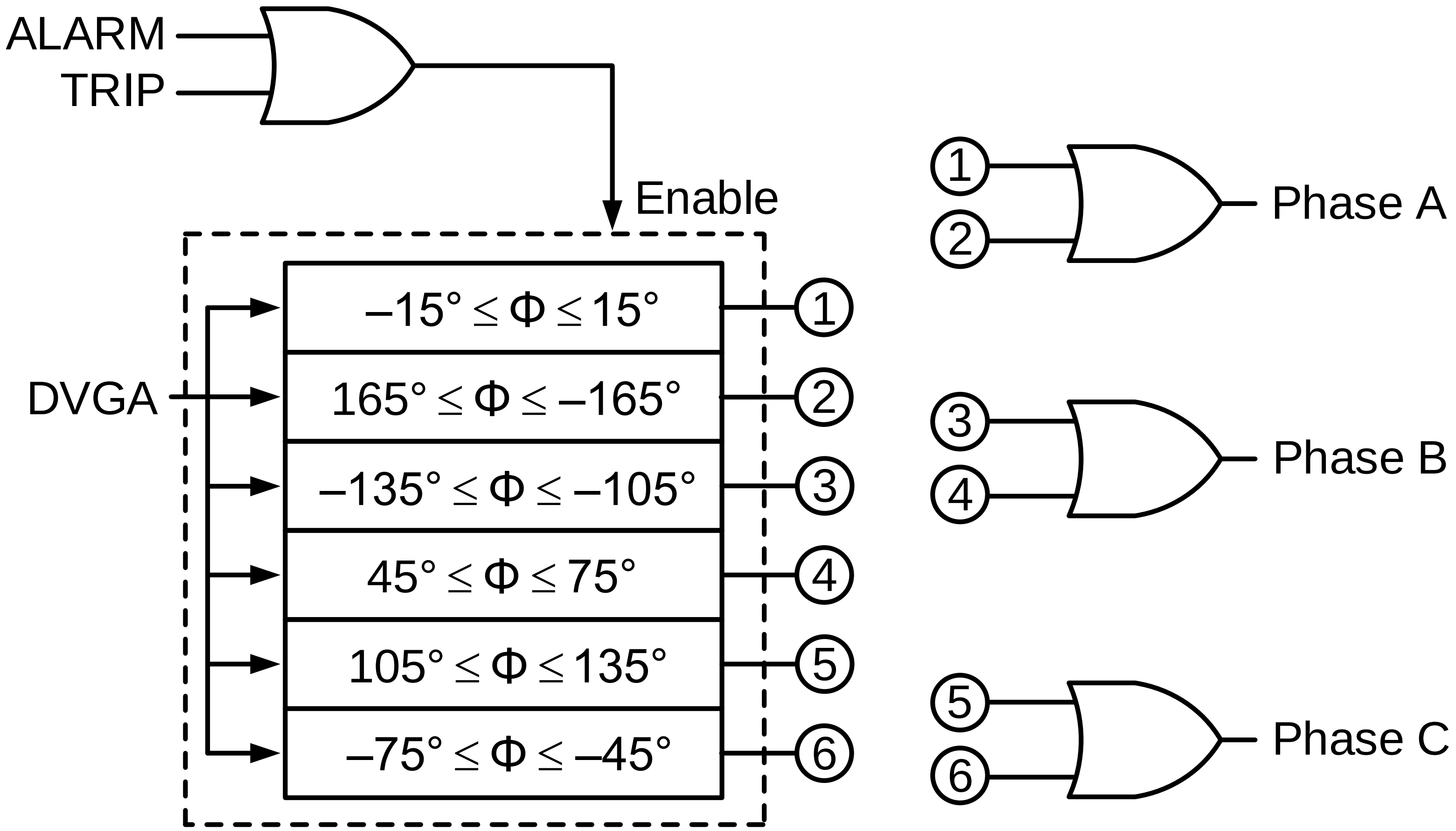
Single-wye bank



DVG = VBUSA + VBUSB + BVUSC – 3 • VN – (K1 • (VBUSB – VN) + K2 • (VBUSC – VN))

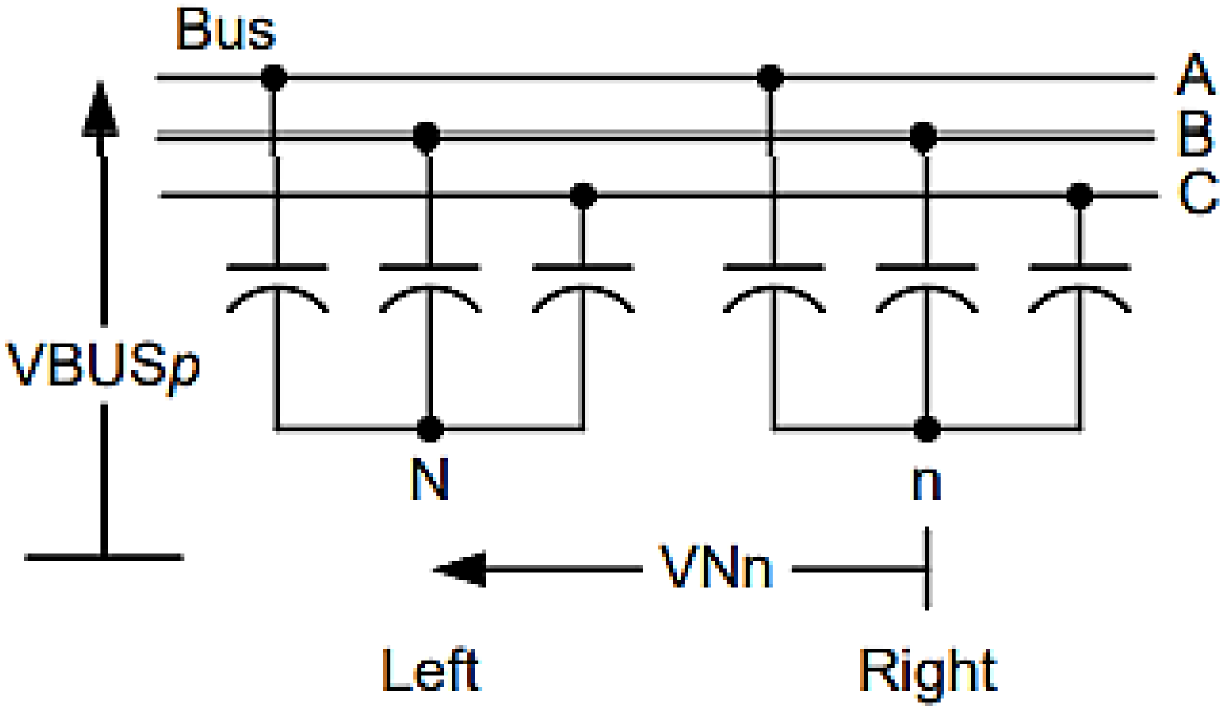
Fault location principle

Fault location for single-wye banks using neutral voltage unbalance protection



Neutral voltage unbalance protection

Double-wye bank

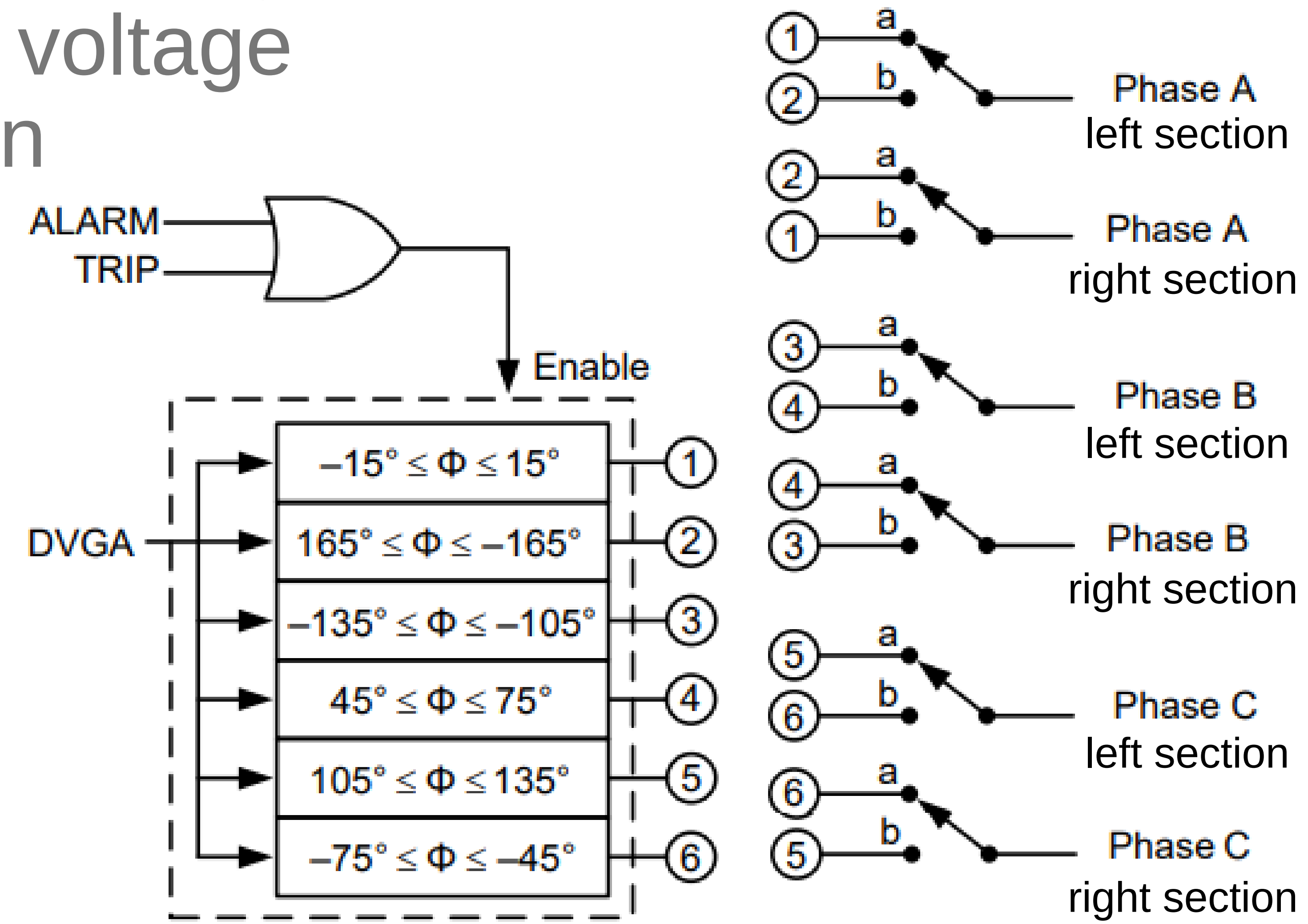


DVG = VNn – Kn • V1BUS

Fault location principle

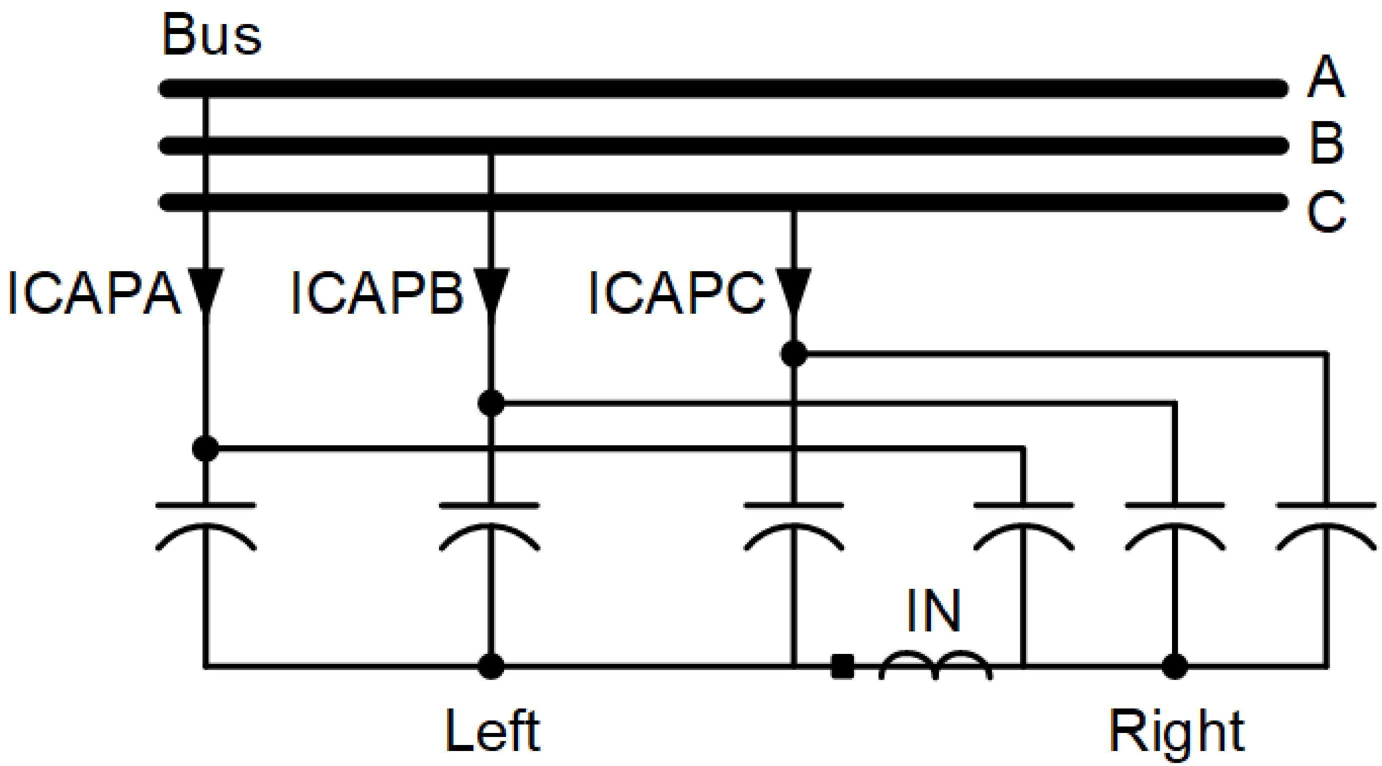
Fault location for double-wye banks using neutral voltage unbalance protection

Switch at the position a if bank is fuseless
Switch at the position b if bank is fused



Neutral current unbalance protection

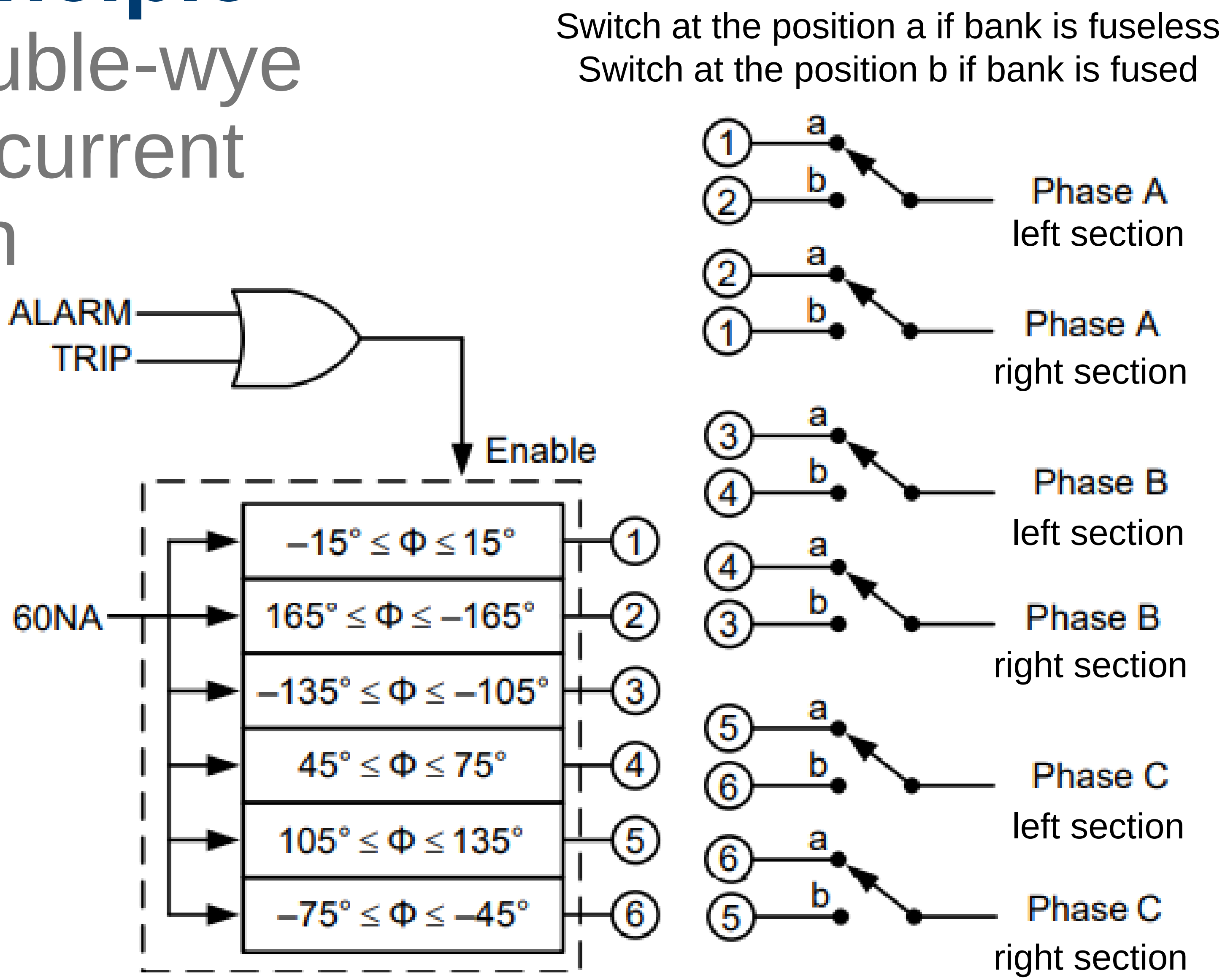
Double-wye bank



60N = IN – (K1 • ICAPB + K2 • ICAPC)

Fault location principle

Fault location for double-wye banks using neutral current unbalance protection

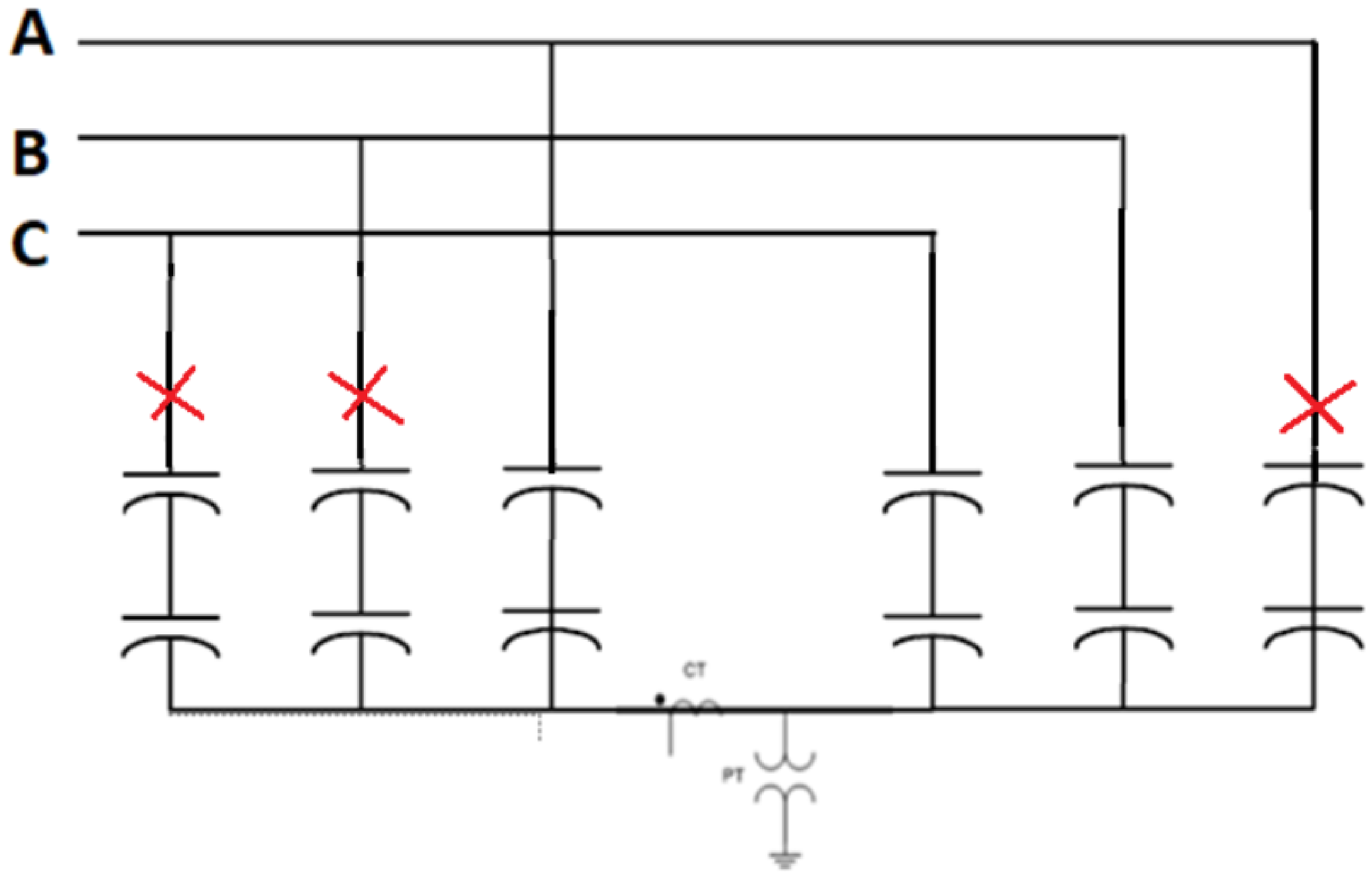


MMFL for SCBs

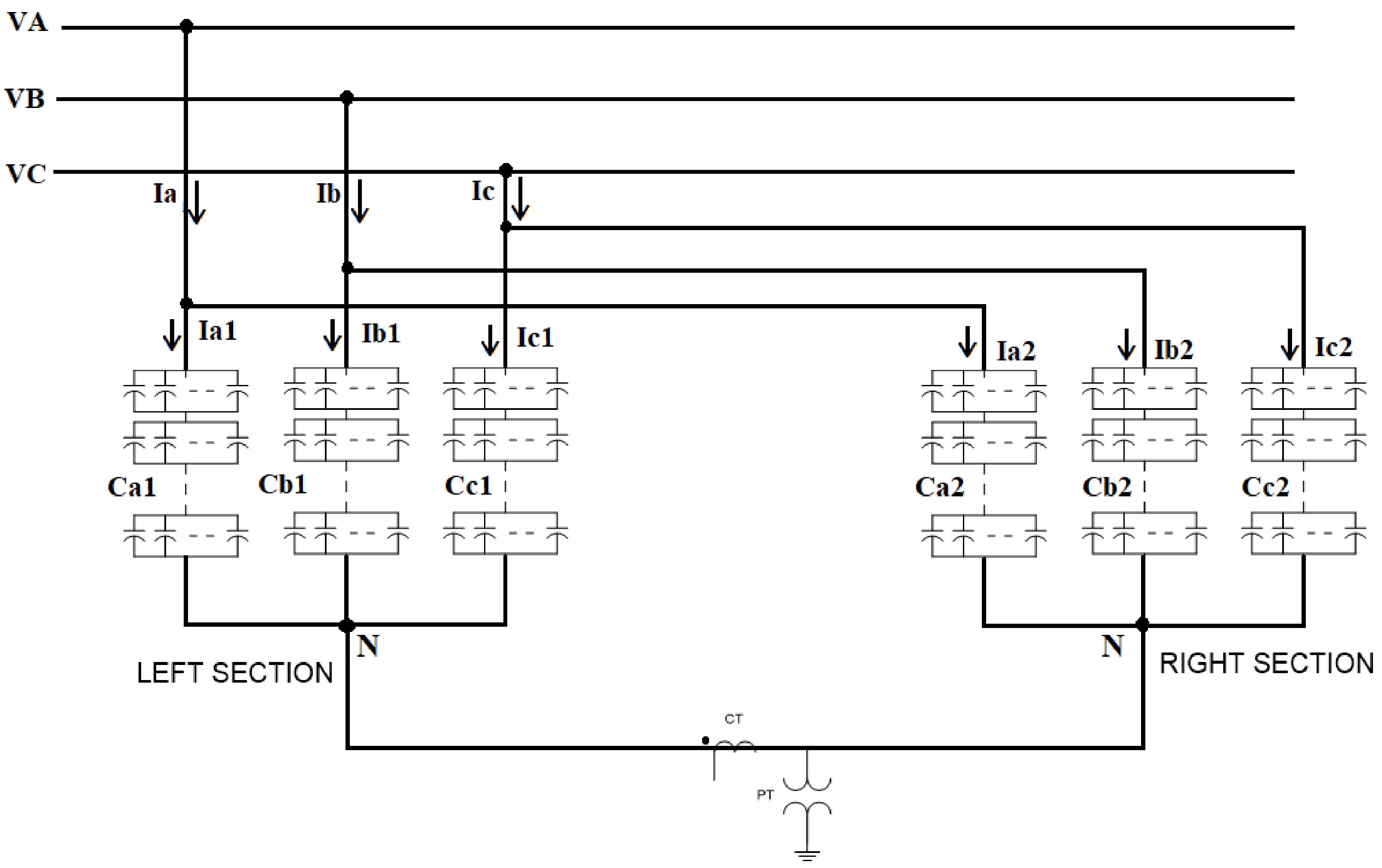
Why MMFL?

Single-phase fault location limitations

- Only fault at one phase is acknowledged
- Only fault in one section of double-wye is acknowledged



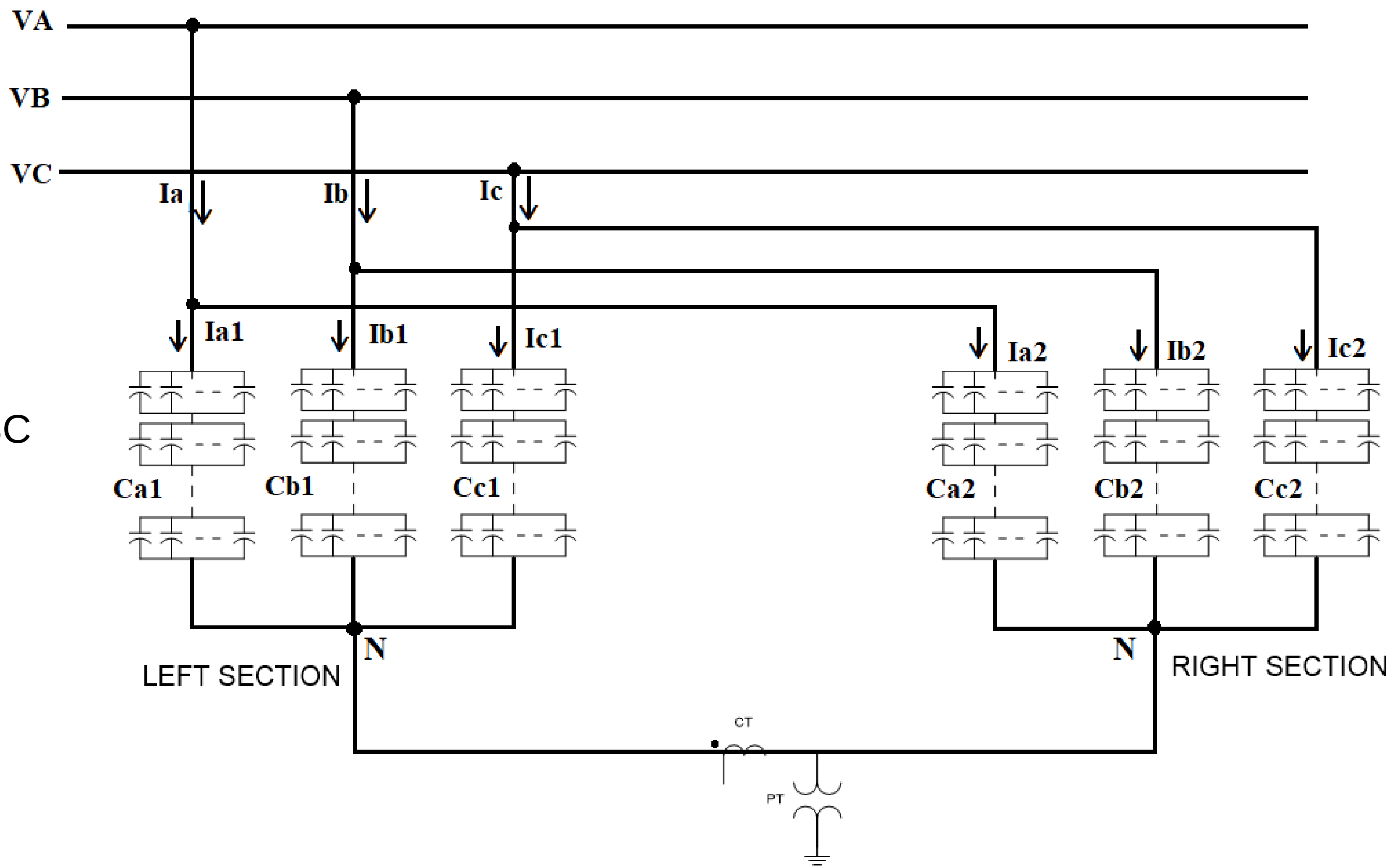
Proposed – MMFL for SCBs



Ungrounded double-wye bank using neutral voltage/neutral current unbalance protection

$60_N = I_N – (K_1 • I_B + K_2 • I_C)$

DVG = VBUSA + VBUSB + VBUSC – 3 • VN – (K_1 • (VBUSB – VN) + K_2 • (VBUSC – VN))



New solution – MMFL

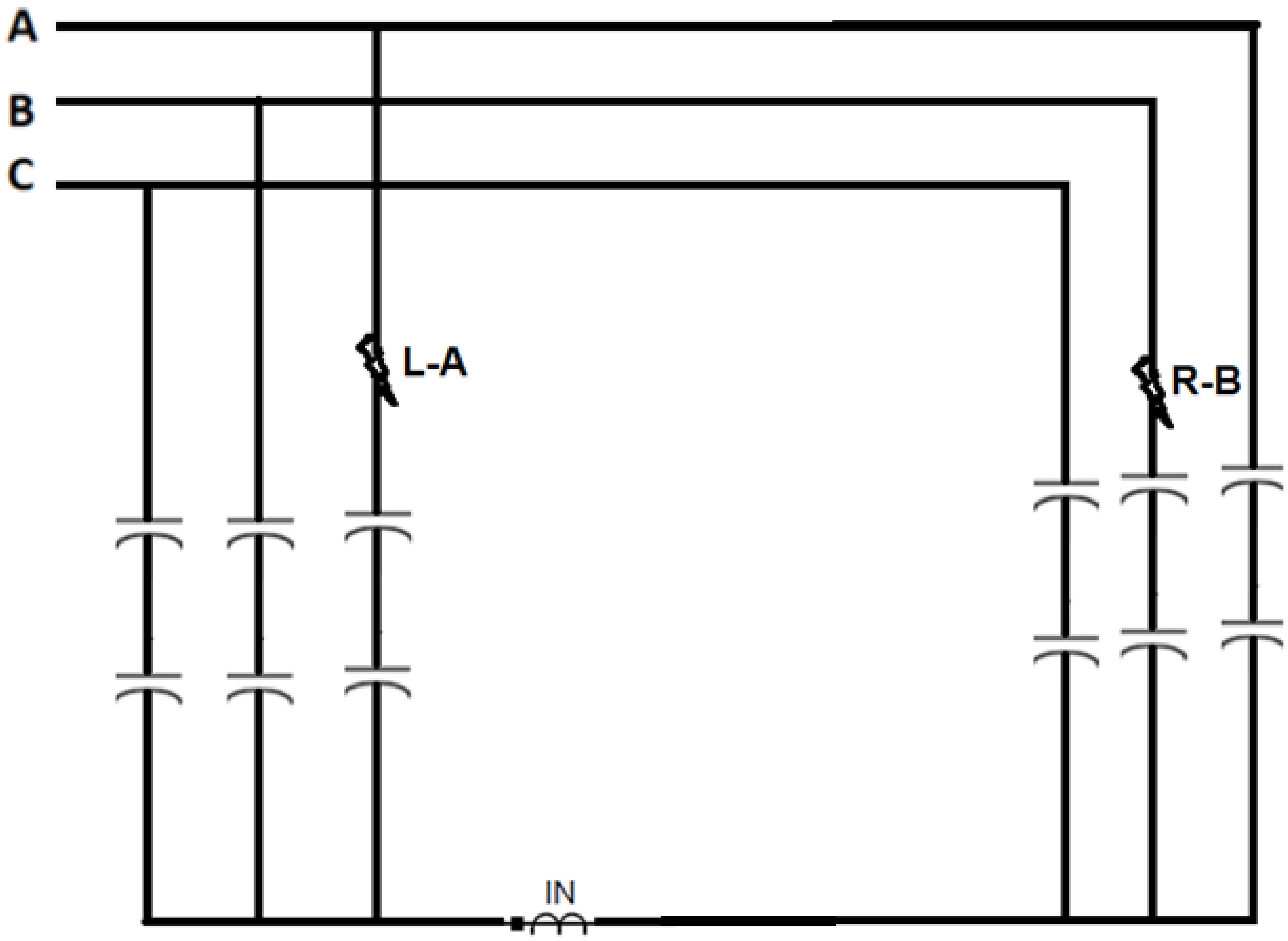
- MMFL applies to
  - Ungrounded neutral wye SCB
  - Ungrounded neutral voltage
  - Ungrounded neutral current
- Same mathematical derivation applies to

  Single-phase-based voltage and current differential calculation that are input to the multiphase one
- CT and PT usages are different and apply to

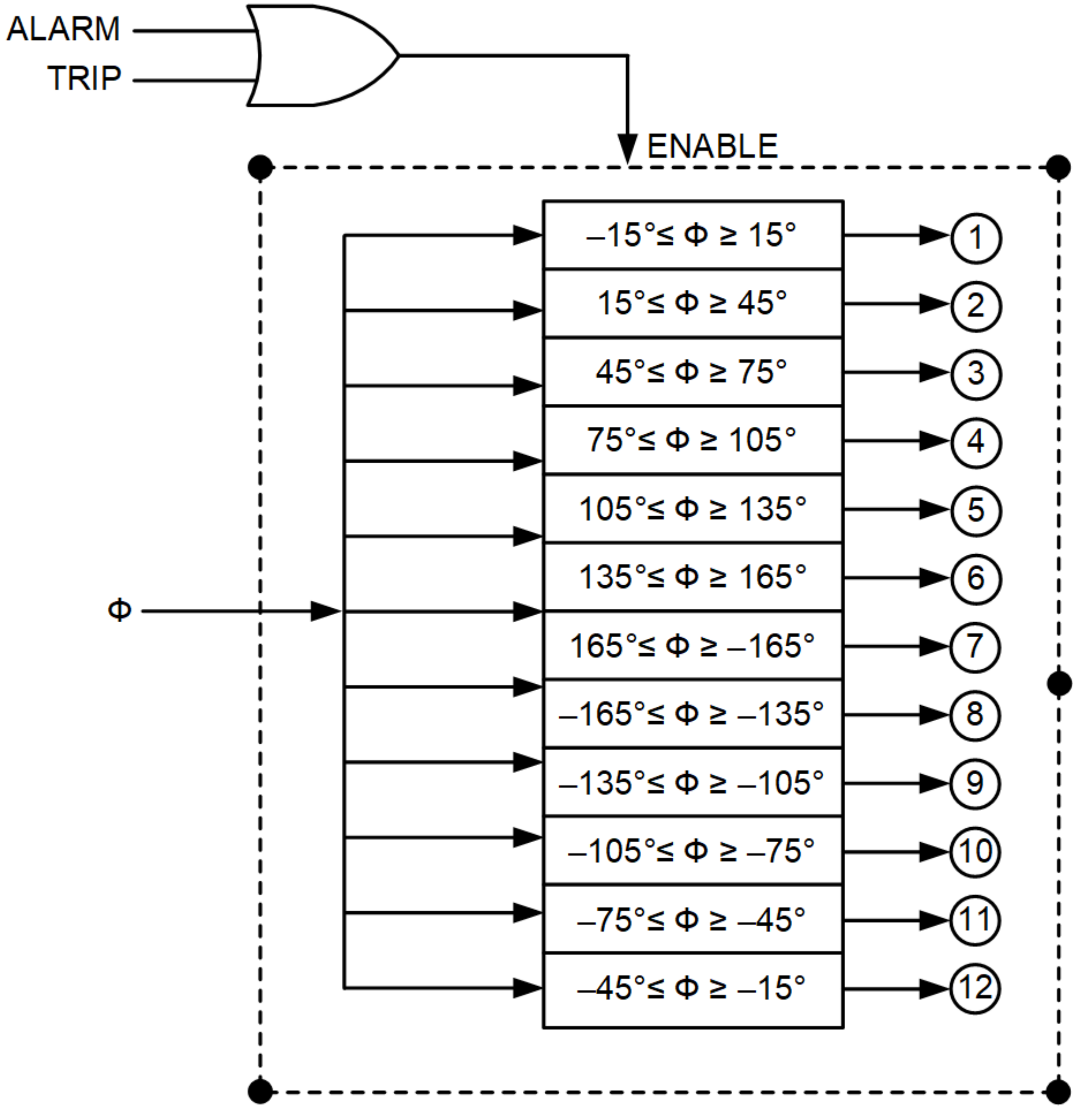
  CT only, PT only, or both CT and PT requirements

MMFL at left and right side of double wye

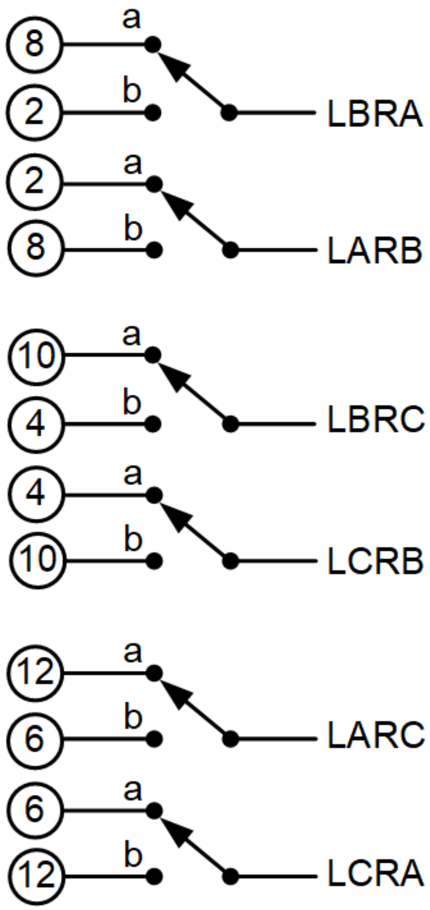
LARB



MMFL at left and right side of double wye

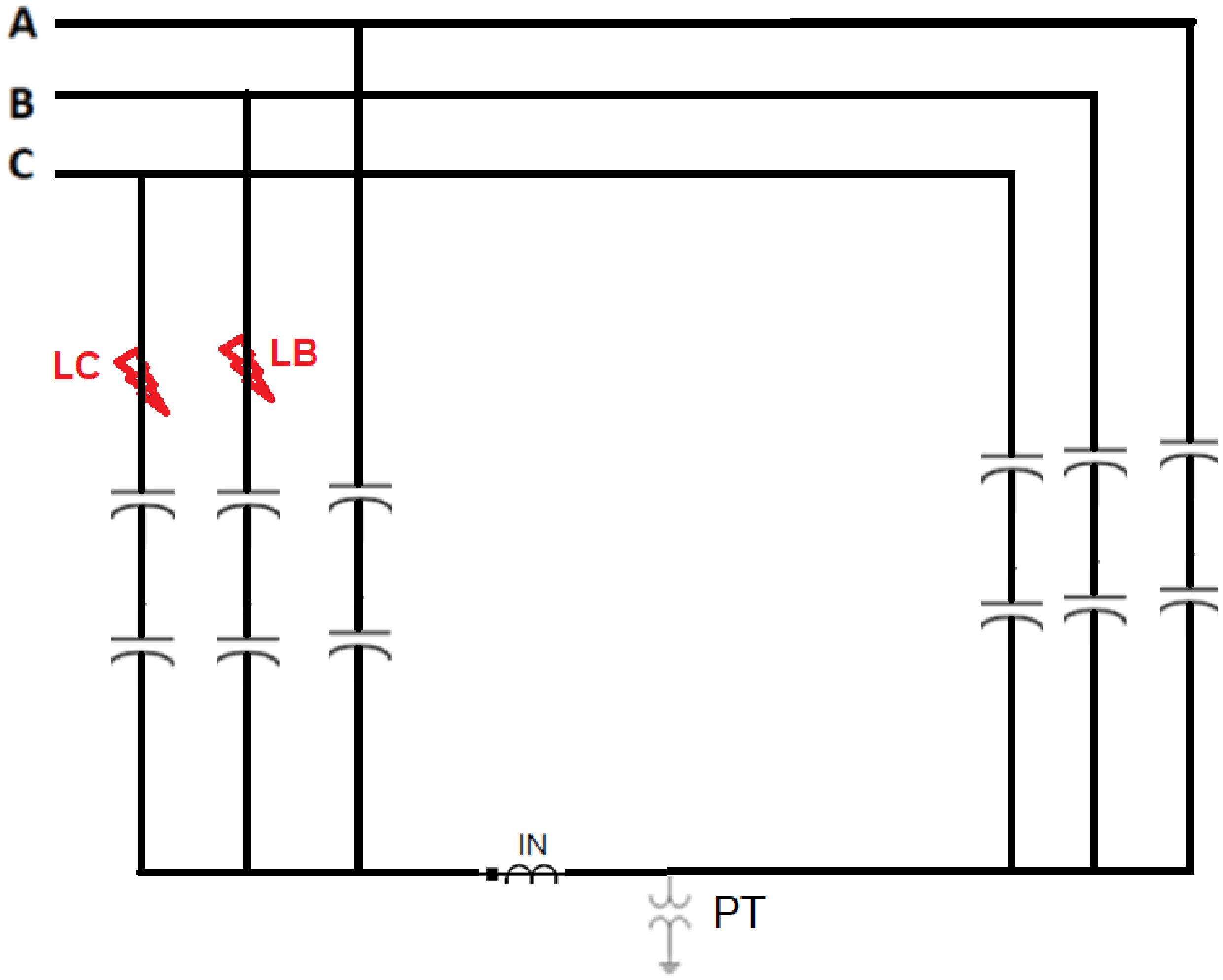


Switch at the position *a* if the bank is fuseless
Switch at the position *b* if the bank is fused

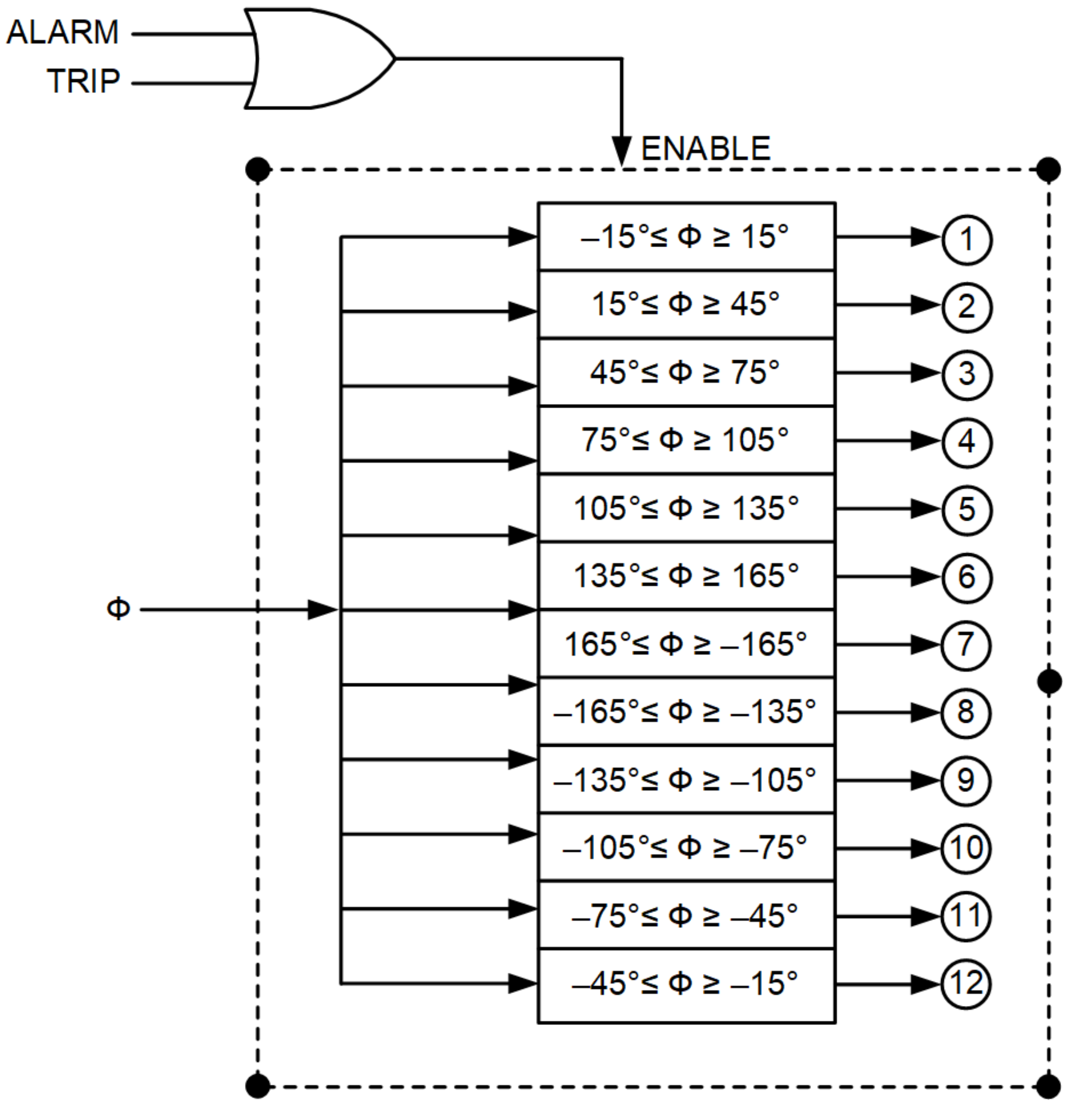


Multiphase fault at left side of double wye

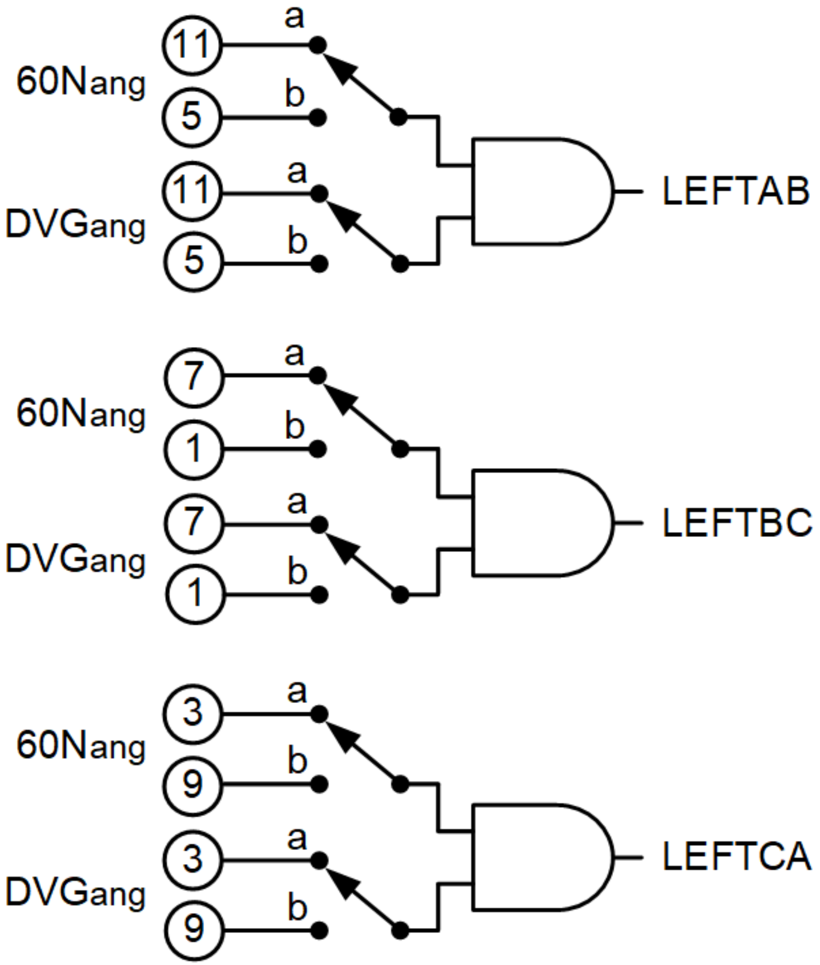
LBLC



Multiphase fault at left side of double wye

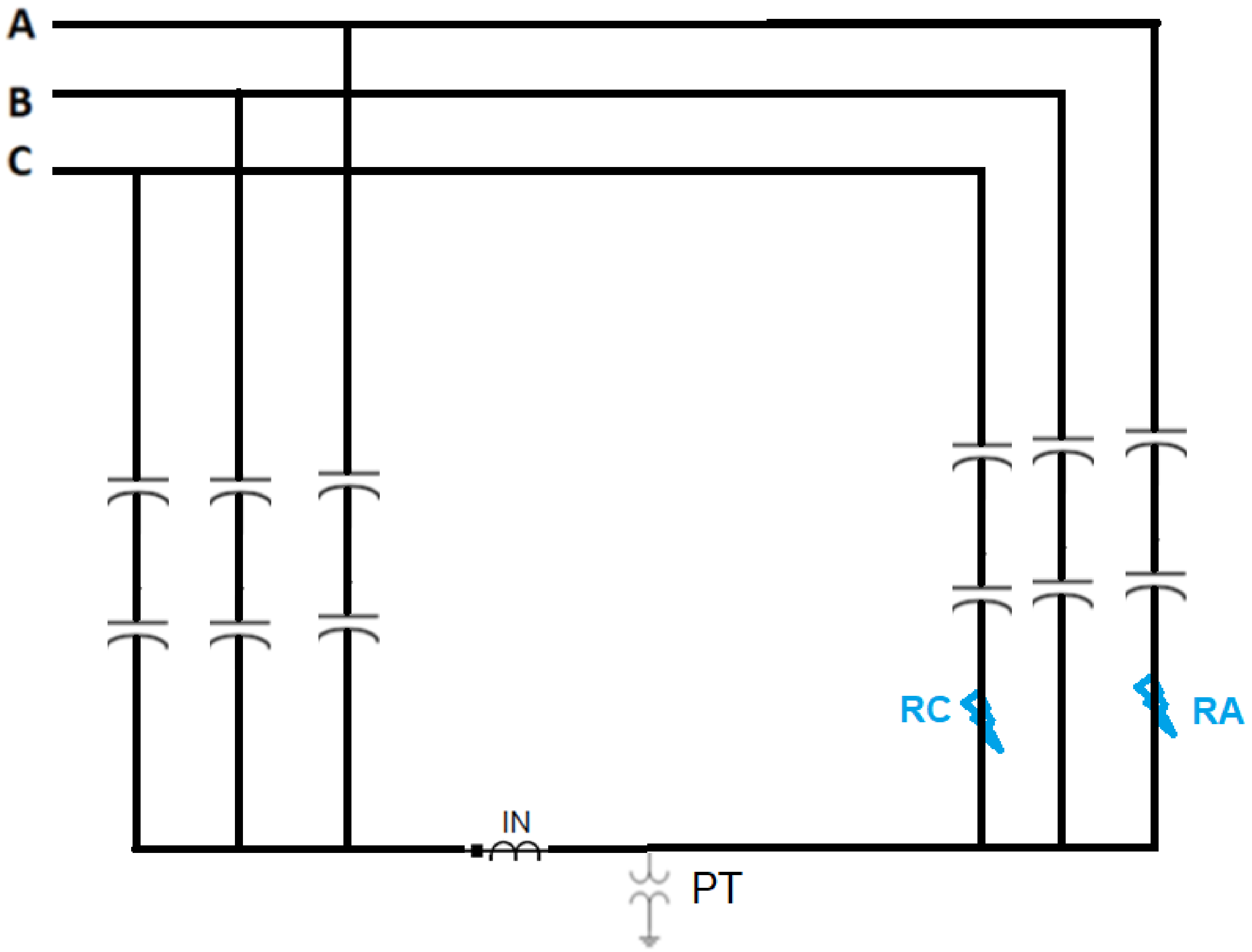


Switch at the position *a* if the bank is fuseless
Switch at the position *b* if the bank is fused

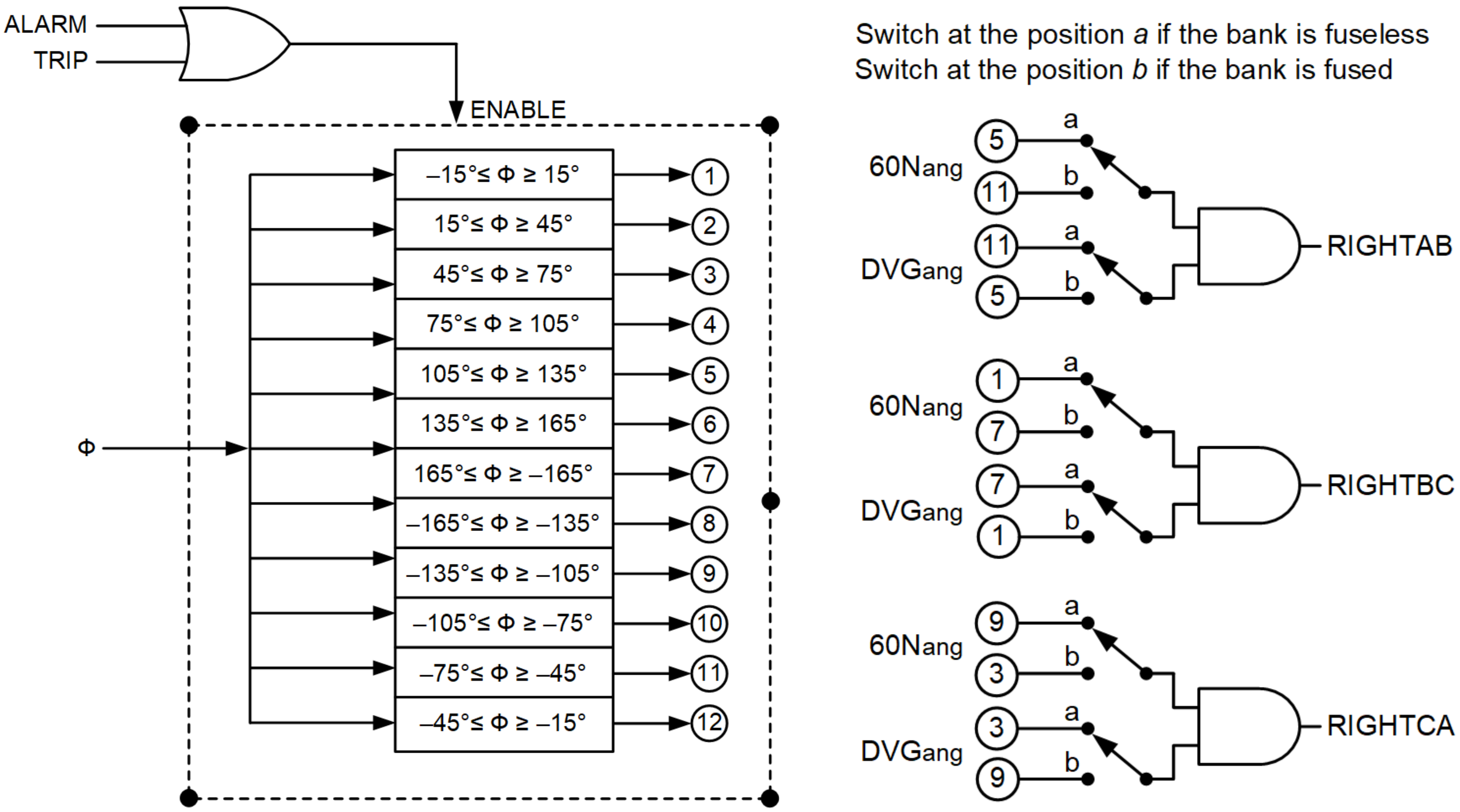


Multiphase fault at right side of double wye

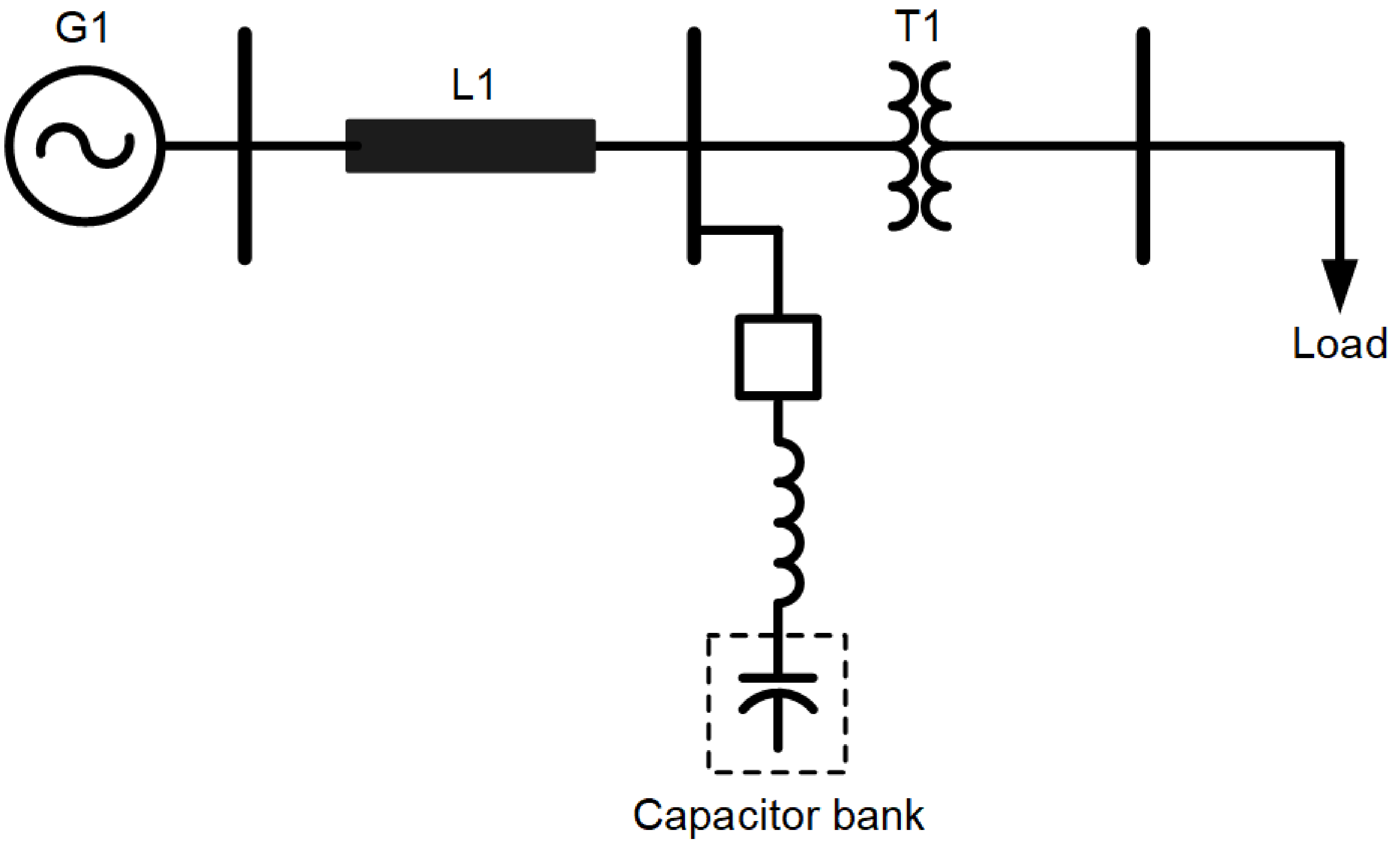
RARC



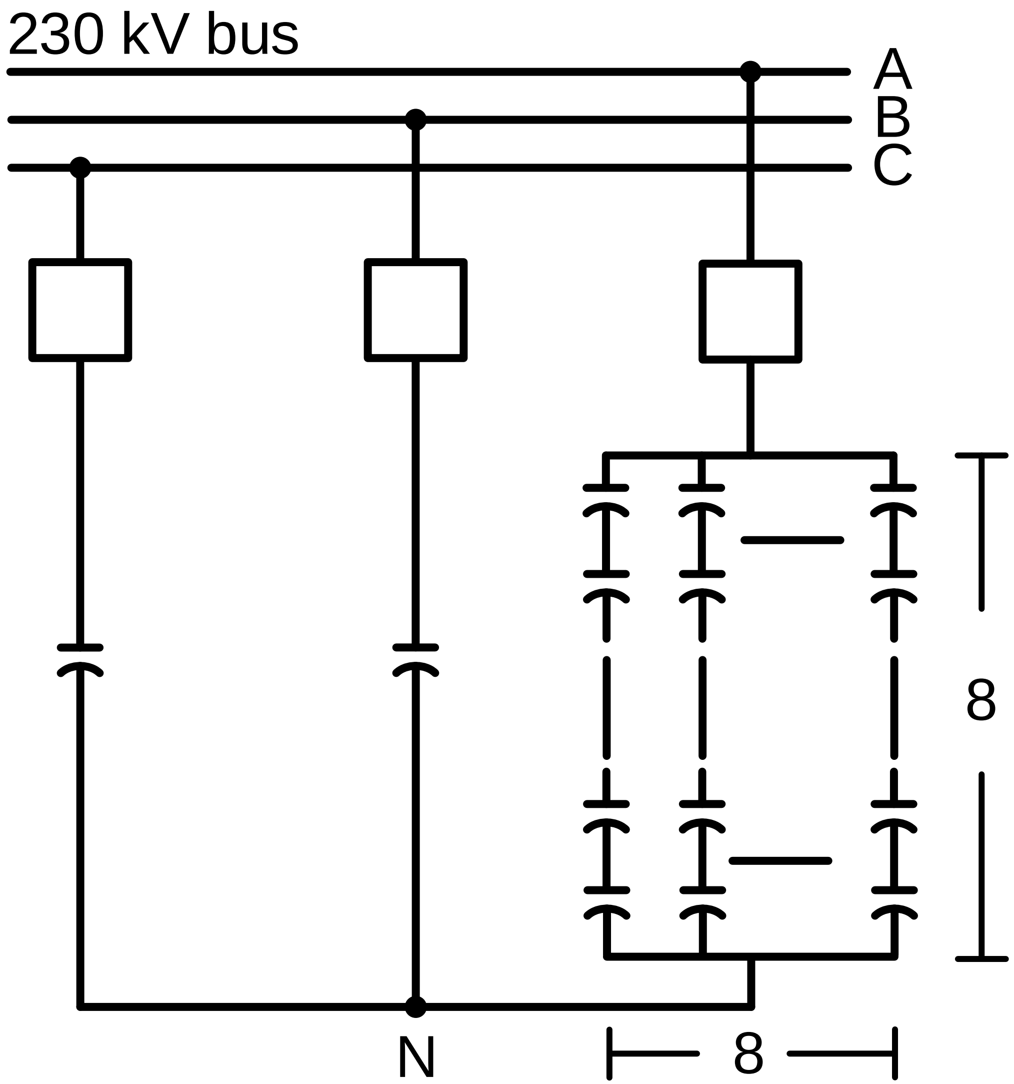
Multiphase fault at right side of double wye



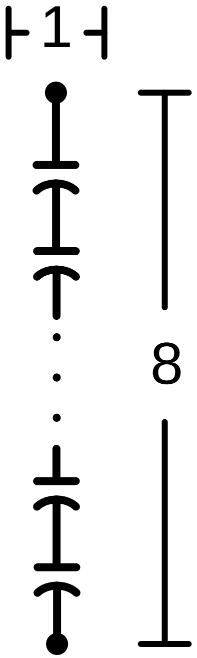
Power system modeled in RTDS



Capacitor bank model

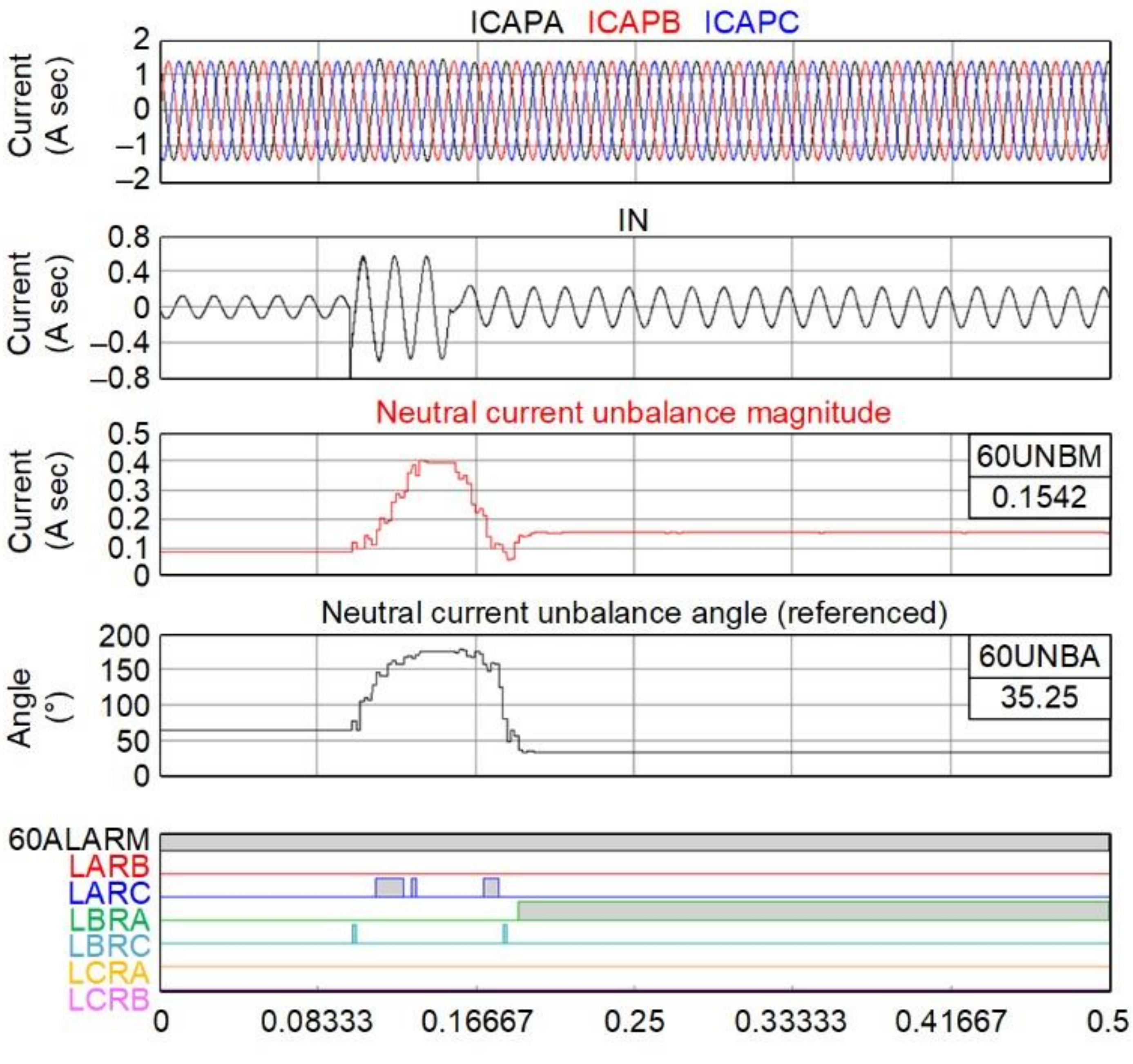


Single capacitor unit



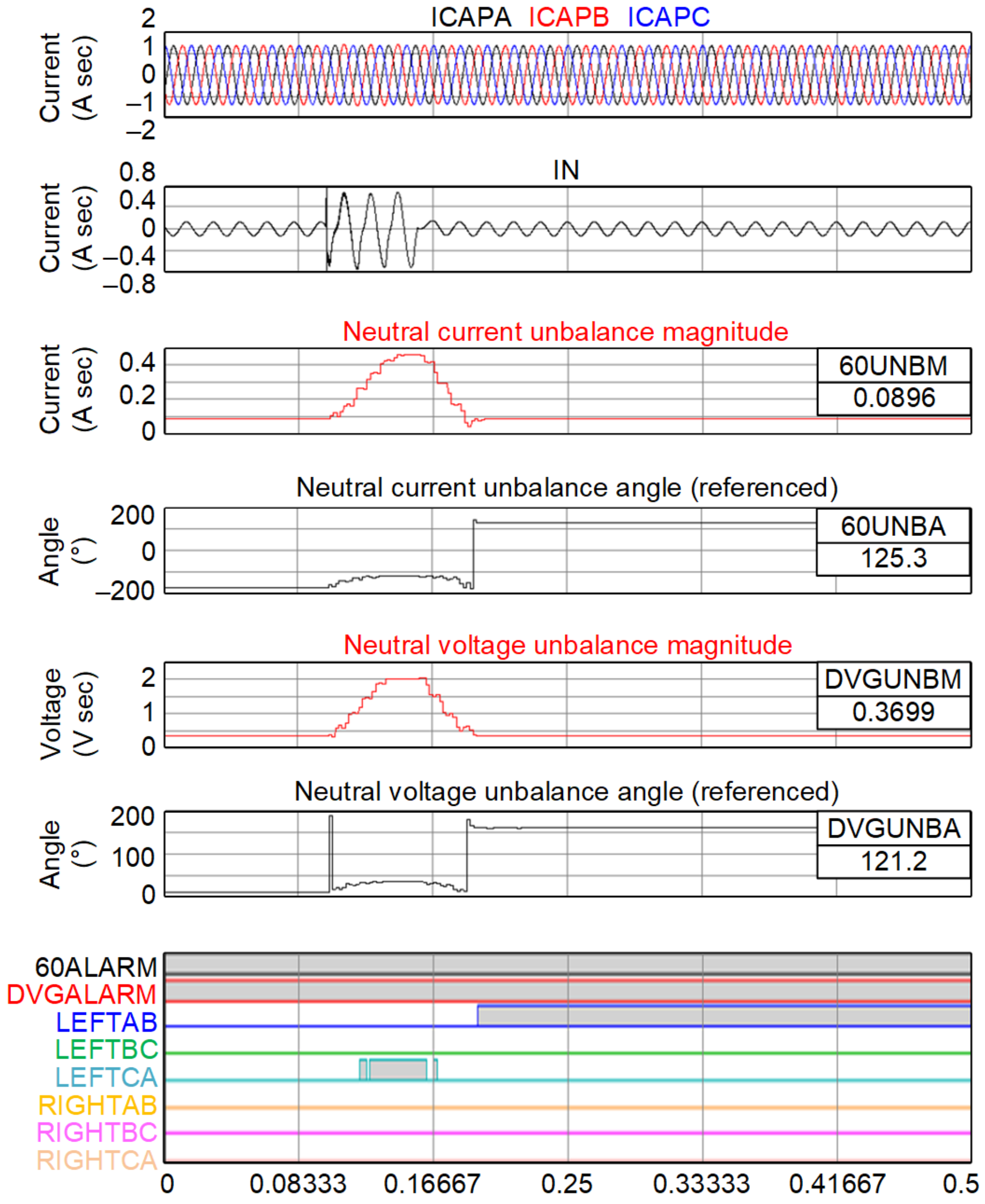
MMFL at left and right side of double wye

LBRA



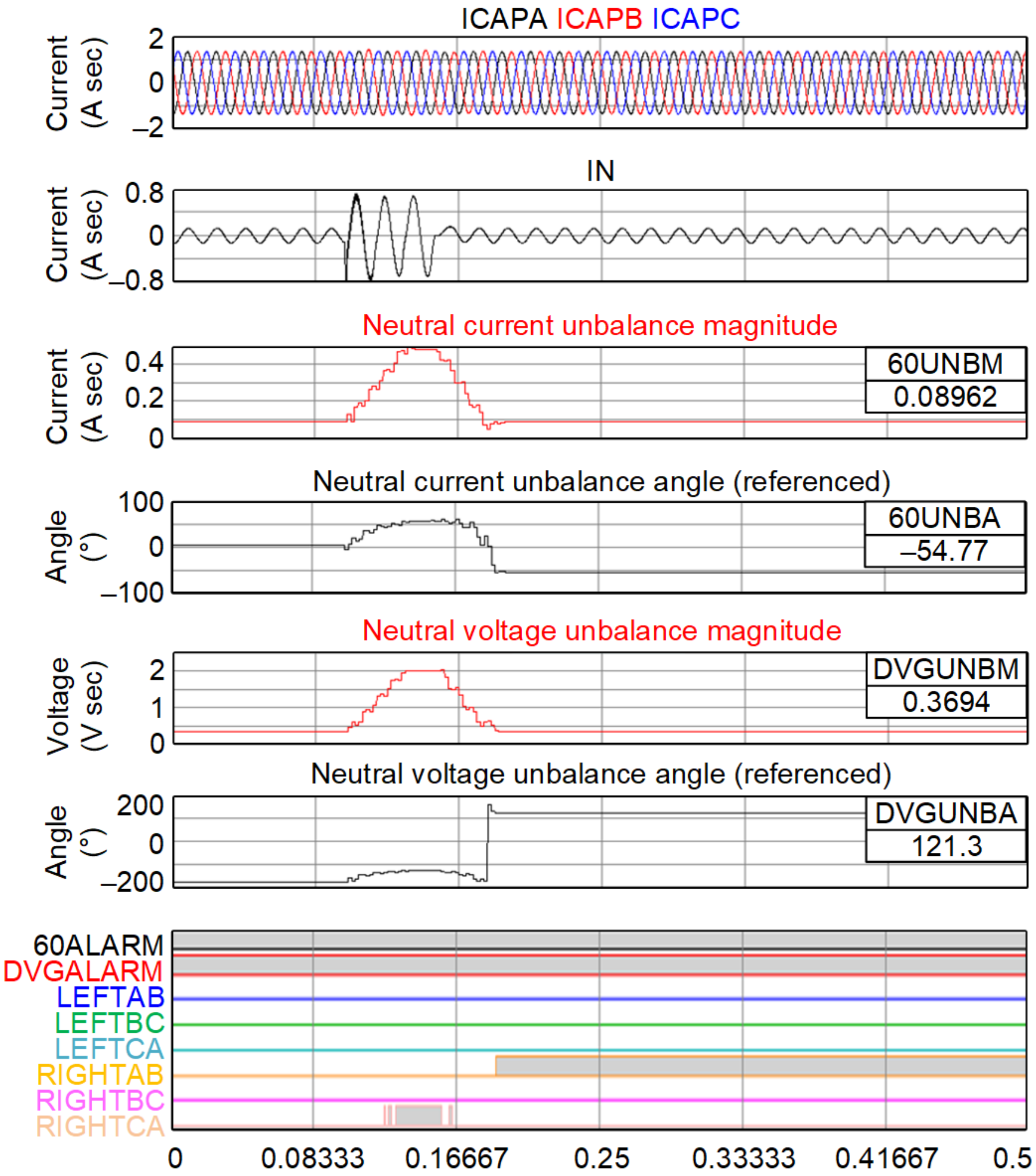
Multiphase fault at left side of double wye

LALB



Multiphase at right side of double wye

RARB



Conclusion

Locating faulty unit is time-consuming

Proposed fault location technique

- Enhances existing single-phase fault location technique
- Reduces investigating time by 50% to 92%
- Further minimizes capacitor bank outage time
- Is embedded in unbalance protection, making it economical
- Can be applied to any bank configuration and fusing method
- Is not affected by inherent unbalance
- Provides advanced alarms for planned maintenance
- Is ready to be used with relay logic programming

Questions?