TEXAS A&M UNIVERSITY
Relay Conference

A Review of High- and Low-Impedance Differential Relaying for Bus Protection

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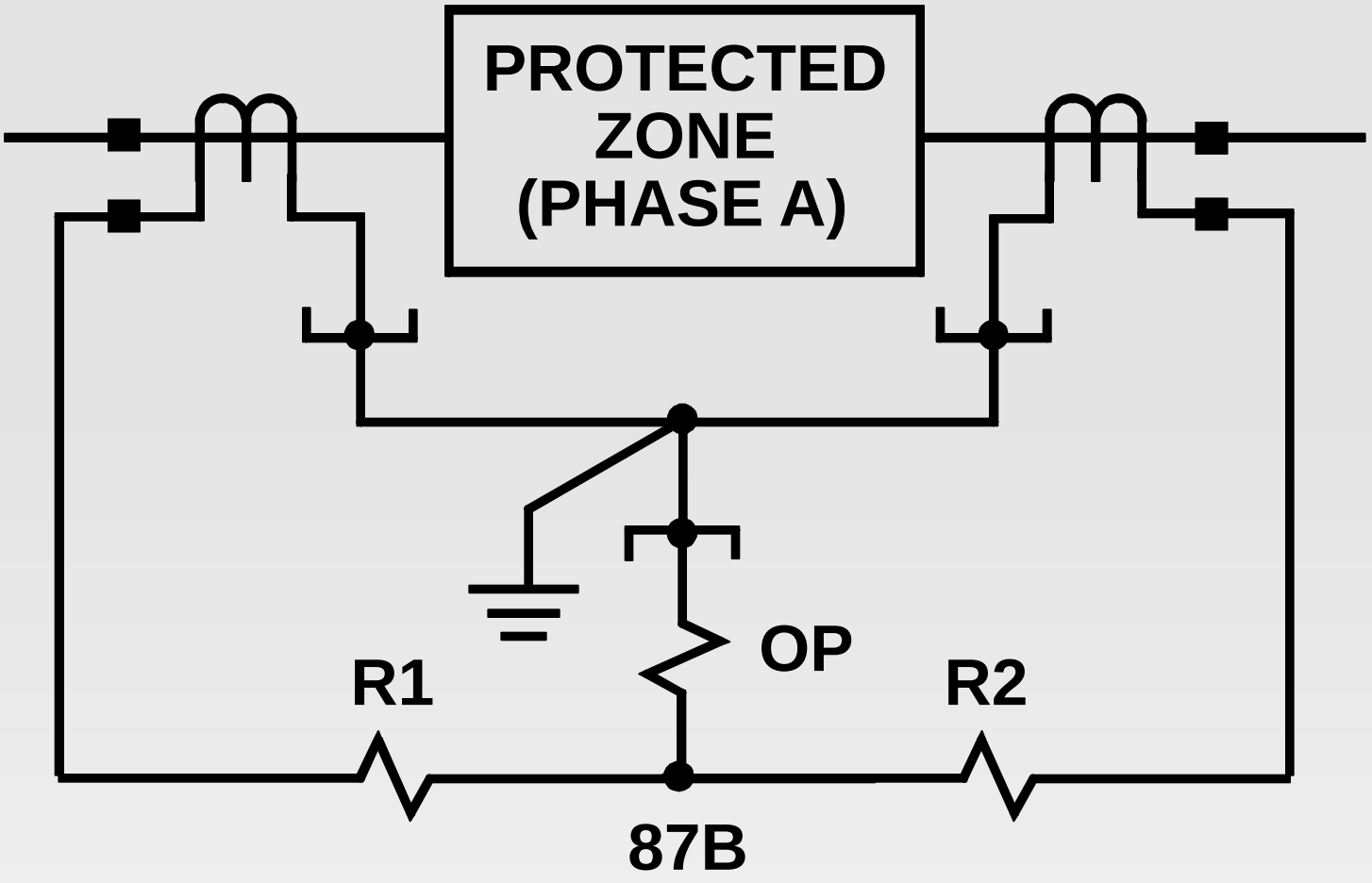
Topics for Discussion

- Low-Z differential basics
- Multi-restraint bus differential
- CT performance requirements for low-Z differential
- High-Z differential basics
- CT performance requirements for high-Z differential
- Mixing CT ratios in high-Z differential

Differential Basics



Low-Z Differential Basics

- Has low impedance to flow of CT secondary current
- Compute vector-sum of currents
- Sum = 0: no internal faults
- Sum ≠ 0: internal fault causes relay operation

Low-Z Differential Quantities

- Restraint quantity (I_R) is through current (normal load currents flow through CTs)
- Operate quantity (I_{OP}) is differential current
- Slope is I_{OP} / I_R

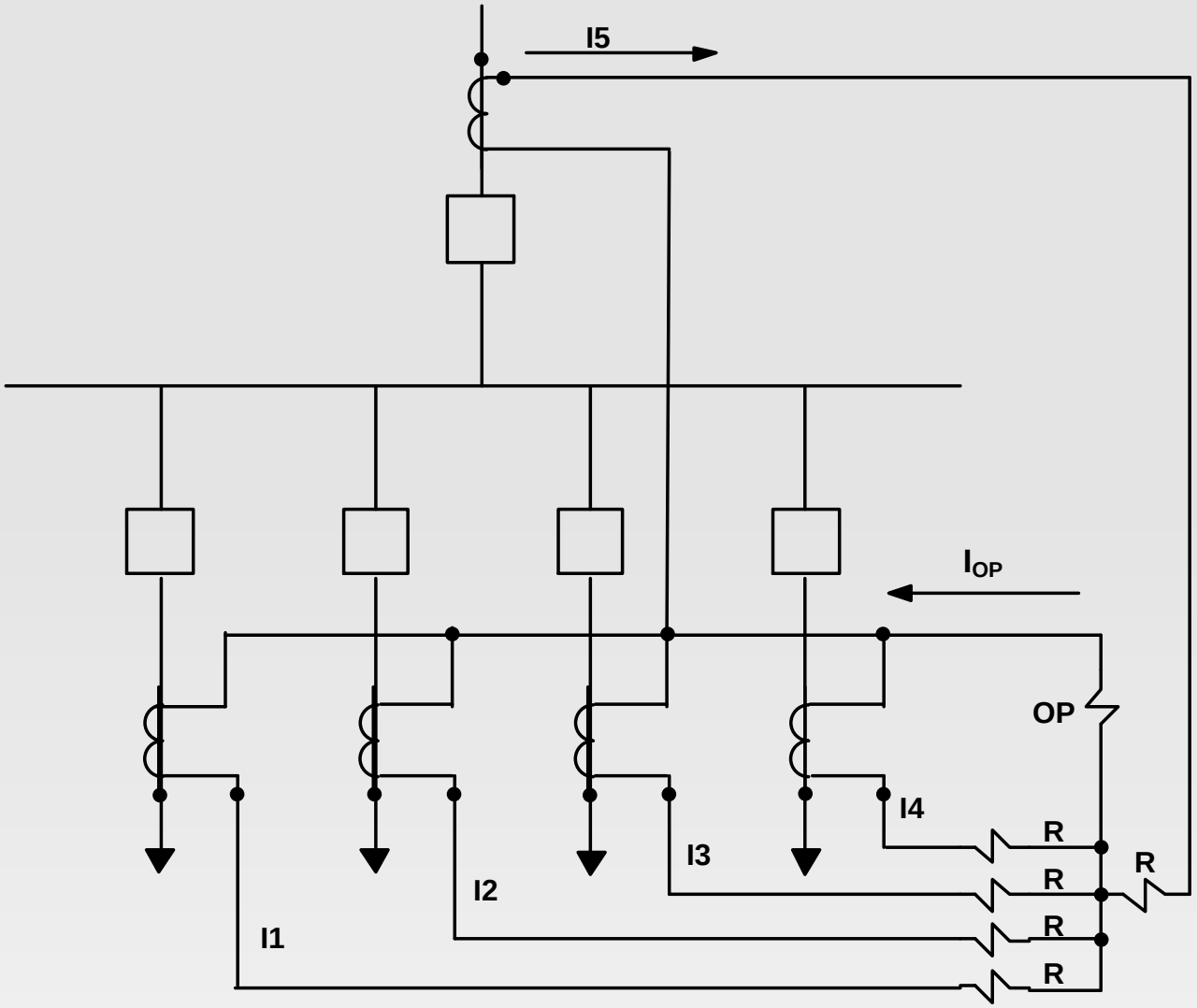
I_R in Low-Z Differential

- I_R is function of through currents

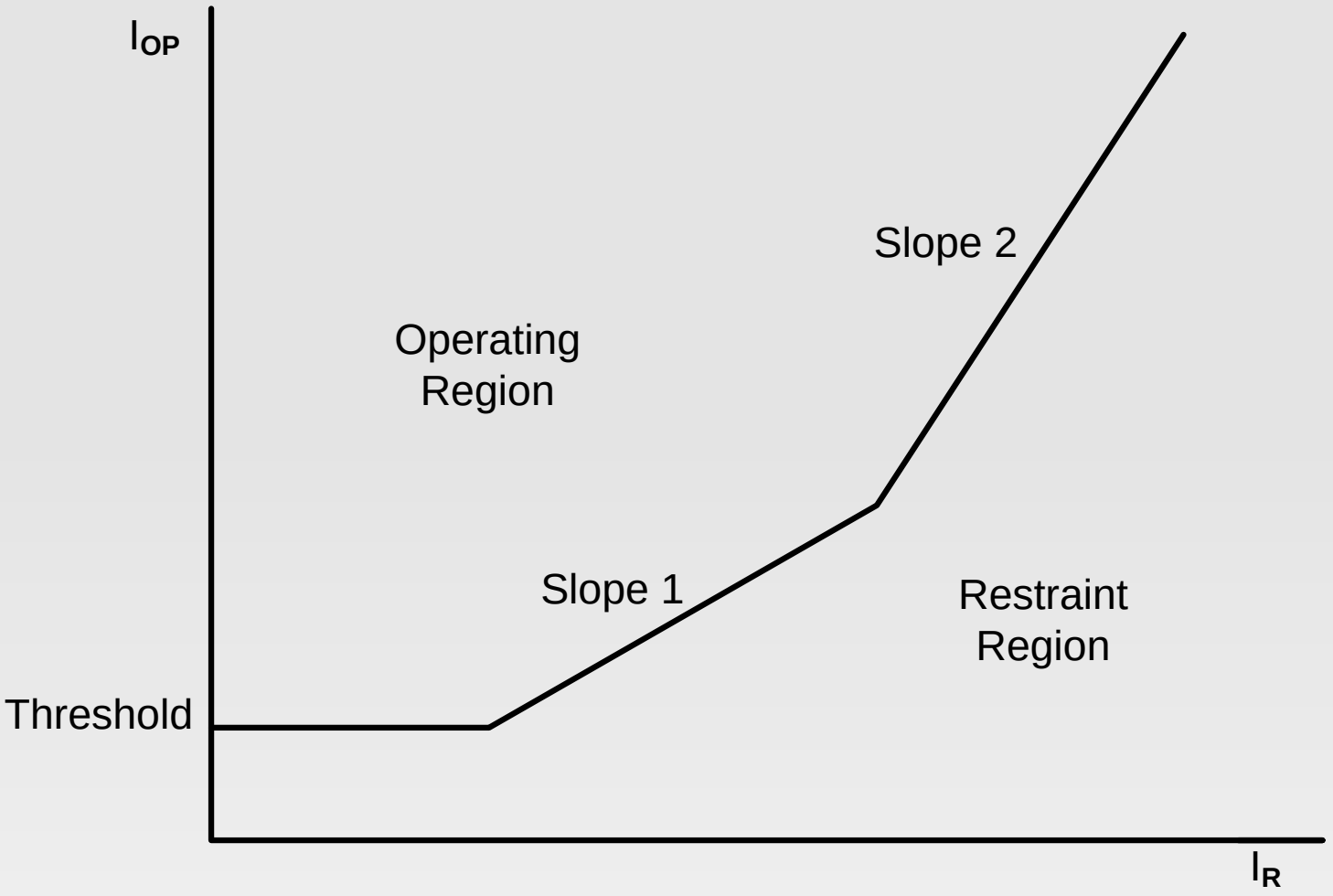
$$I_R = f(|I_1|, |I_2|, \ldots, |I_n|)$$

- Depending on Manufacturer
  - $I_R = \frac{1}{n} \bullet (|I1| + |I2| + \cdots + |In|)$
  - $I_R = \max(|I_1|, |I_2|, \ldots, |I_n|)$
  - $I_R = \frac{1}{2} \bullet (|I1| + |I2| + \cdots + |In|)$
  - $I_R = (|I_1| + |I_2| + \ldots + |I_n|)$

Multi-restraint Bus Differential



Percentage Current Differential



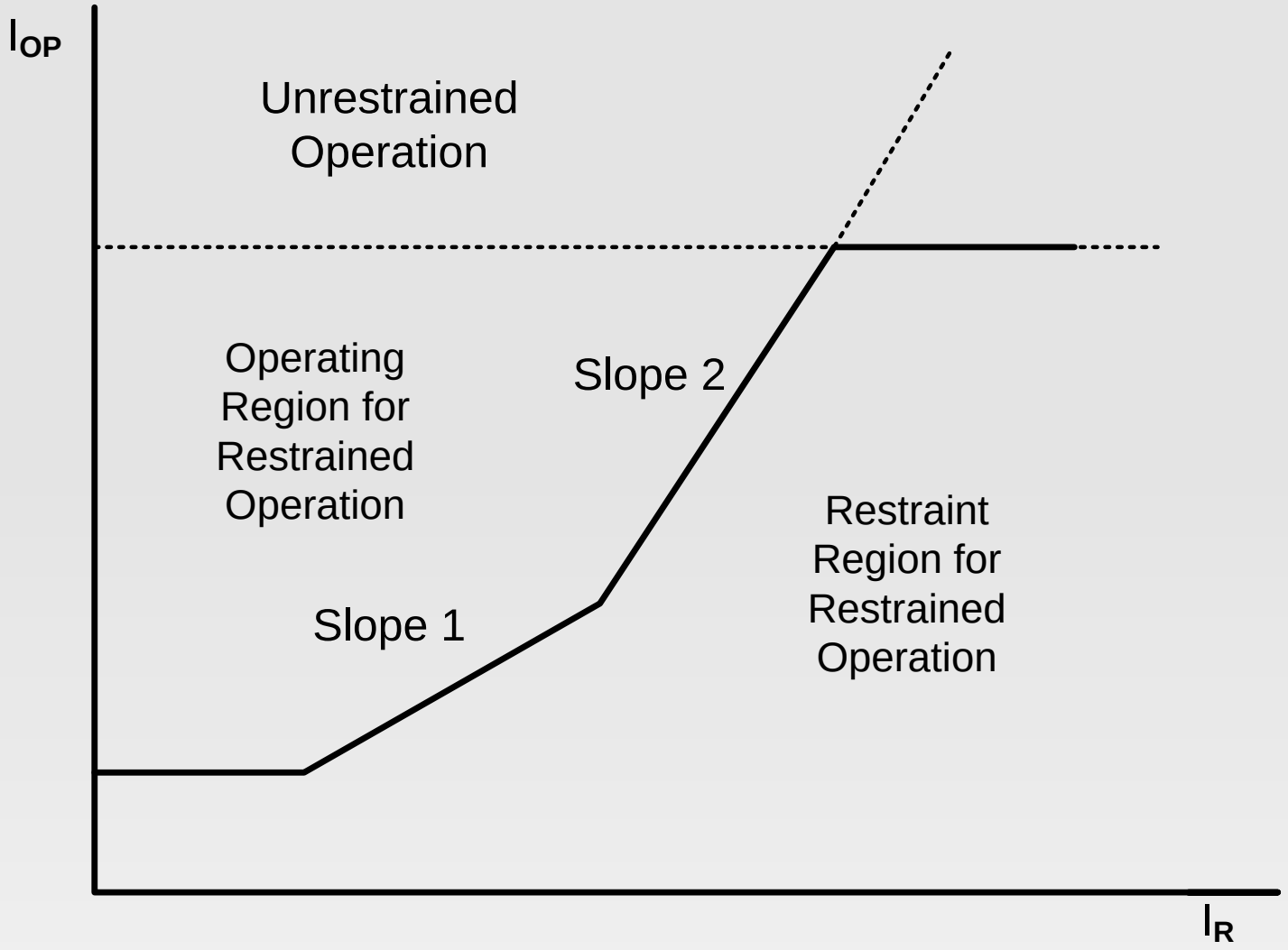
Setting Low-Z Differential

- Set threshold below minimum bus fault
- Set threshold above maximum current leaking from differential zone
- Set threshold above maximum load level

Setting Slope—Low-Z Differential

- Slope 1 typical setting: 10–25% of maximum bus current
- Set Slope 2 to restrain false differential current — caused by CT saturation during heavy external fault

Unrestrained Operation



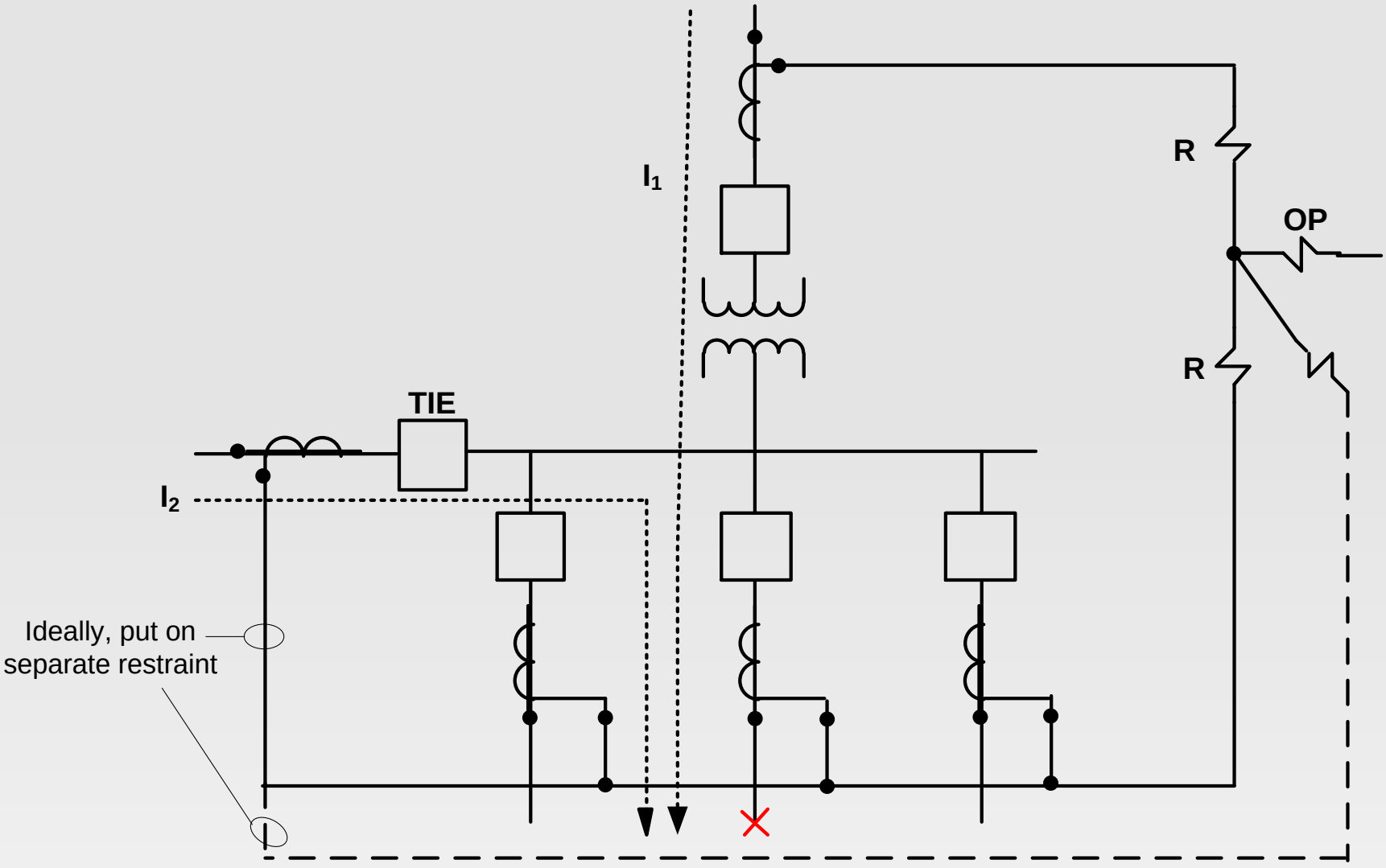
CT for Low-Z Differential

- CT polarity plays a critical role
- CT ac voltage rating must be greater than steady-state ac voltage during external fault

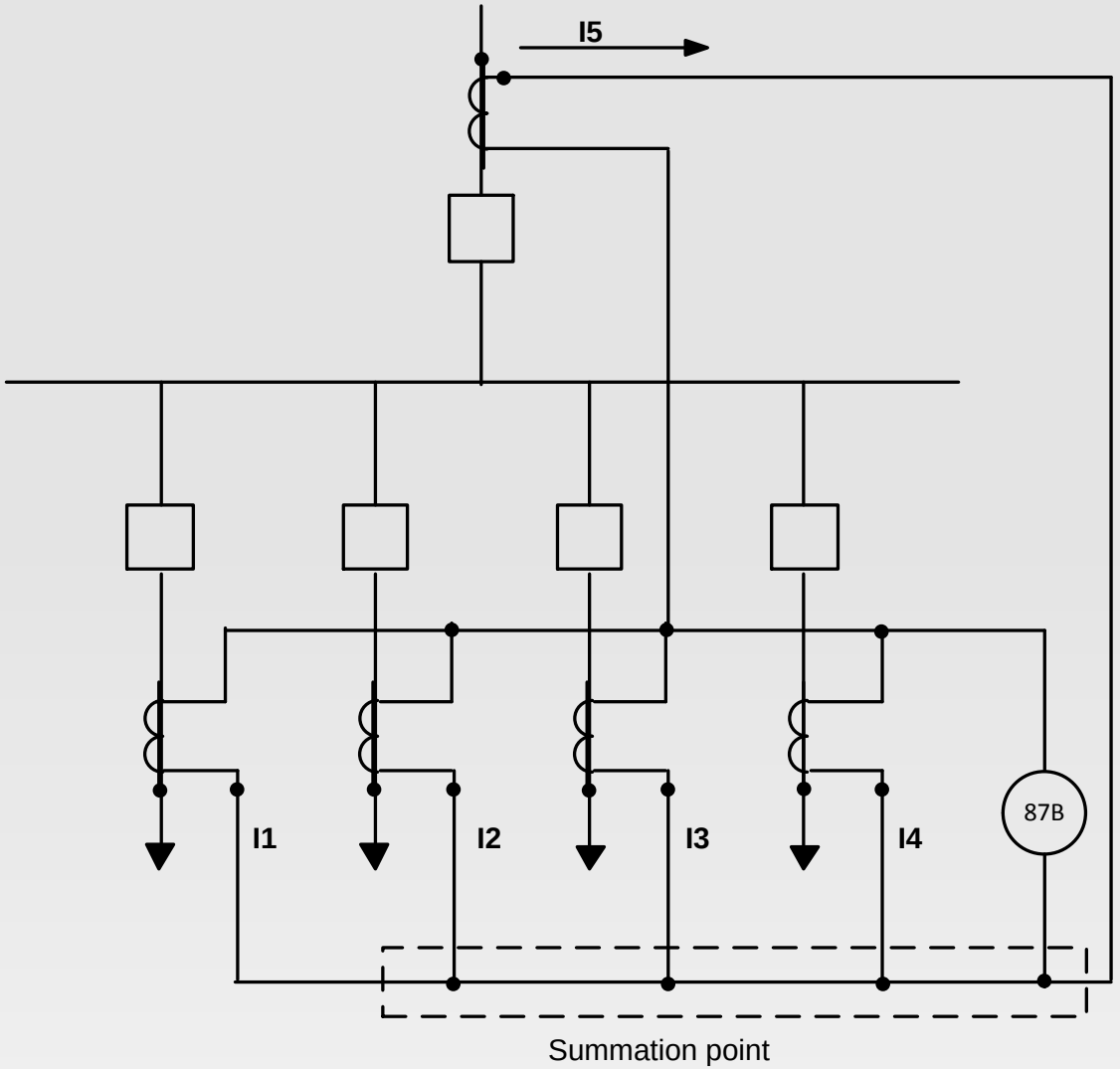
Paralleling CTs—Low-Z Differential

- Must have same ratio
- Only CTs on load side can be paralleled with minimal risk
- Combined maximum load current from paralleled CTs must not exceed continuous rating of relay current inputs

Paralleling CTs—Low-Z Differential



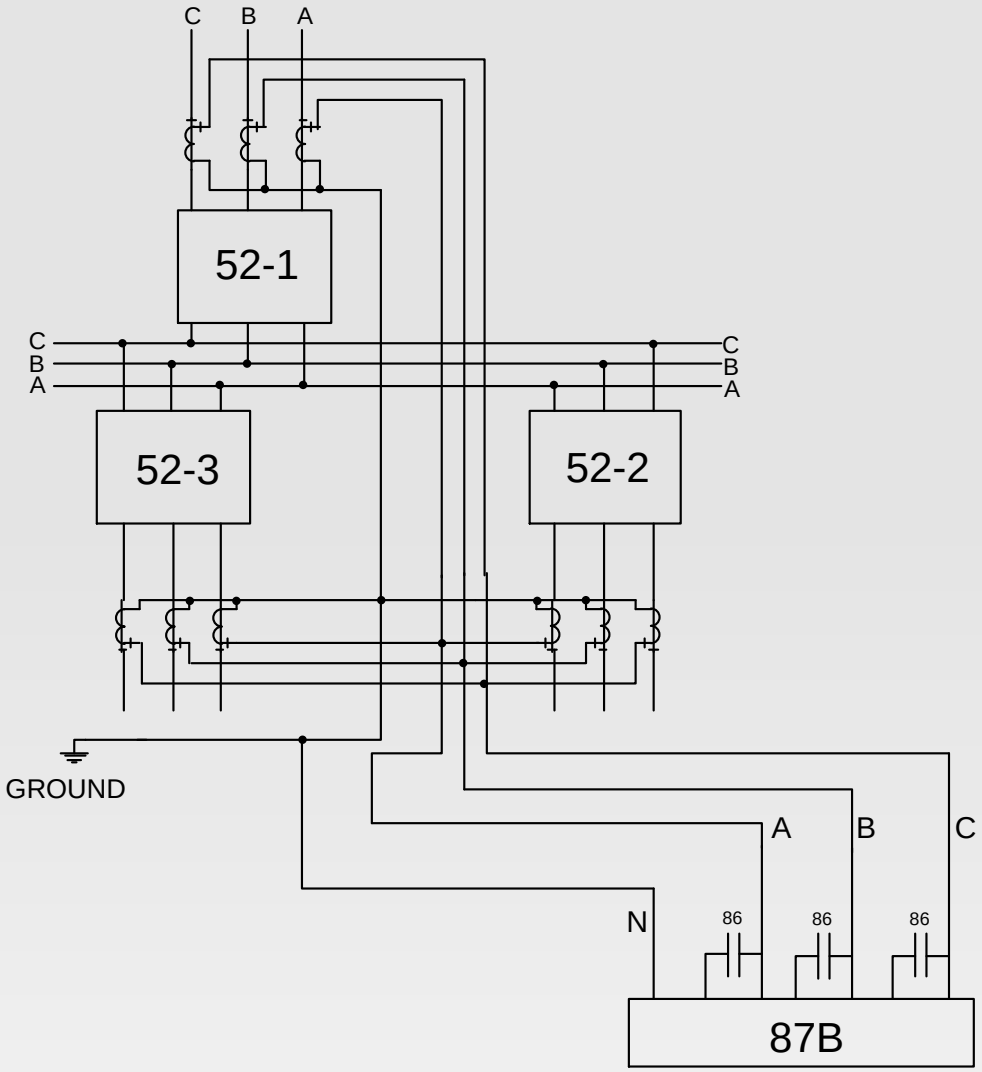
High-Z Differential Basics



High-Z Differential Basics — cont'd

- Has high impedance to flow of CT secondary current — generally greater than 1 kΩ resistive
- Parallels output of all CTs in system
- Connects CTs to a common bus
- Wires bus to relay
- Operates based on rising voltage at the summing point

High-Z Differential Connections



Setting High-Z Differential

- Set threshold greater than maximum possible voltage across relay for external fault
- $V_{threshold} = \frac{I_F}{N} \bullet (R_{ct} + R_L \bullet P)$

Setting High-Z Differential—cont'd1

- I_F is maximum fault current
- N is CT ratio
- R_{CT} is dc resistance of CT secondary winding plus lead resistance to CT terminals
- R_L is one-way dc resistance of a lead from differential junction point to CT terminals
- P is 1 for three-phase faults and 2 for single-phase faults

Setting High-Z Differential—cont'd3

- $V_{relay} = K \bullet V_{threshold}$
- K is safety margin, usually 1.25 and greater

Setting High-Z Differential—cont'd4

- If single-phase fault current is greater than three-phase fault current, calculate only single-phase
- Resistance of CTs and leads will increase as temperature rises

CT for High-Z Differential

- Toroidal design and fully distributed around core
- Same full ratio value and connected to full-ratio taps
- Same voltage rating, accuracy class, and thermal rating

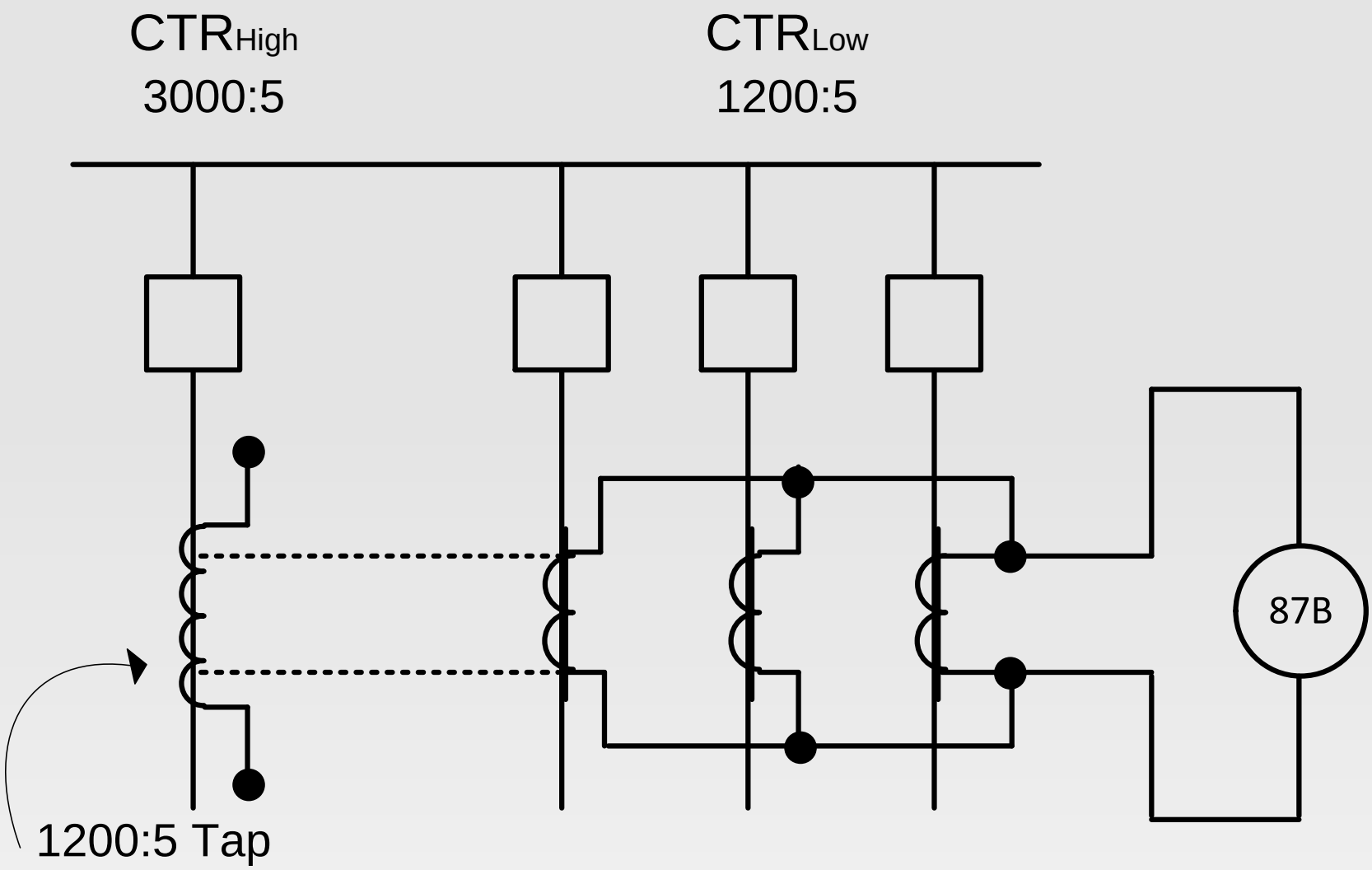
CT for High-Z Differential—cont'd

- Should only be dedicated to differential application
- At least one set of CTs in new breaker has same ratio and accuracy class as existing scheme
- No primary and secondary voltage limiting devices on CTs

Mixing CT ratios

- Using partial tap on CTs
- Connecting two CTs in parallel
- Interconnecting CTs at tap

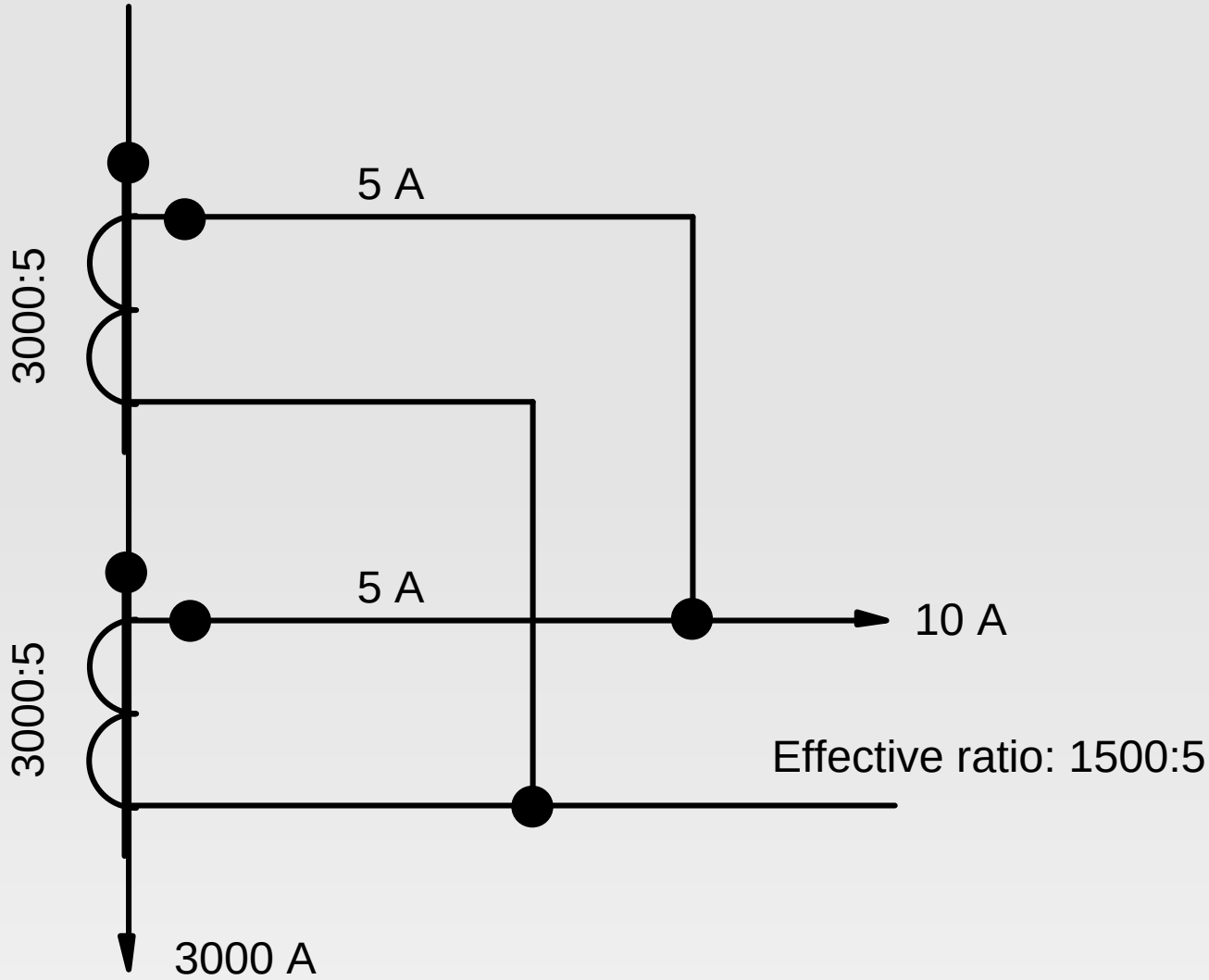
Using Partial Tap on CTs



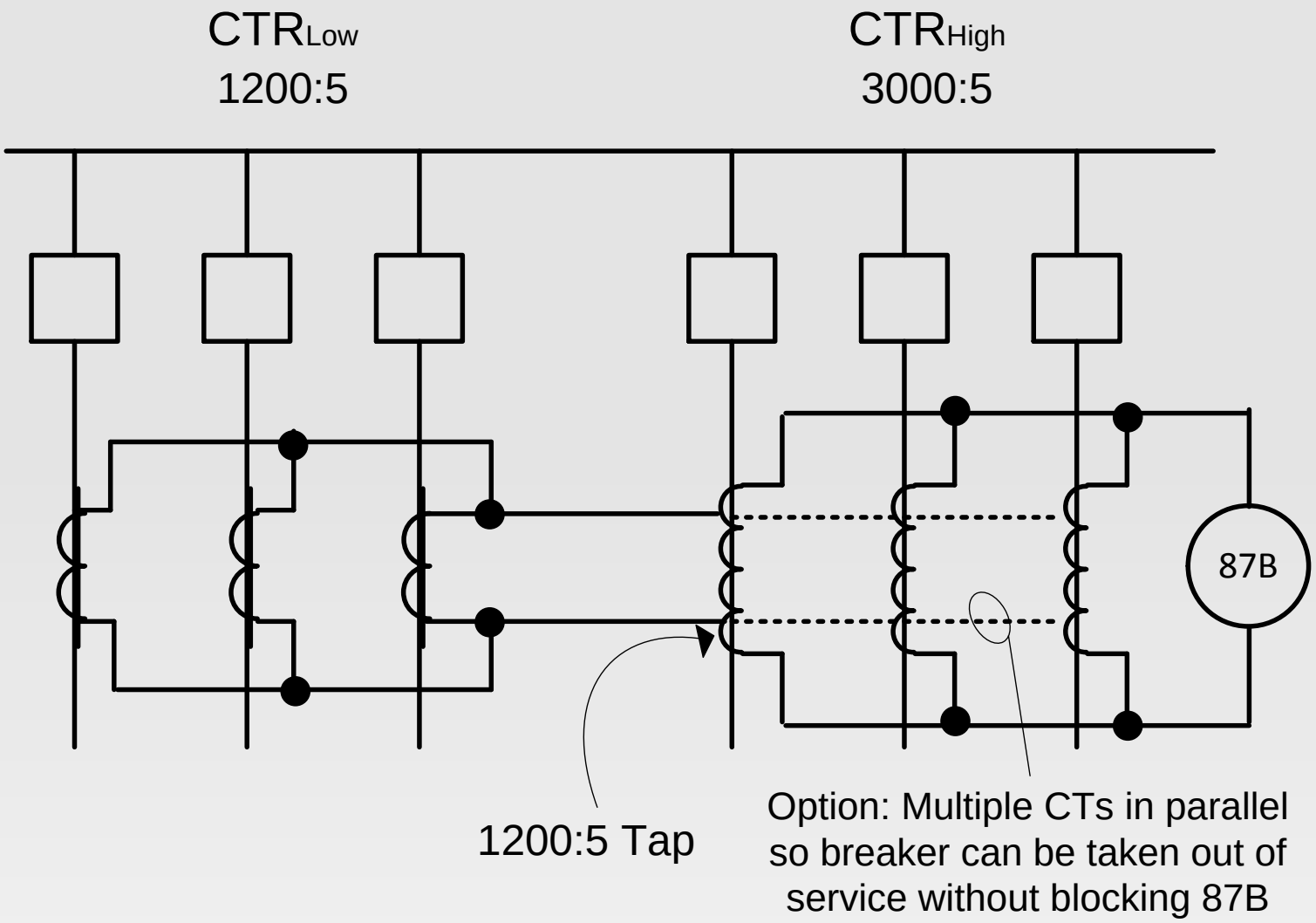
Using Partial Tap on CTs

- CT overload
  - If 1200:5 and 3000:5, then tap 3000:5 at 1200:5
  - If 3000 A flows: (3000/1200) • 5 = 12.5 A secondary
- High voltage across open terminals of tapped CTs
- Unadvised method

Connecting Two CTs in Parallel



Interconnecting CTs at Tap



Conclusions

	Low-impedance	High-impedance
Multiple CT ratios	Yes	Strongly not recommended
Paralleling CTs	Plausible if paralleled CTs are of the same ratio and are load side CTs (refer to Low-Impedance Bus Differential Section)	Yes
Numbers of current inputs	Limited by relays current inputs	Not limited (however, careful consideration must be taken when connecting more than 10 current inputs)

Conclusions—cont'd

	Low-impedance	High-impedance
Future expansion	Limited by relays current inputs	Not limited (however, careful consideration must be taken when connecting more than 10 current inputs)
CT polarity compensation	Yes	No
Security	Good	Good
Sensitivity	Good	Depending on settings
Speed	< 34 ms at 2 multiples of pickup < 27 ms at 4 multiples of pickup	< 6 ms

Thank you

Question?