TEXAS A&M UNIVERSITY
Relay Conference

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

Basler Electric

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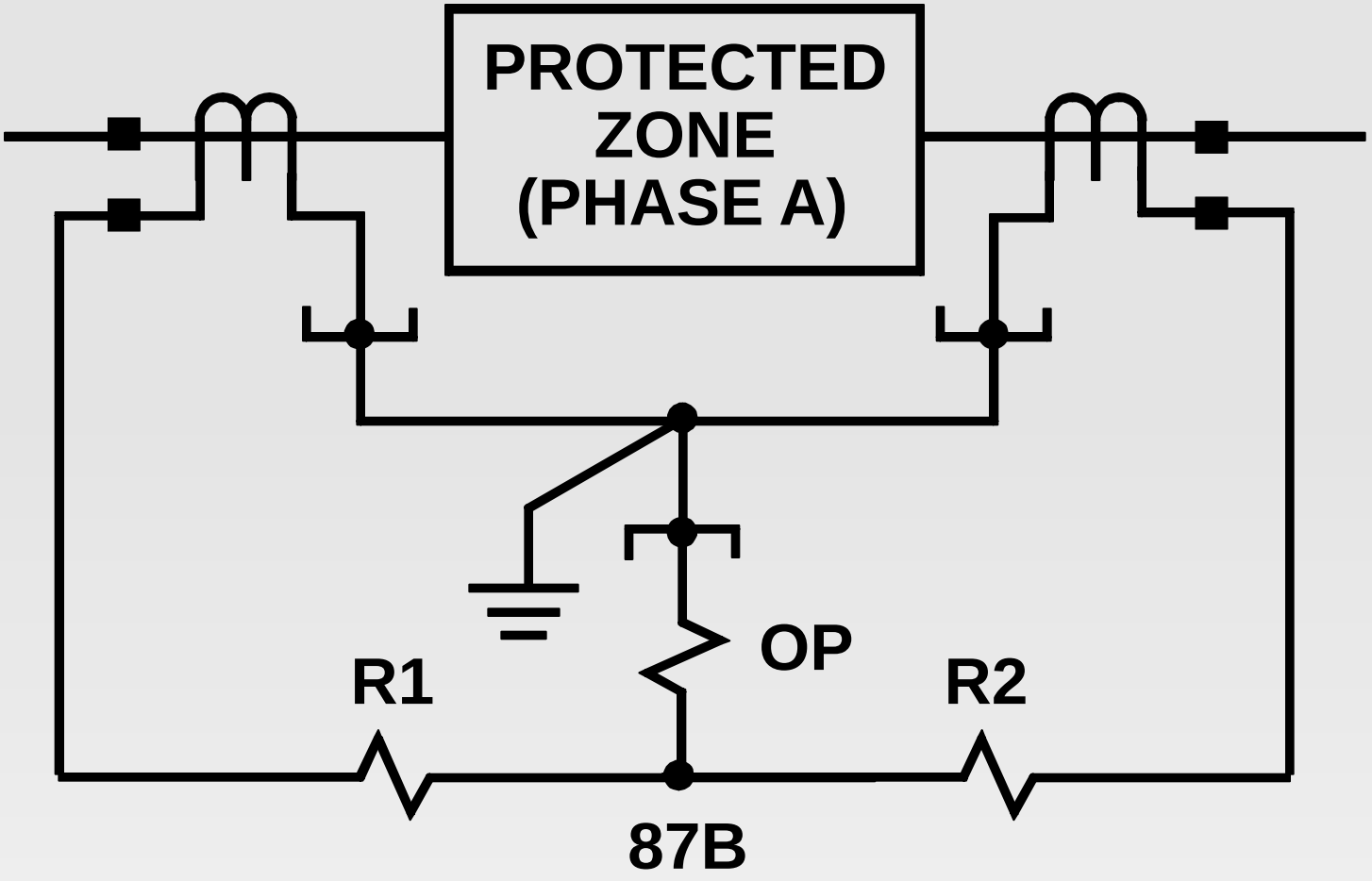
Outline

- Low-Z Diff Basics
- Multi-restraint Bus Diff
- High-Z Diff Basics
- Mixing CT ratios in High-Z Diff
- CT Performance Requirements for Low-Z Diff
- CT Performance Requirements for High-Z Diff
- Conclusion

Diff Basics



Low-Z Diff Basics

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

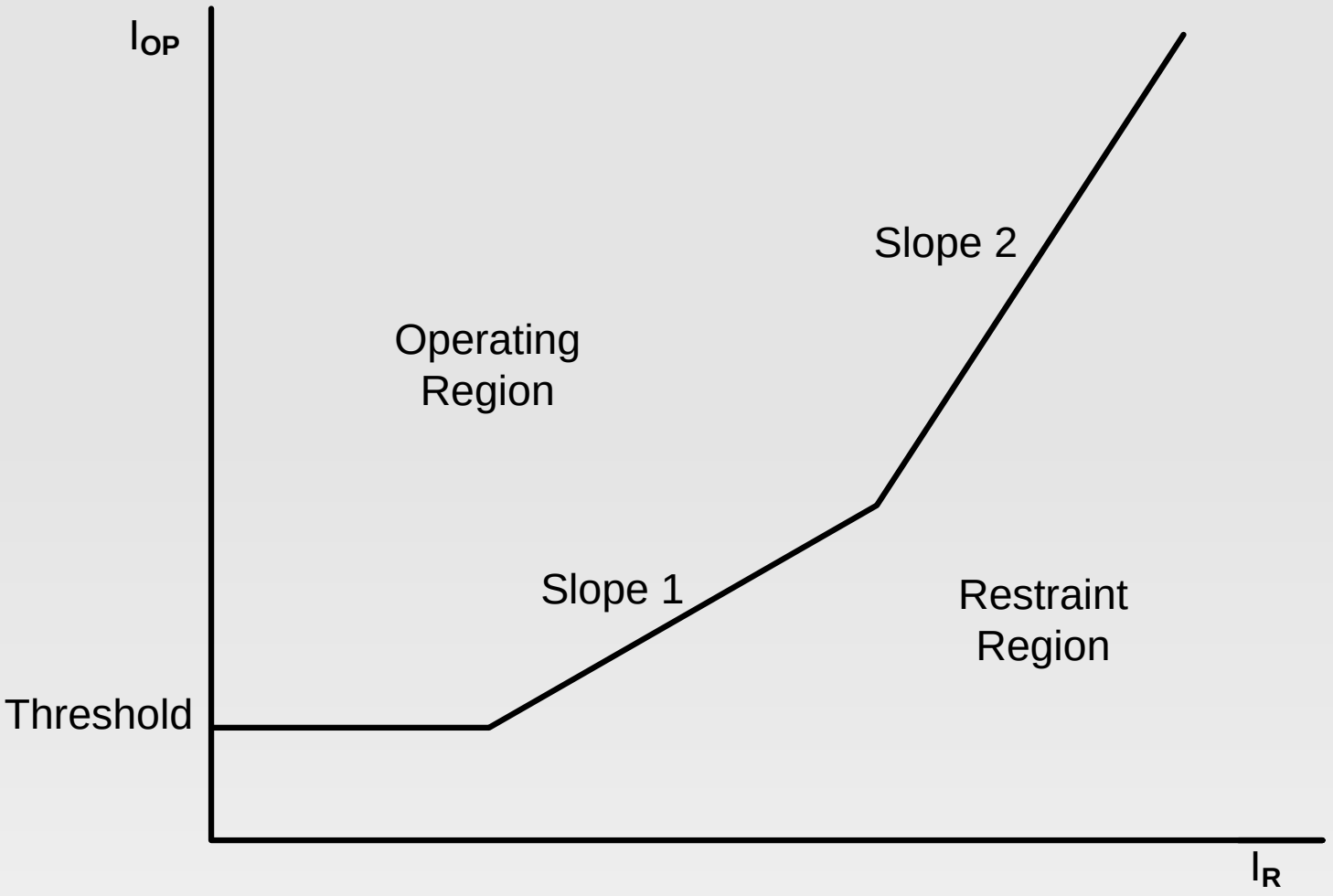
Low-Z Diff Basics

- Restraint quantity (I_R) = Through current or normal load current flowing through CTs
- Operate quantity (I_{OP}) = Differential current
- Slope = I_{OP} / I_R

Low-Z Diff Basics

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

Percentage Current Diff Characteristics



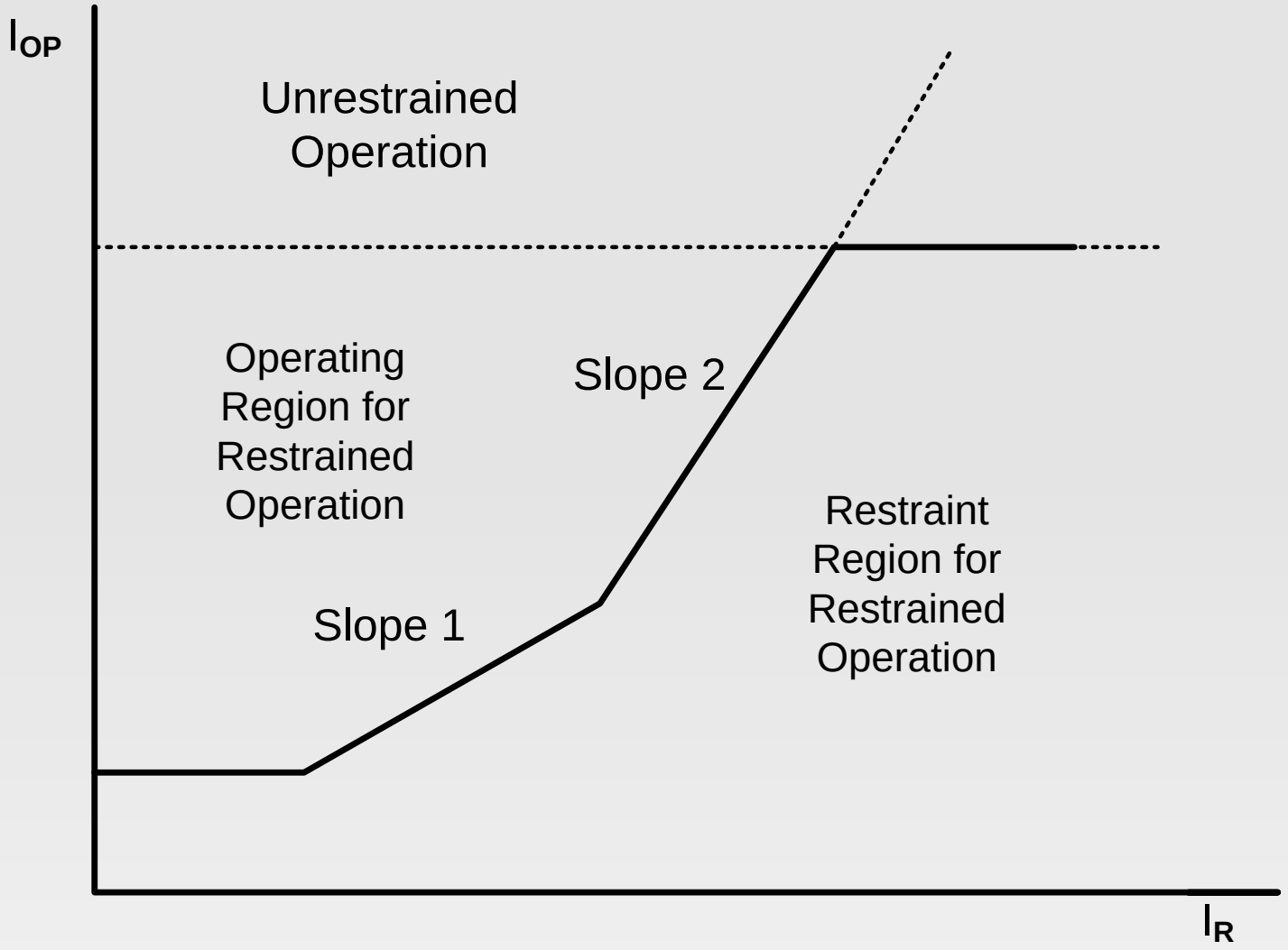
Setting Low-Z Diff

- Select a min. bus fault for which the relay should operate
- Set the threshold above the max. current leaking from the differential zone
- Set above the max. load level

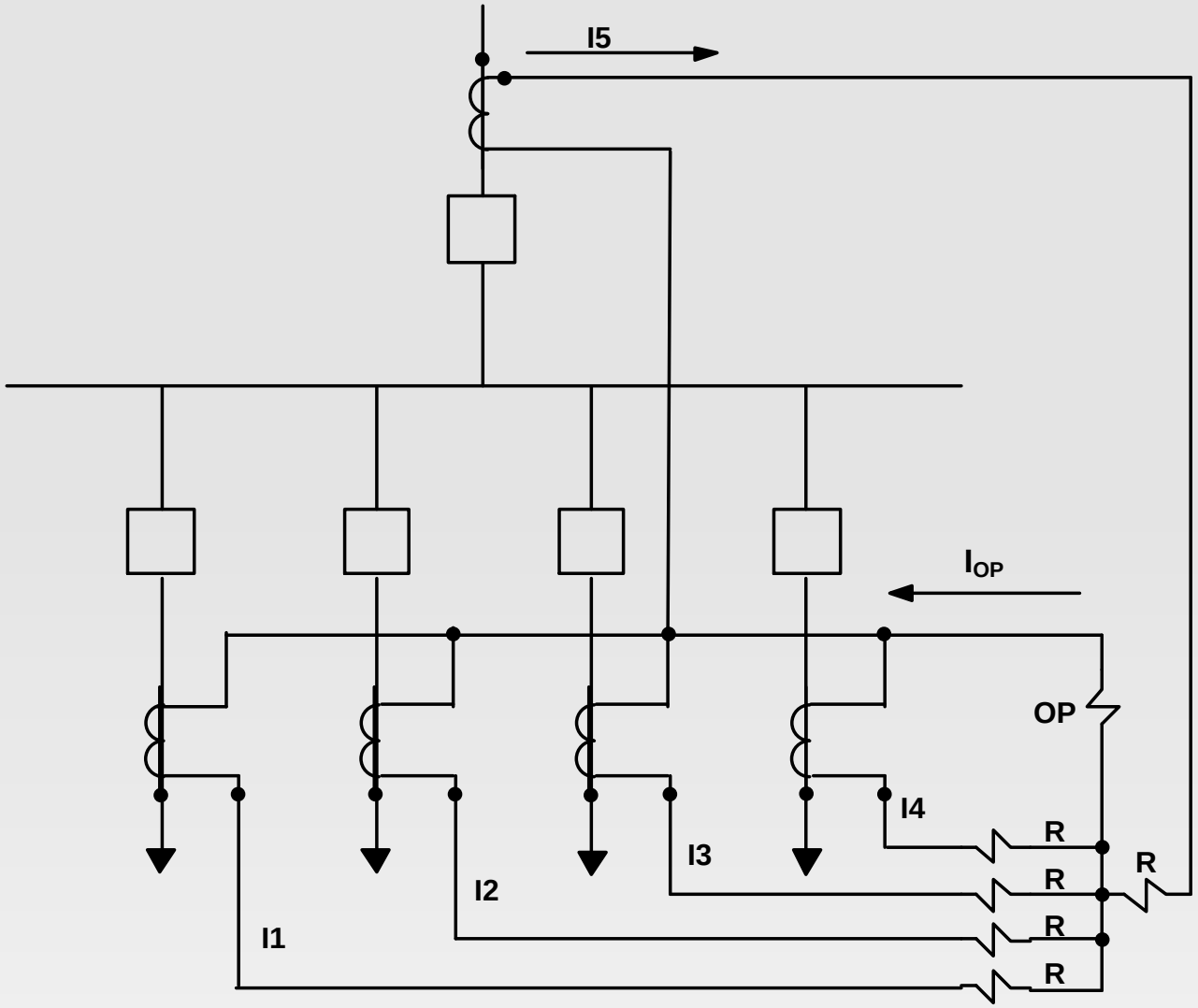
Setting Low-Z Diff

- Slope 1 typical setting -> 10-25% of max. bus current
- Set Slope 2 to restrain false diff current caused by CT saturation during heavy external fault

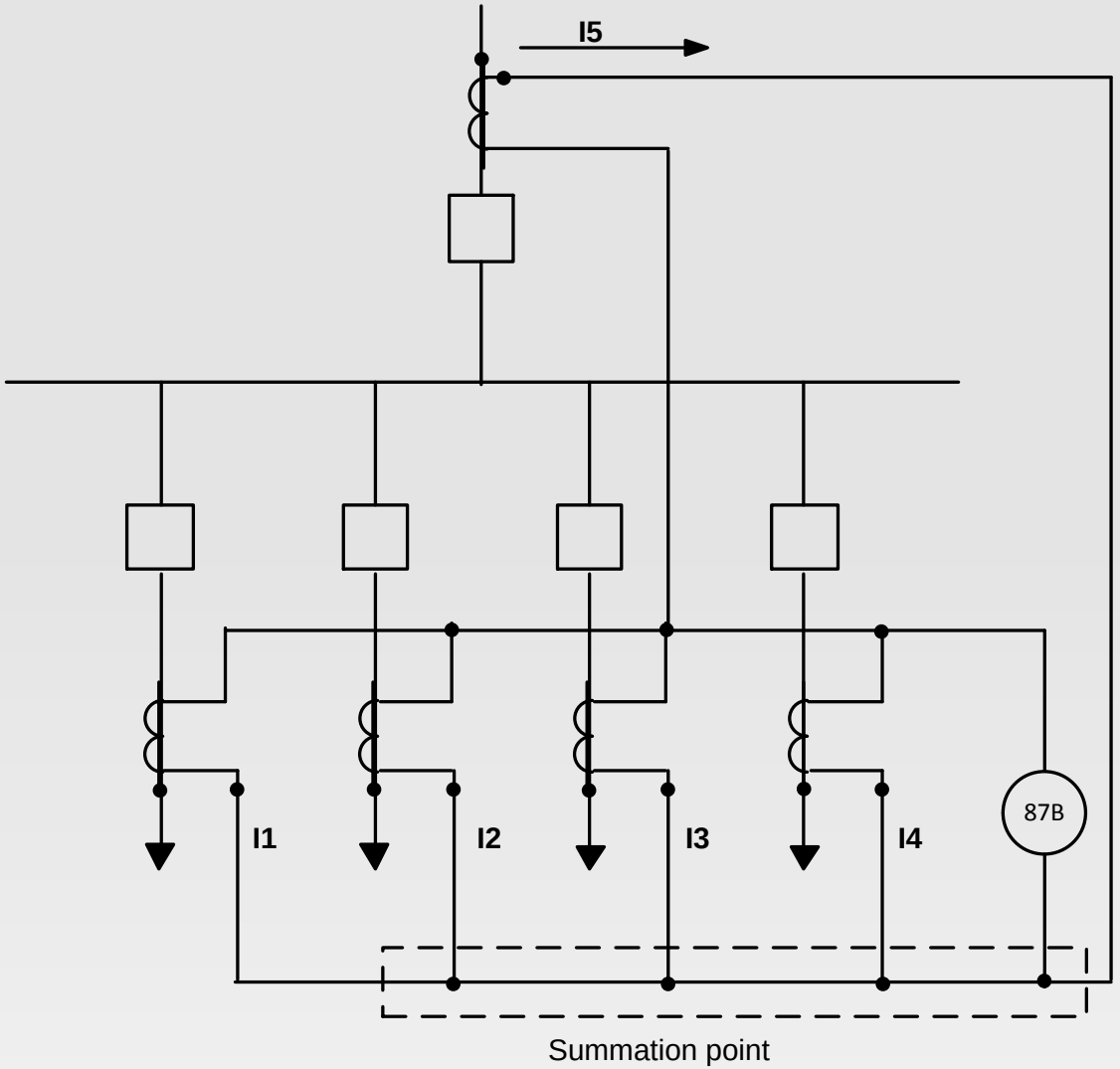
Unrestrained Operation



Multi-restraint Bus Diff



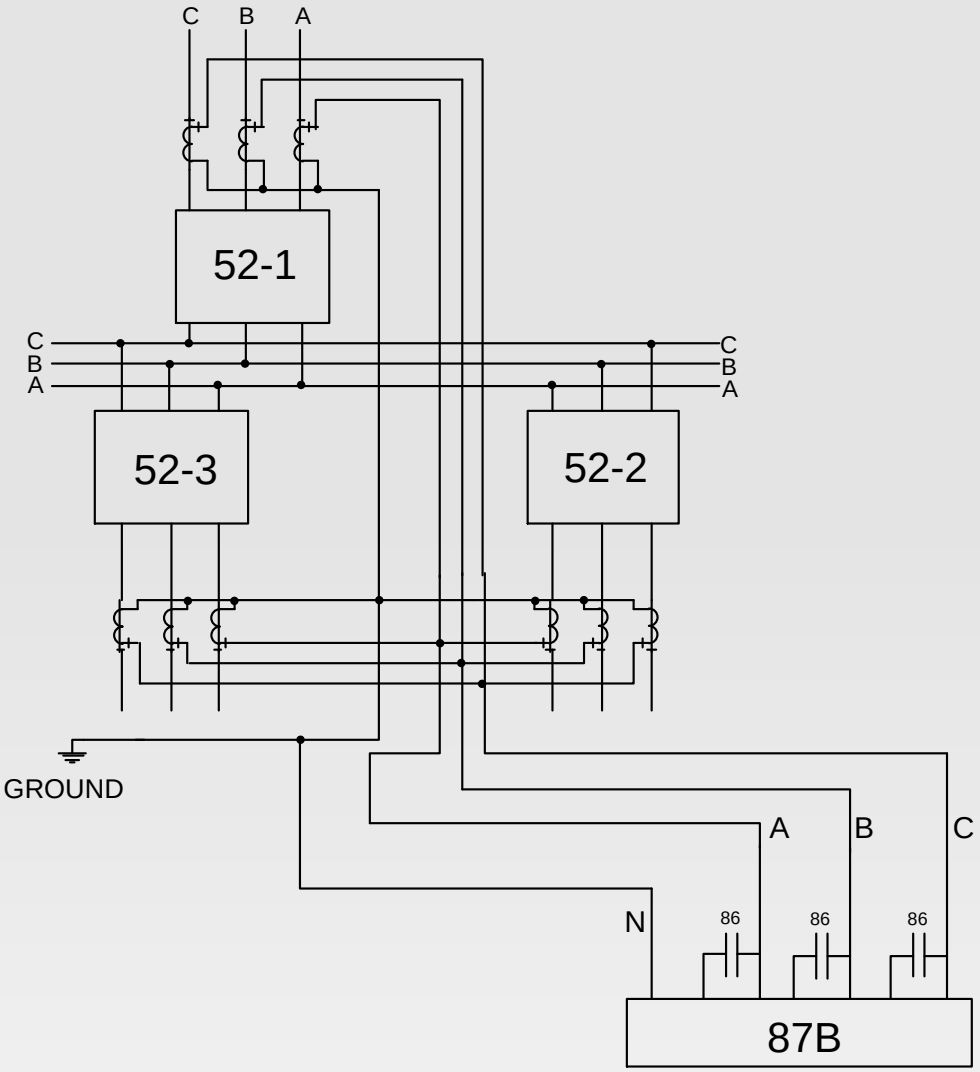
High-Z Diff Basics



High-Z Diff Basics

- Has High-Z to the flow of CT secondary current
  - Generally ≥ 1,000 Ω resistive
- Paralleled output of all CTs in the system and connecting them to a common bus, then wired to the relay
- Operates based on the rising voltage which appears at the summing point

High-Z Diff Basics



Setting High-Z Diff

- Threshold > the max. possible voltage developed across the relay for an external fault
- Vthreshold = $\frac{I_F}{N}$ * (R_{CT} + R_L * P)

Setting High-Z Diff

- I_F = the max. fault current
- N = CT ratio
- R_{CT} = dc resistance of CT sec. wdg. and lead resistance up to the CT terminals (at max. expected operating temp.)
- R_L = a one-way dc resistance of a lead from the diff junction point to the fault CT terminals (at max. expected operating temp.)
- P = 1.0 for t 3Ø faults and 2.0 for 1Ø faults

Setting High-Z Diff

- $V_{relay} = K * V_{threshold}$
- Where:
  - K = margin for safety to ensure secured operation, usually 1.25 or higher

Setting High-Z Diff

- Only calculate 3Ø and 1Ø faults
- For 1Ø faults, CT sec. fault current flows through both fault CT leads. P = 2
- For 3Ø faults, CT sec. currents = 0 in the return lead. P = 1

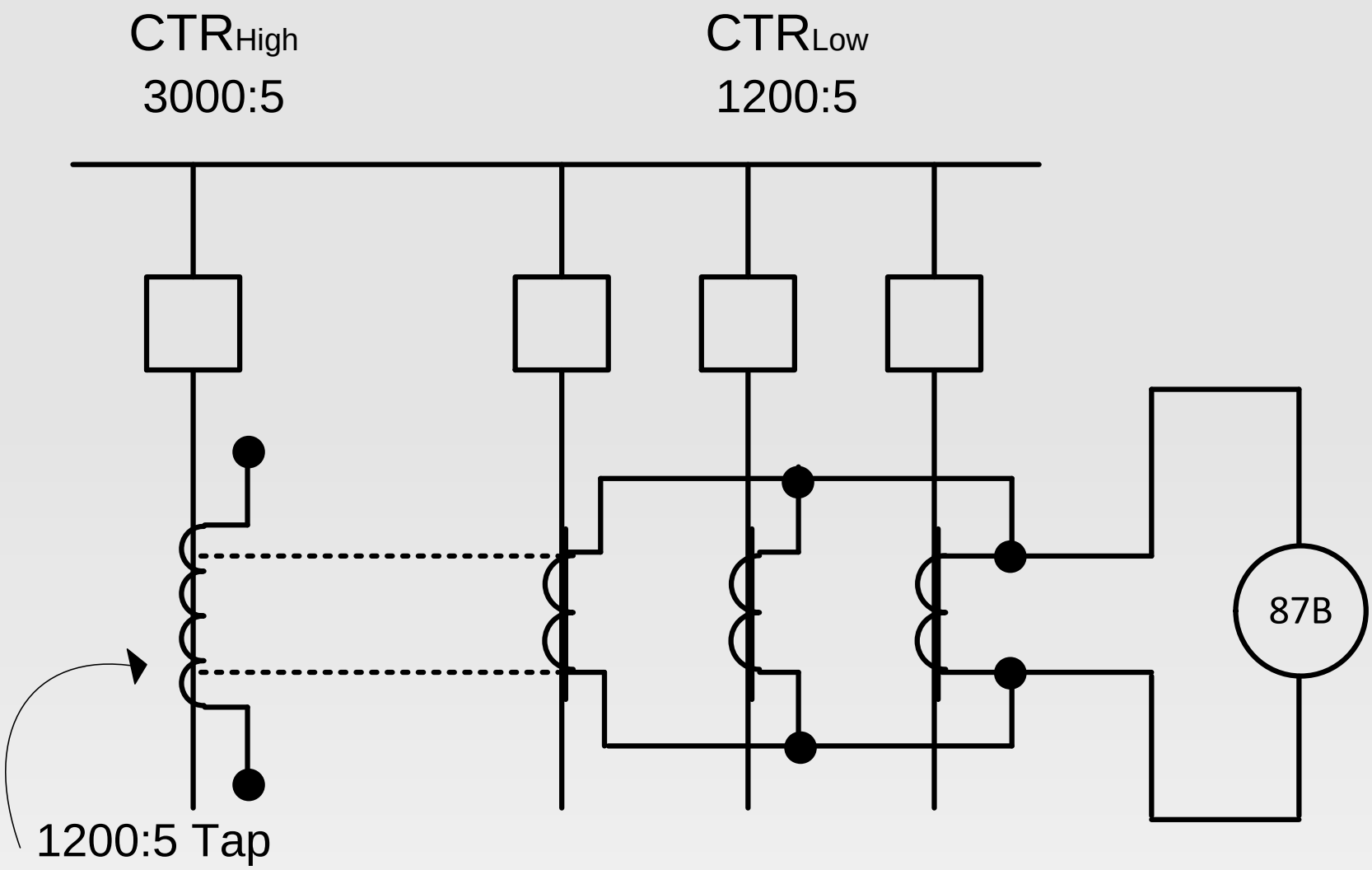
Setting High-Z Diff

- If 1Ø fault current ≥ 3Ø fault current, calculate only for the 1Ø faults
- Resistance of the CTs and leads will increase as the temperature rises

Mixing CT ratios

- Using Partial Tap on CTs
- Connecting 2 CTs in Parallel
- Interconnecting CTs at Tap

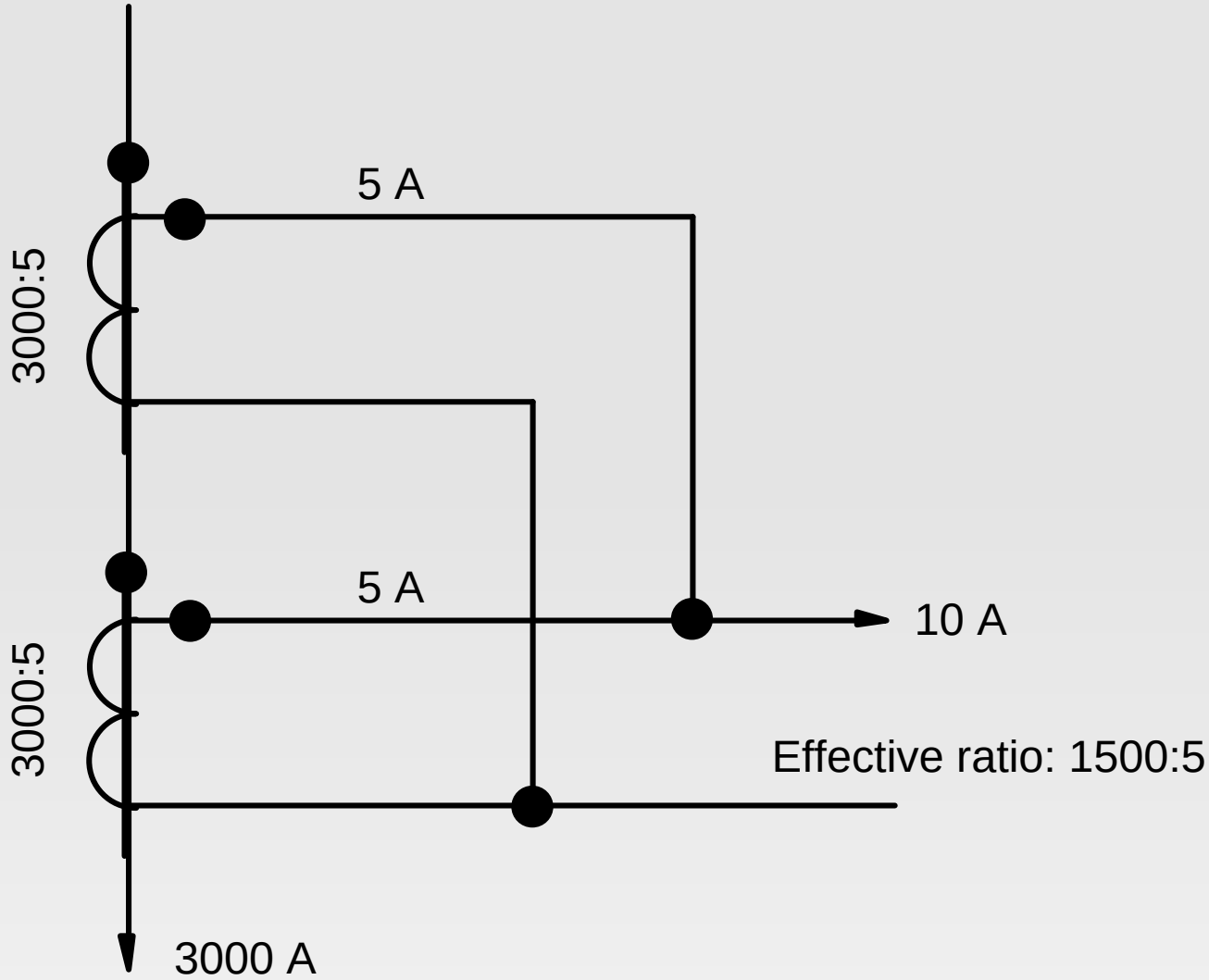
Using Partial Tap on CTs



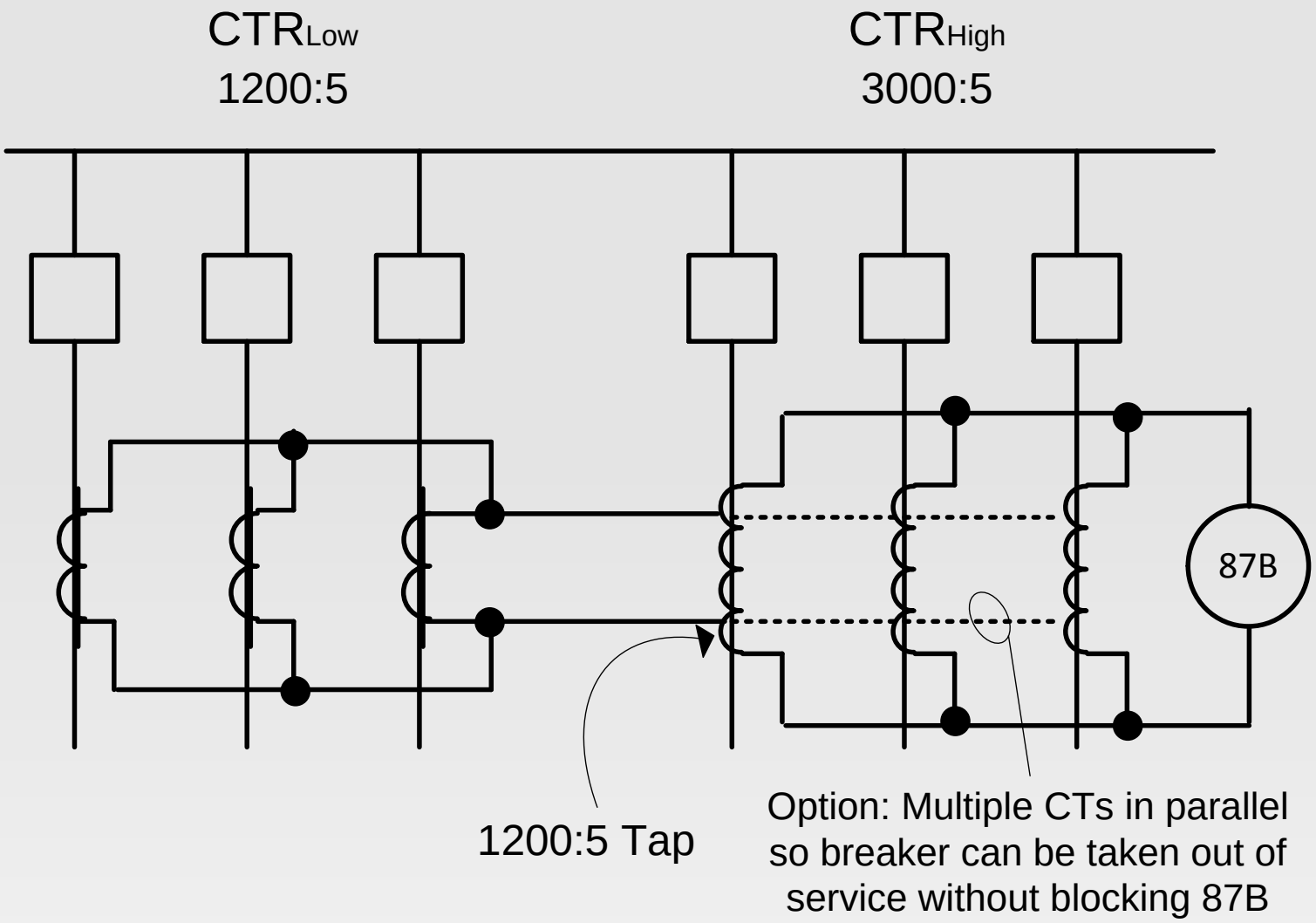
Using Partial Tap on CTs

- CT overload
  - 1200:5MR and 3000:5MR, tap 3000:5 at 1200:5
  - If 3000 A flows -> (3000/1200)*5 = 12.5 A sec
- High voltage across the open terminals of tapped CTs
- Unadvisable Method

Connecting 2 CTs in Parallel



Interconnecting CTs at Tap



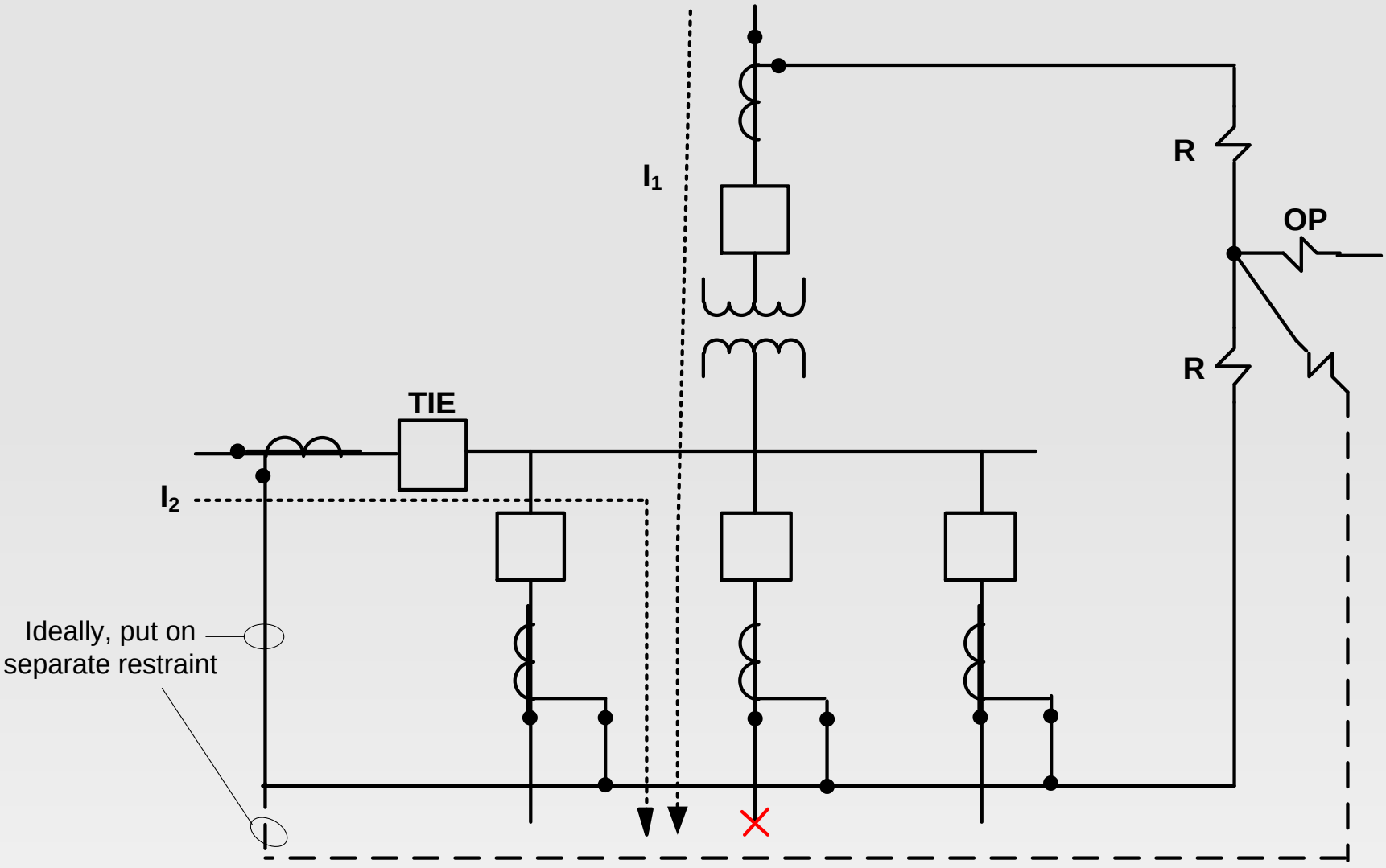
CT for Low-Z Diff

- CT Polarity plays a critical role
- CT AC Volt rating > Steady state AC volt during external fault

Paralleling CTs on Low-Z Diff

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

Paralleling CTs on Low-Z Diff



CT for High-Z Diff

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

CT for High-Z Diff

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

Conclusion

	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)

Conclusion

	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?