Practical EHV Reactor Protection

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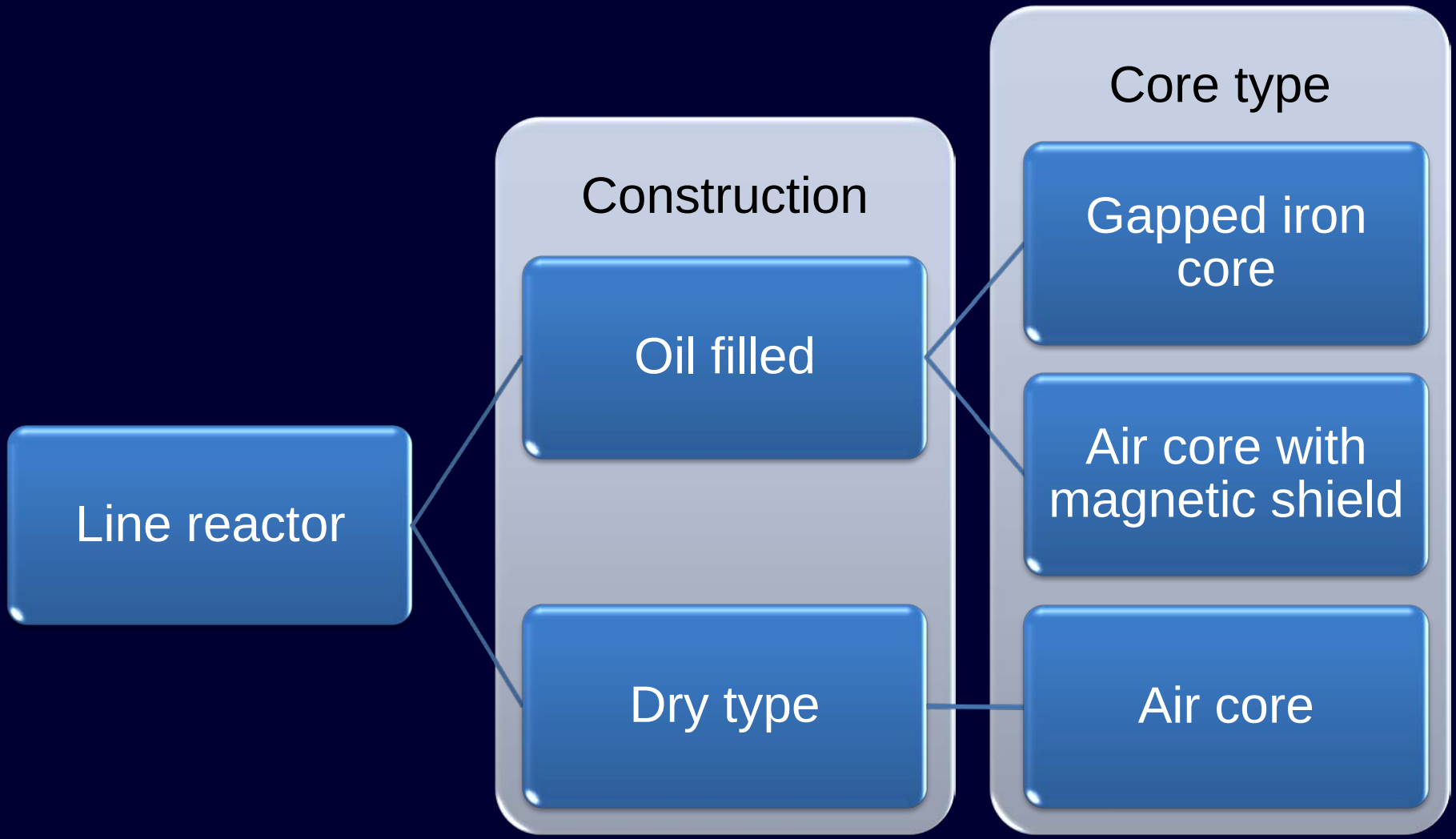
Outline

- Transmission line reactors
- Shunt reactor characteristics
- Reactor faults
- CT selection criteria
- Proposed protection
- Summary

Transmission Line Reactors

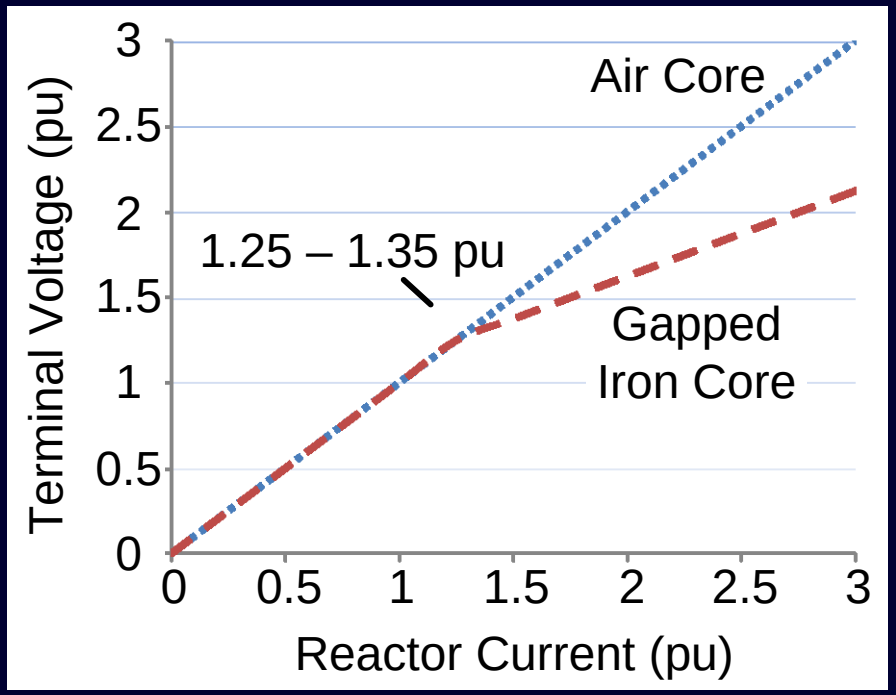


Transmission Line Reactors

- Gapped iron core
  Inrush and harmonics
  - Higher knee point than transformers
  - Lower saturation effects
  - Very little remanence
- Oil Filled
  Mechanical protection possible

Reactor Characteristics
Linearity

- Air core – current varies linearly with voltage
- Gapped iron core – current is nonlinear beyond knee-point voltage



Reactor Characteristics
Switching

- Reactors have high X/R ratio and long dc time constants
- 3Φ windings experience different degrees of dc offset
- Air core has
  - No inrush
  - Current sinusoidal with dc

Reactor Characteristics
Switching

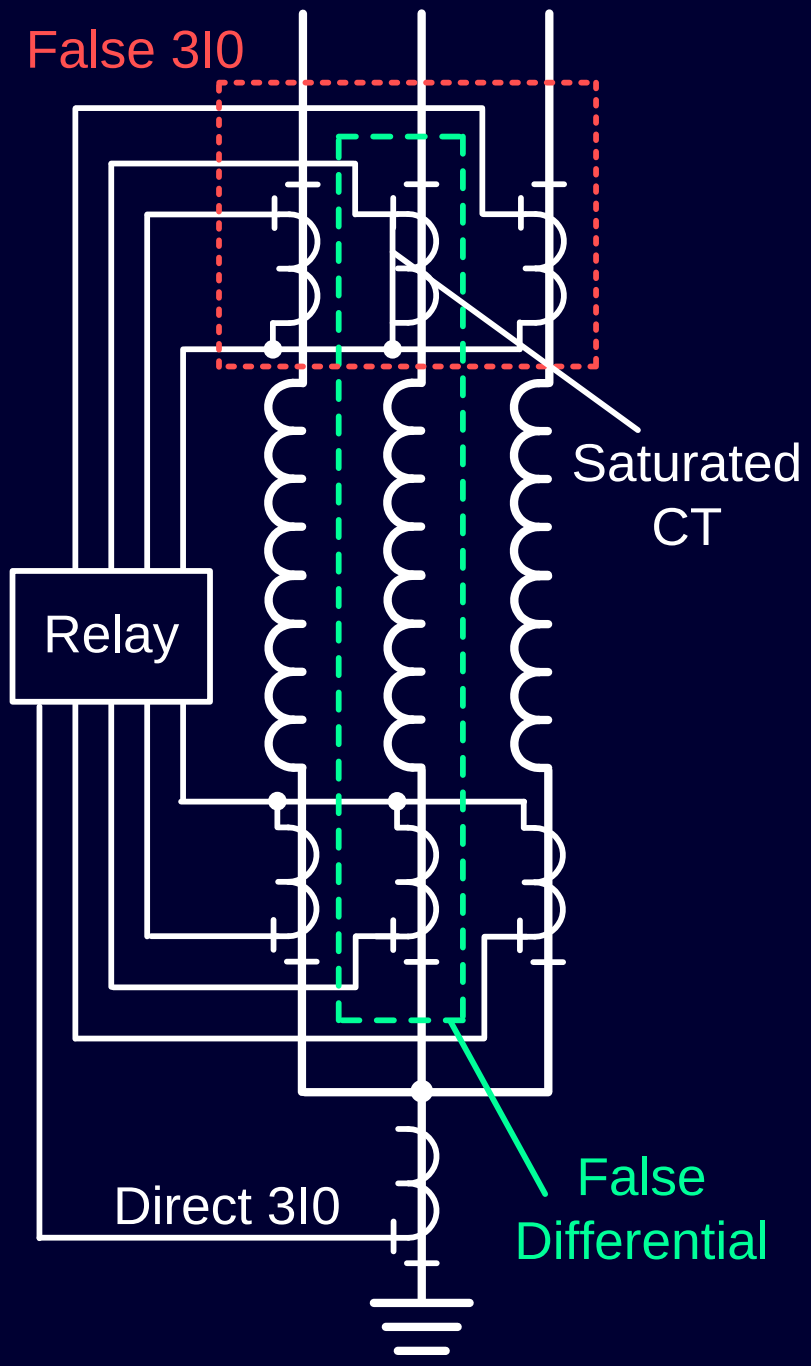
- Gapped iron-core reactor has
  - Inrush and harmonics generated on saturation
  - Current nonsinusoidal with dc
  - Unbalance current at neutral point
  - Instantaneous current peak at 3 to 5.5 pu
- Relay filters dc and harmonics

Reactor Characteristics
Switching and De-Energization

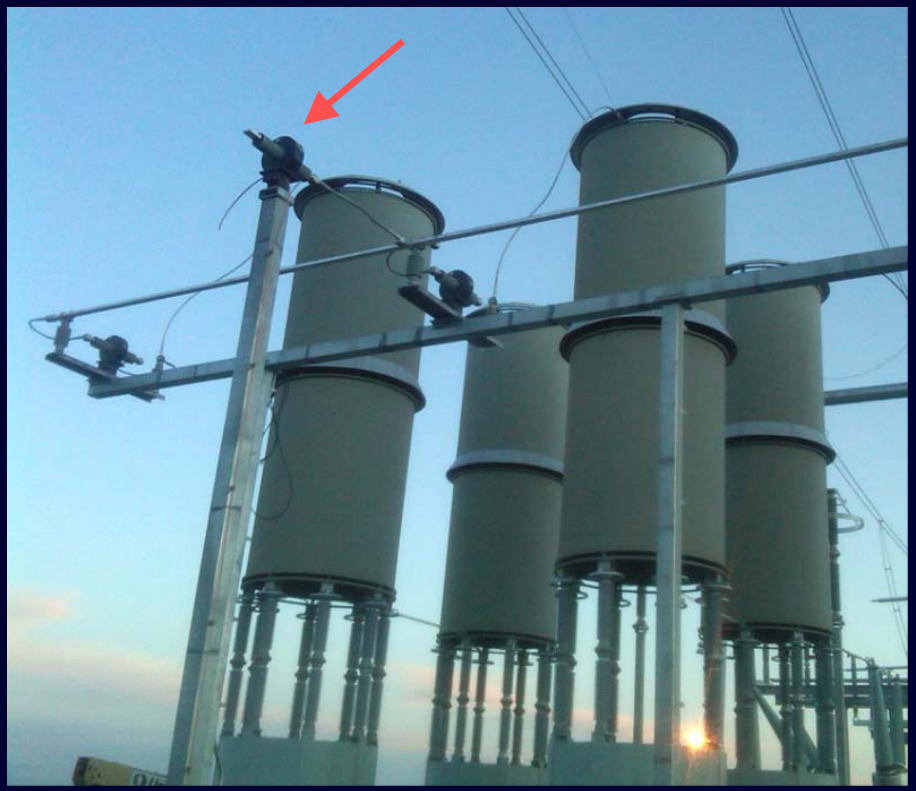
- Circuit breaker
  - Current chopping → high TRV → breaker restrikes
  - Restrike → fast transient voltage wave → turn-to-turn failure near high-voltage terminals
- Alternate approach
  - Circuit switcher with high TRV withstand
  - Low fault interruption capability

CT Performance
Switching

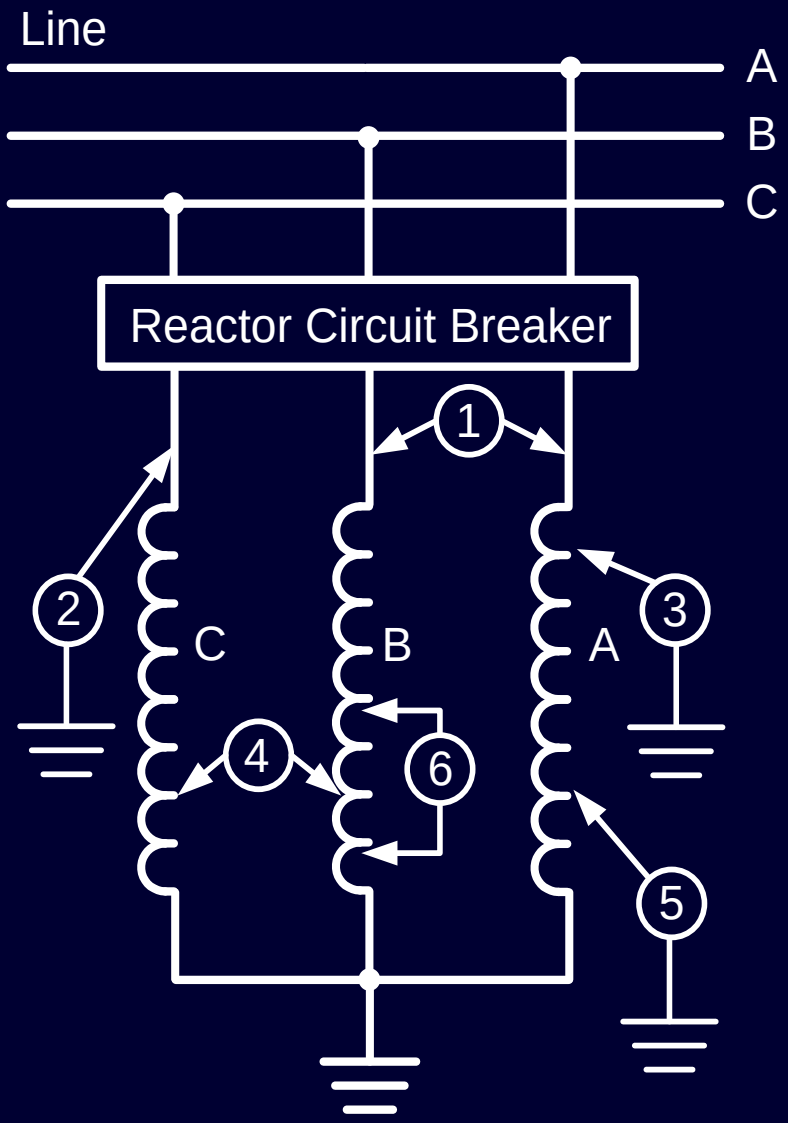
- Factors
  - High X/R, long dc
  - Frequent switching
  - Remnant flux
- Unequal CT performance
- Ground CT
  Immune to false 3I0



Ground CT
Critical



Faults on a Shunt Reactor



Validating CT Suitability

- Relatively low reactor rated load
- High sensitivity for low-grade faults
- Adequate performance on high-grade faults to ensure dependability

Type	Voltage	MVAR	Rated Current	Reactor X/R	Max Fault
Dry-type air core	345 kV	20	33.5 A (Primary)	53.75	6,800 A (Primary)

Criteria 1
Provide Adequate Sensitivity

- Desired sensitivity is 10 to 15% of reactor rating
- 5 A and 1 A relays considered for low and high CT ratios

CT Ratio	Minimum Sensitivity in Percent of Reactor Rating	
	5 A Relay, 0.25 A	1 A Relay, 0.05 A
10T	7.5	NA
13.4T	10	NA
20T	15	NA
60T	NA	9
67T	NA	10
80T	NA	12
100T	NA	15

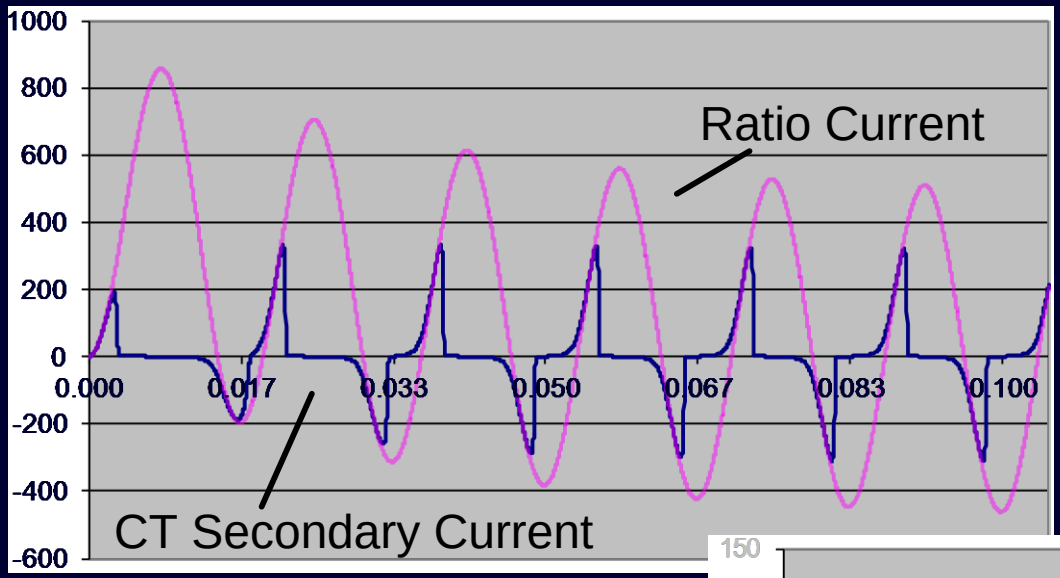
Criteria 2

Prevent Asymmetrical Saturation on Switching With CT Saturation Check

$$20 \geq V_S = \left(1 + \frac{X}{R}\right) \bullet I_S \bullet Z_B$$

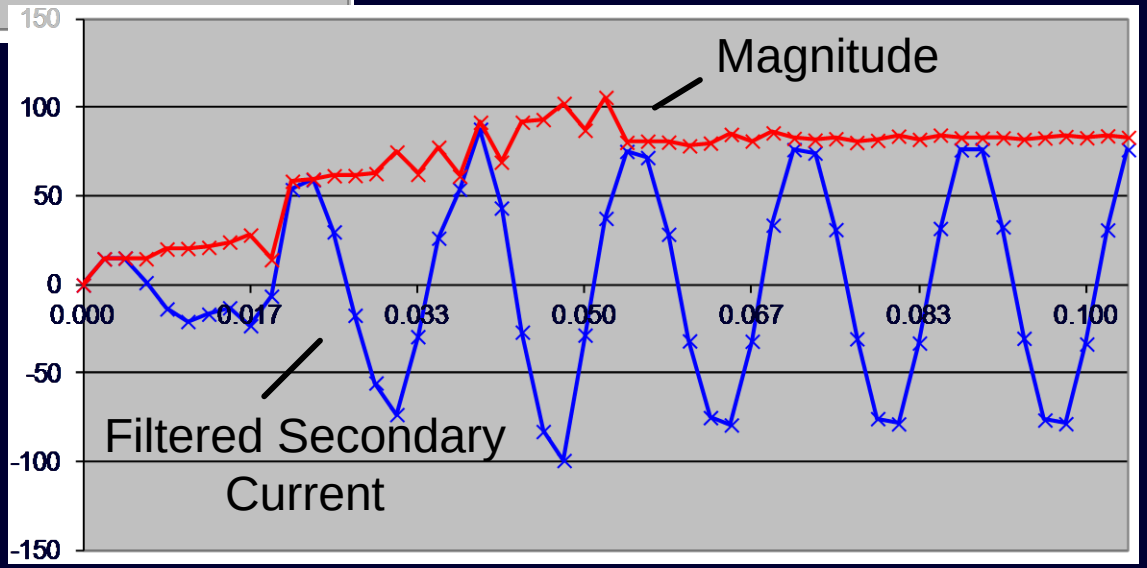
	Current Rating	Accuracy Class	Full Turns	Tapped Turns	V_S
Low-Ratio CT	100:5	C100	20T	20T	24
High-Ratio CT	1200:5	C800	240T	100T	1.6
	2000:5	C800	400T	100T	2.6

Criteria 3
Limit Saturation to Reasonable Level



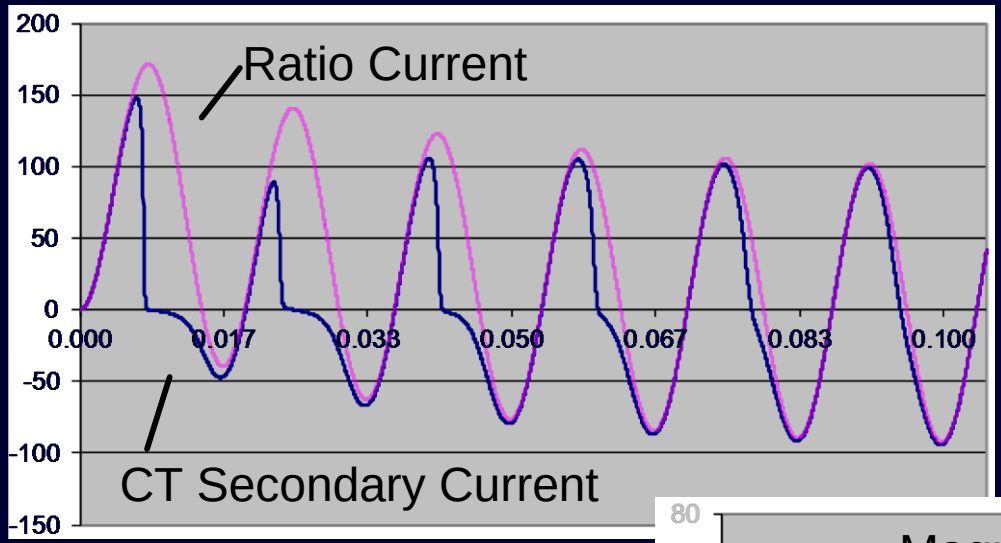
C100, 20T
CT Ratio for
5 A Relay

Raw Current



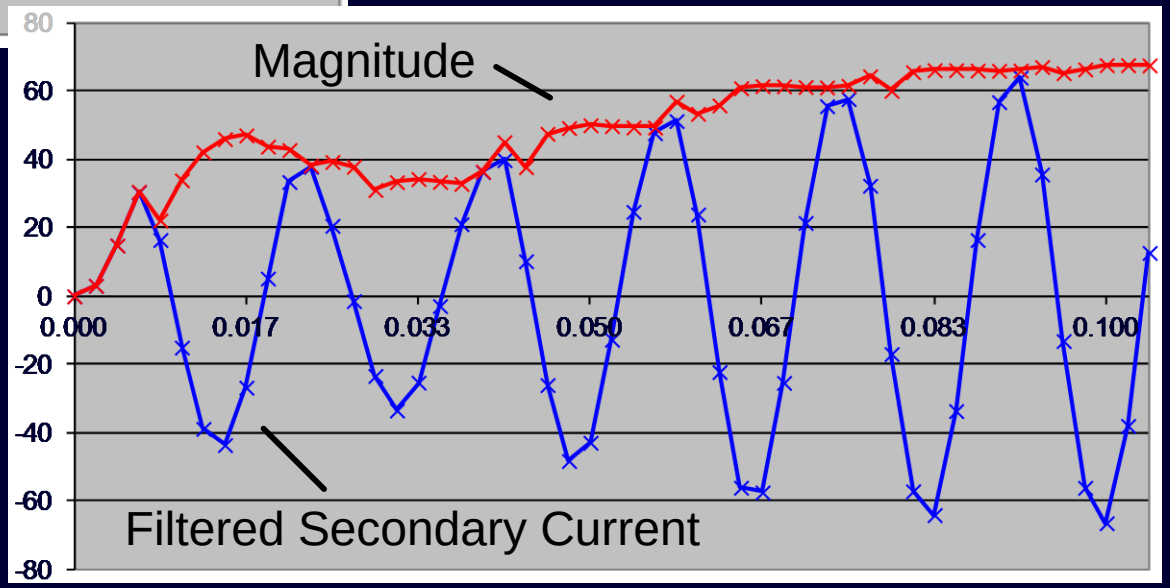
Filtered Current

Criteria 3
Limit Saturation to Reasonable Level



C800, 2000:5
Multiratio, 100T
Tap for 1 A Relay

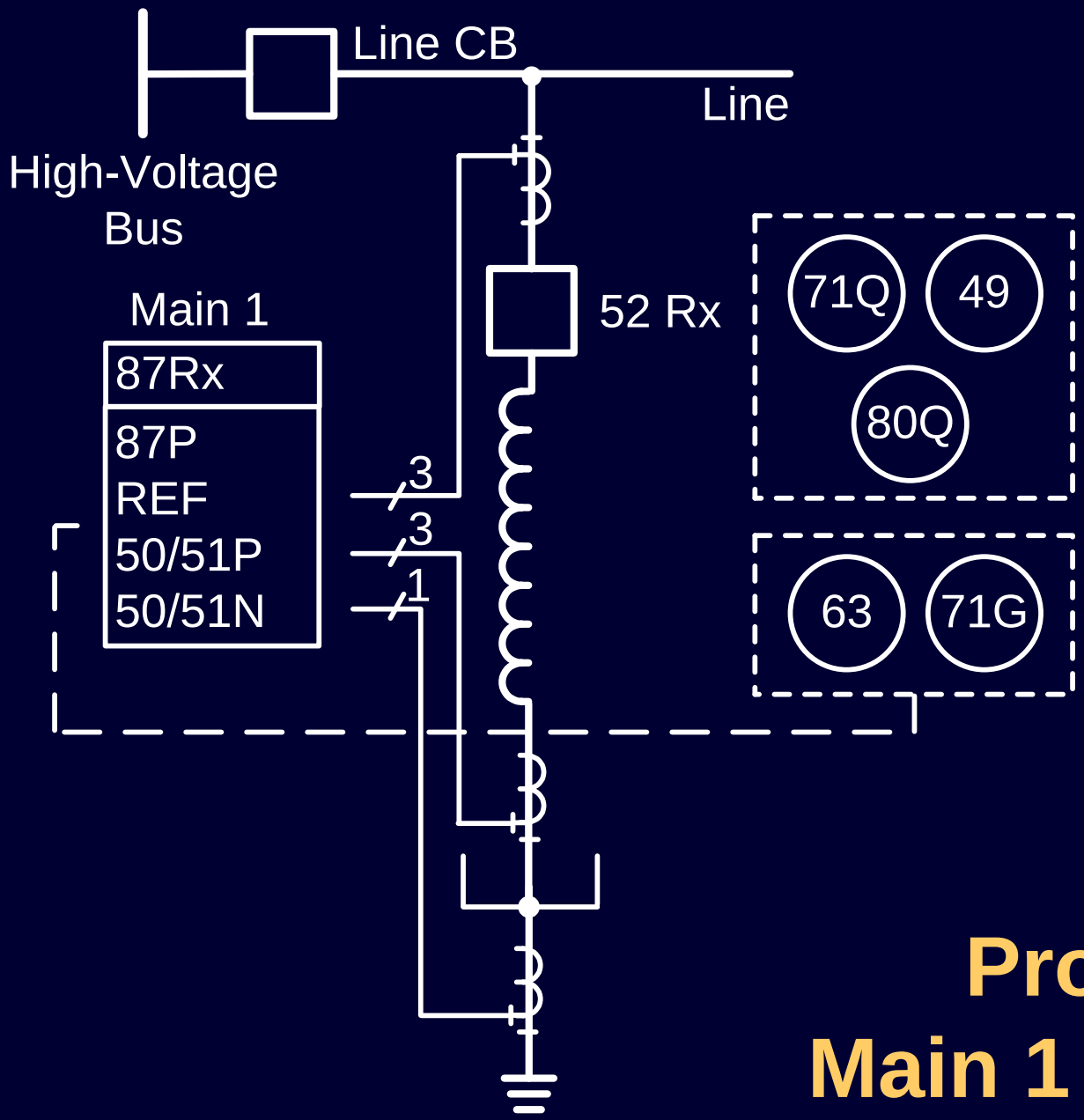
Raw Current



Filtered Current

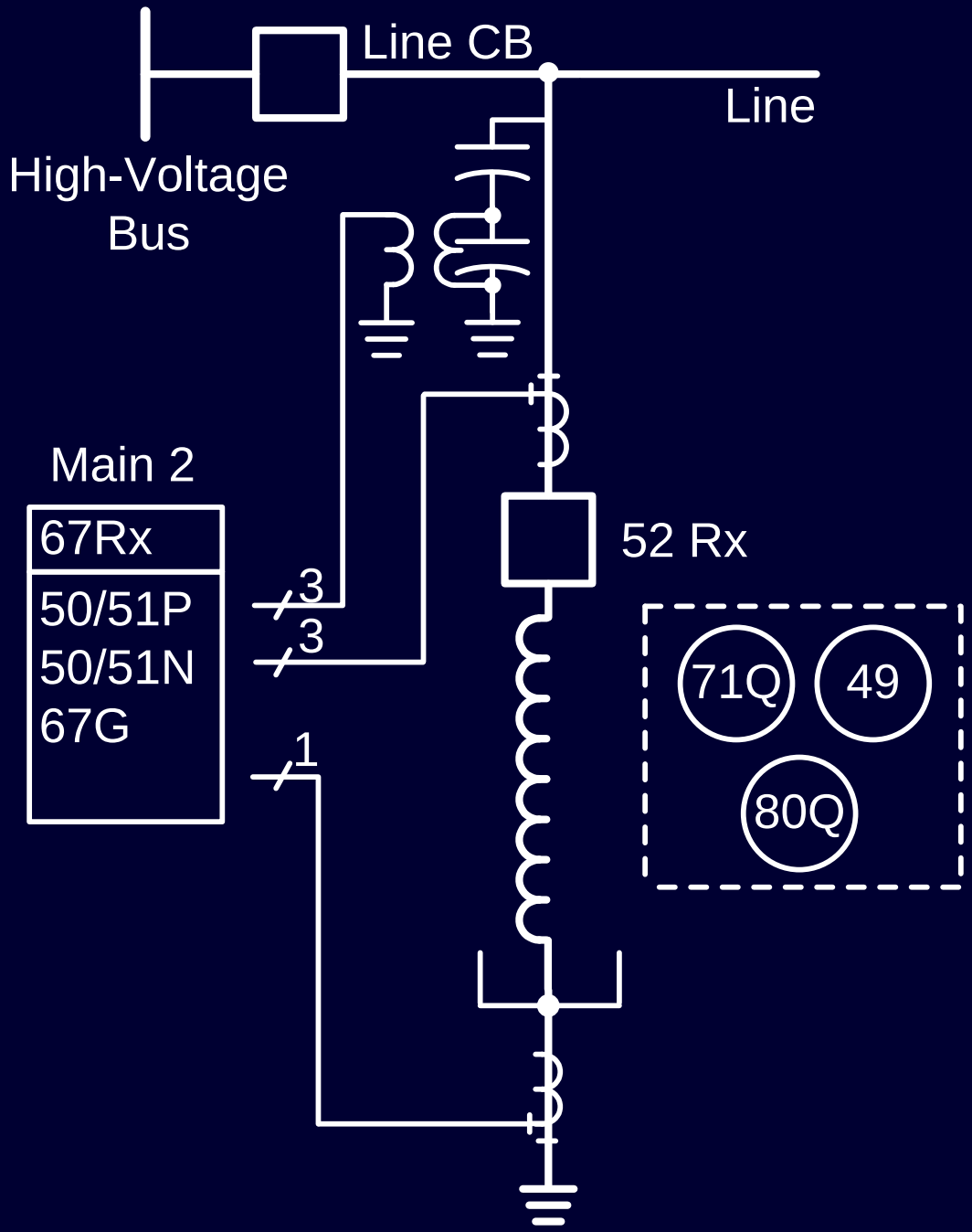
CT Evaluation – Conclusion

- High CT ratio with 1 A nominal relay
  - Ensures adequate sensitivity
  - Provides dependability for high-grade faults
  - Requires check of I^2t capability
- High-set element (50) set below minimum saturated CT current
- CT analysis tools for engineers



Proposed Main 1 Protection

Proposed Main 2 Protection

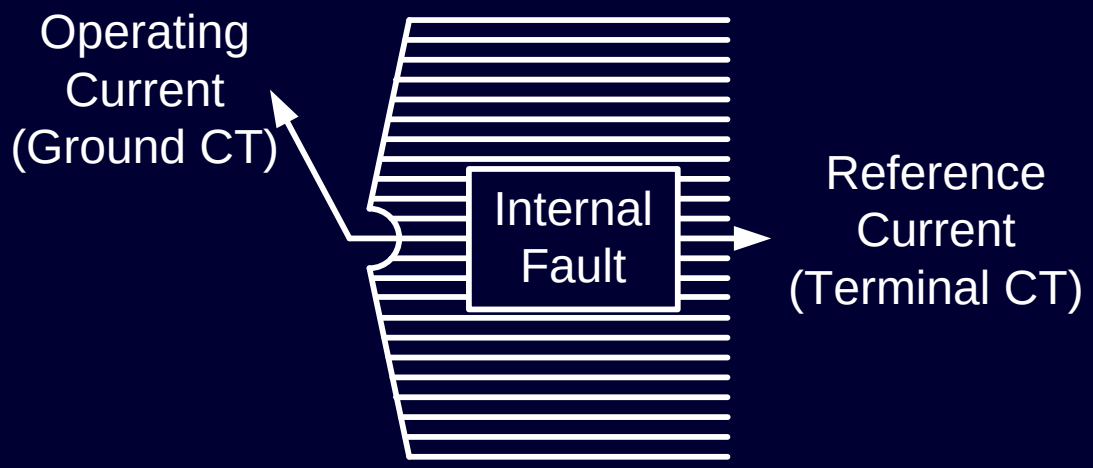


87P, KCL Differential Protection

- In-zone phase and ground fault protection
- Factors to consider
  - Sensitivity – minimum internal winding faults
  - Security – false differential on unequal CT performance
  - Pickup – balance sensitivity with security
  - Slope – external fault?
  - KCL – no inrush and harmonics

Restricted Earth Fault

- Principle – current polarized directional
- Zone – terminal 3I0 versus ground 3I0
- Resulting torque
- Terminal CT performance tolerance

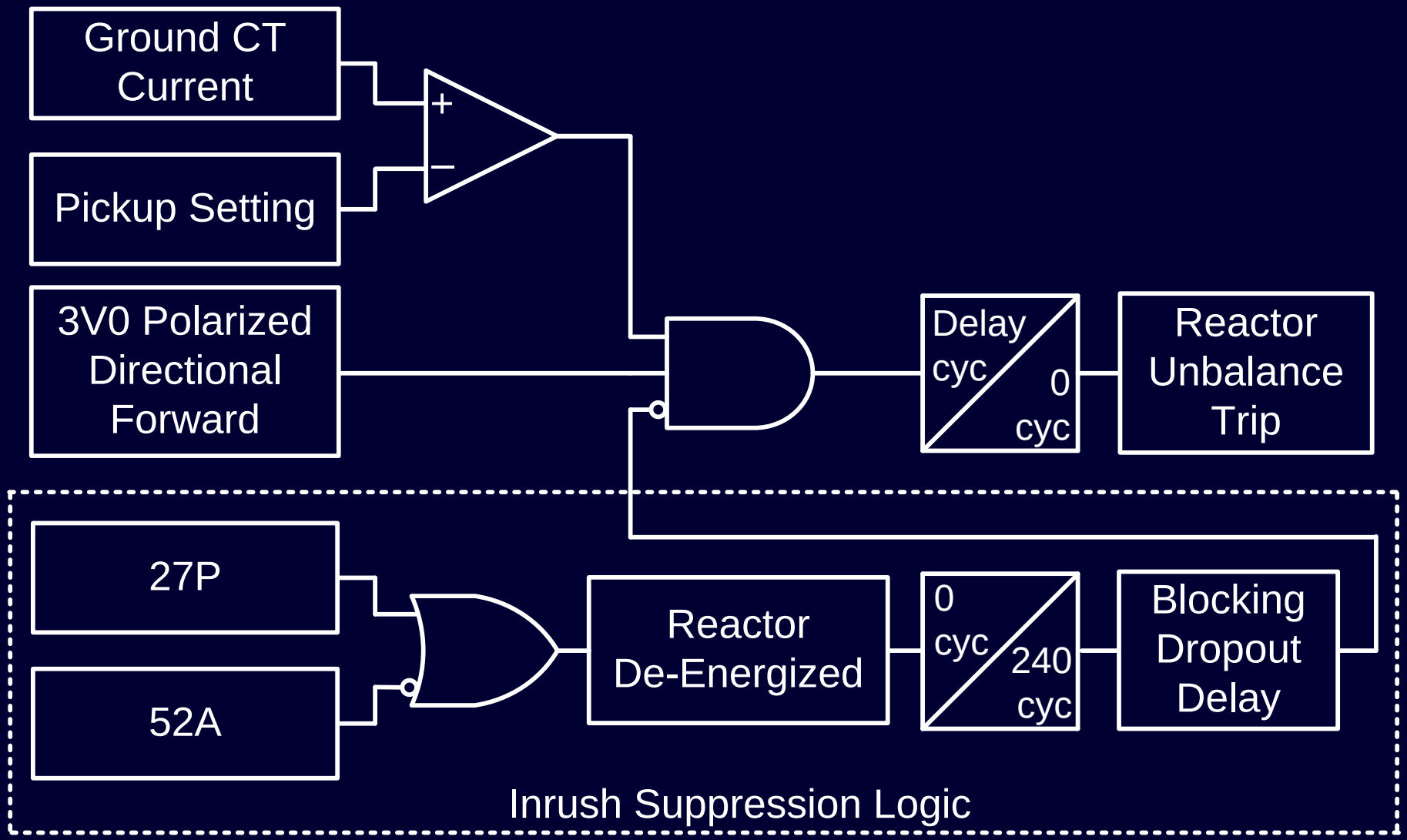


Turn-to-Turn Fault Protection

- 87P, REF, and 87Q are blind
- 67G scheme
  - Directional element – 3I0 from terminal CTs
  - Tripping element – 3I0 from ground CT
- Z0 directional element sensitivity
  - Low 3I0 and near zero 3V0
  - Z0 ≤ 0 for internal fault
  - Z0 = Z_{RX} for external fault

500 kV Reactor Faulted Turns

Inrush Suppression Logic



Overcurrent Backup

- Phase and ground faults
- Instantaneous (50)
  - Security – above switching current
  - Dependability – minimum saturated CT current
- Time-delayed (51)
  - Allows temporary rise in voltage
  - Time delay based on thermal load rating

Summary

- Shunt reactor types
  - Dry type – no 63SPR for turn-to-turn faults
  - Gapped iron core – inrush must be considered
- Reactor faults
  - Dependability and fast operation on high faults
  - Sensitivity on low-grade faults
- CT performance and selection factors

Proposed Protection

- Electrical and mechanical devices
- 87P for high-speed detection
- REF for sensitive detection of ground faults
- Turn-to-turn protection
  - 87P, 87Q, and REF do not respond
  - 67G and 63SPR provide redundant protection
- 50/51 overcurrent backup

Questions?