

Application Considerations When Protecting Lines With Tapped and In-Line Transformers

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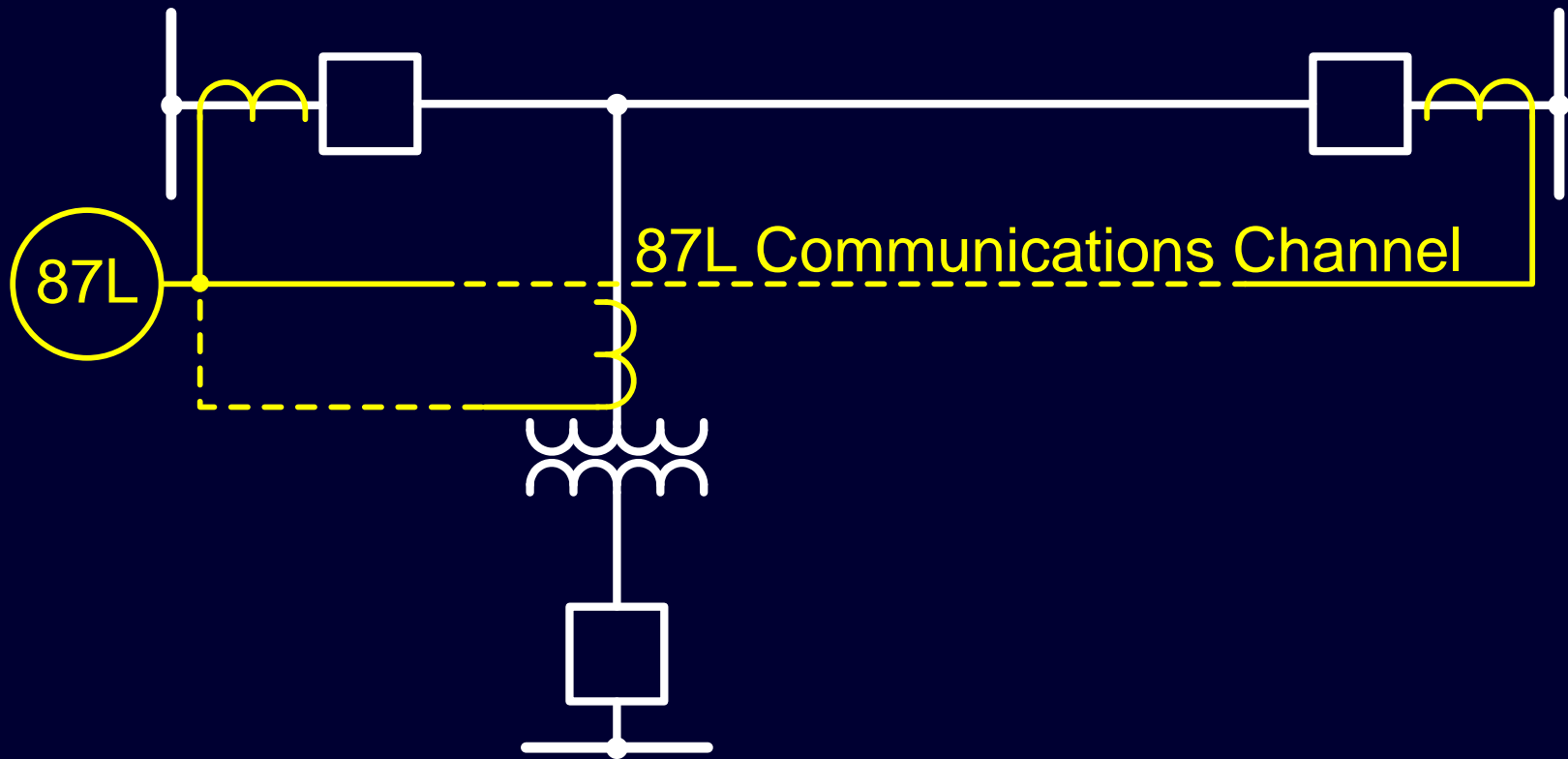
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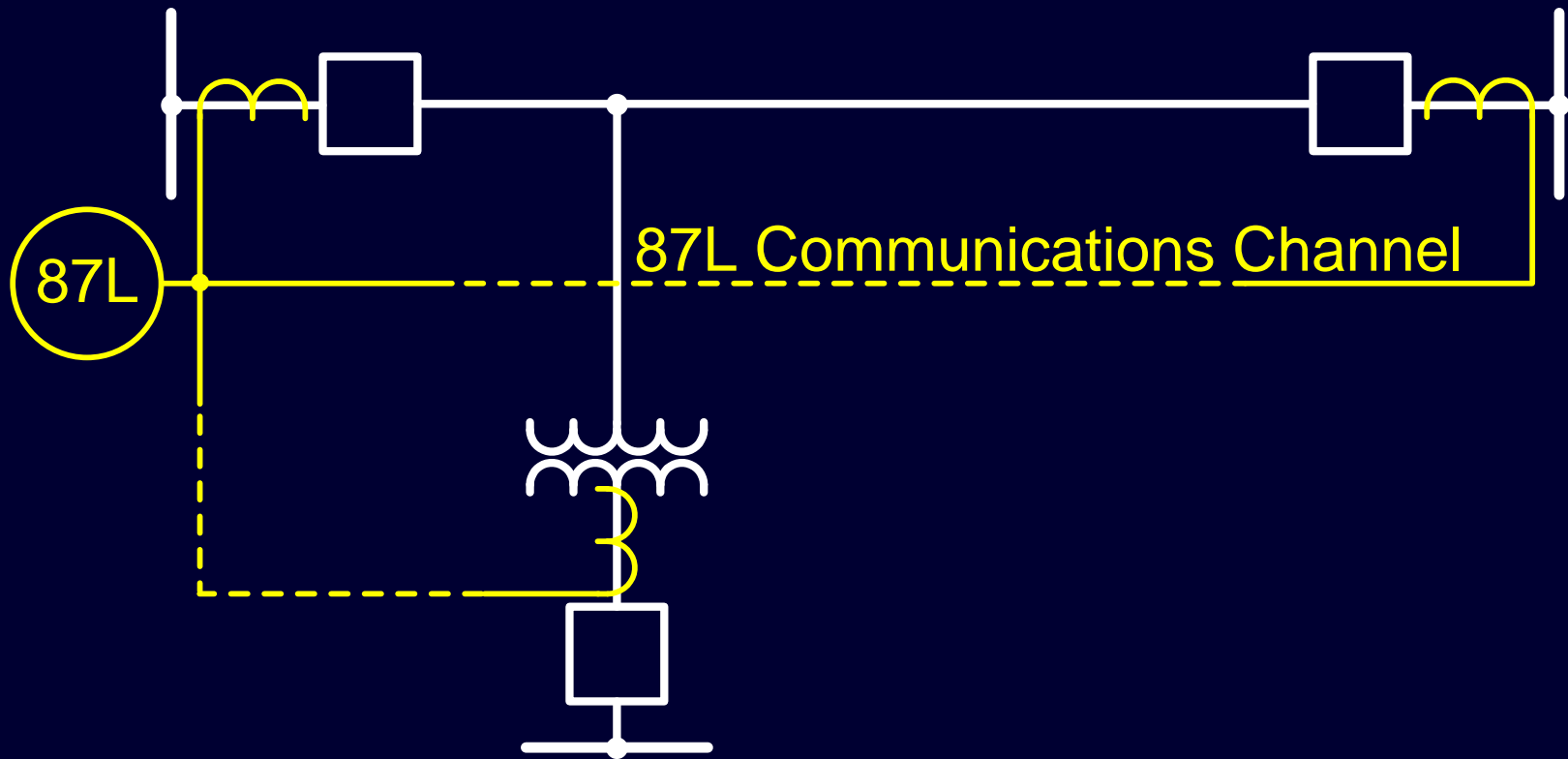
Outline

- Taps on transmission lines
- Tapped station protection
- Line protection challenges
- Line protection considerations
 - ◆ 67, 21, POTT / DCB, and 87L
 - ◆ AR and breaker failure
- Summary

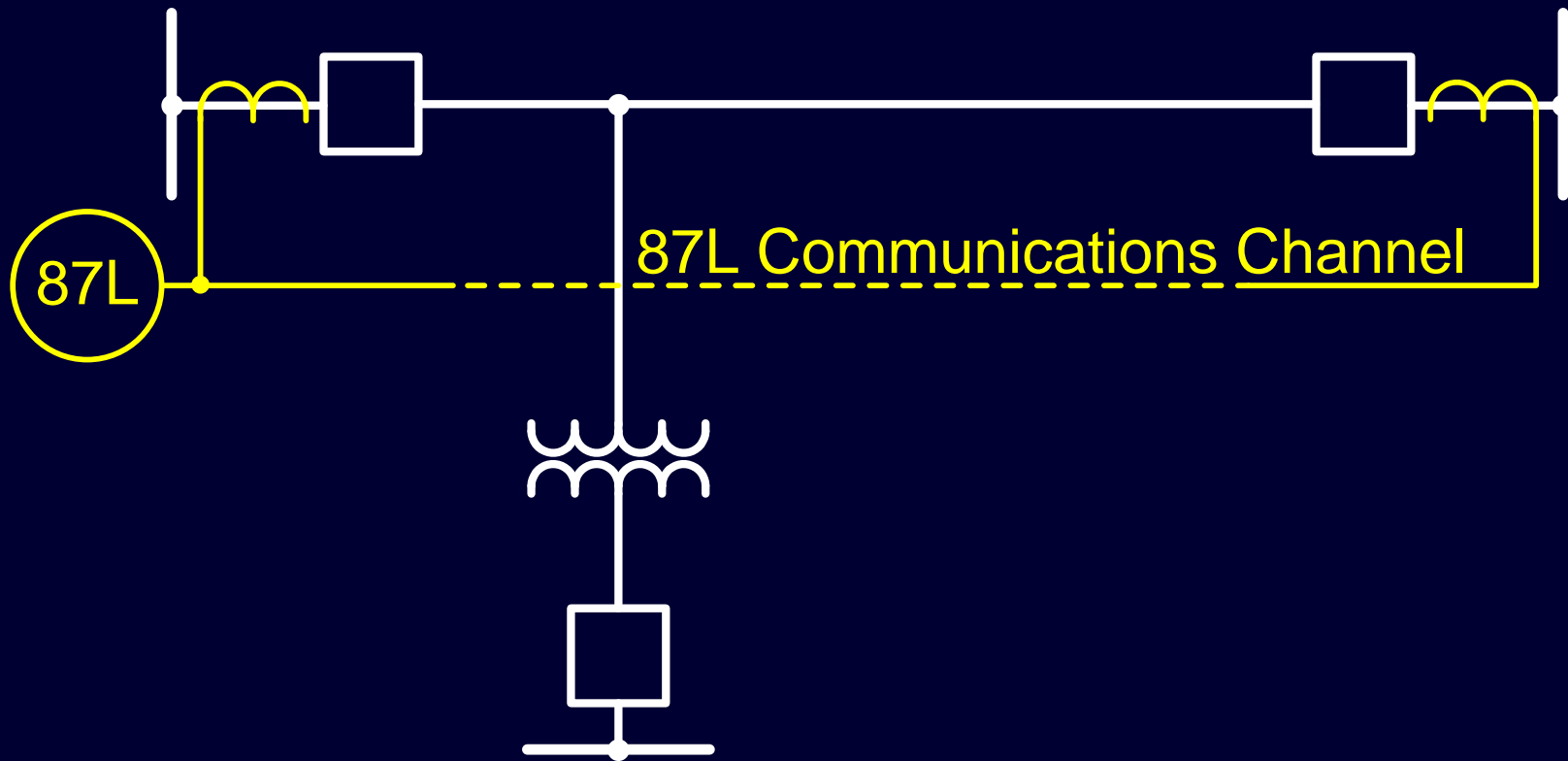
Three-Terminal Line



Three-Terminal Line With In-Line Transformer



Two-Terminal Line With Unmeasured Tap

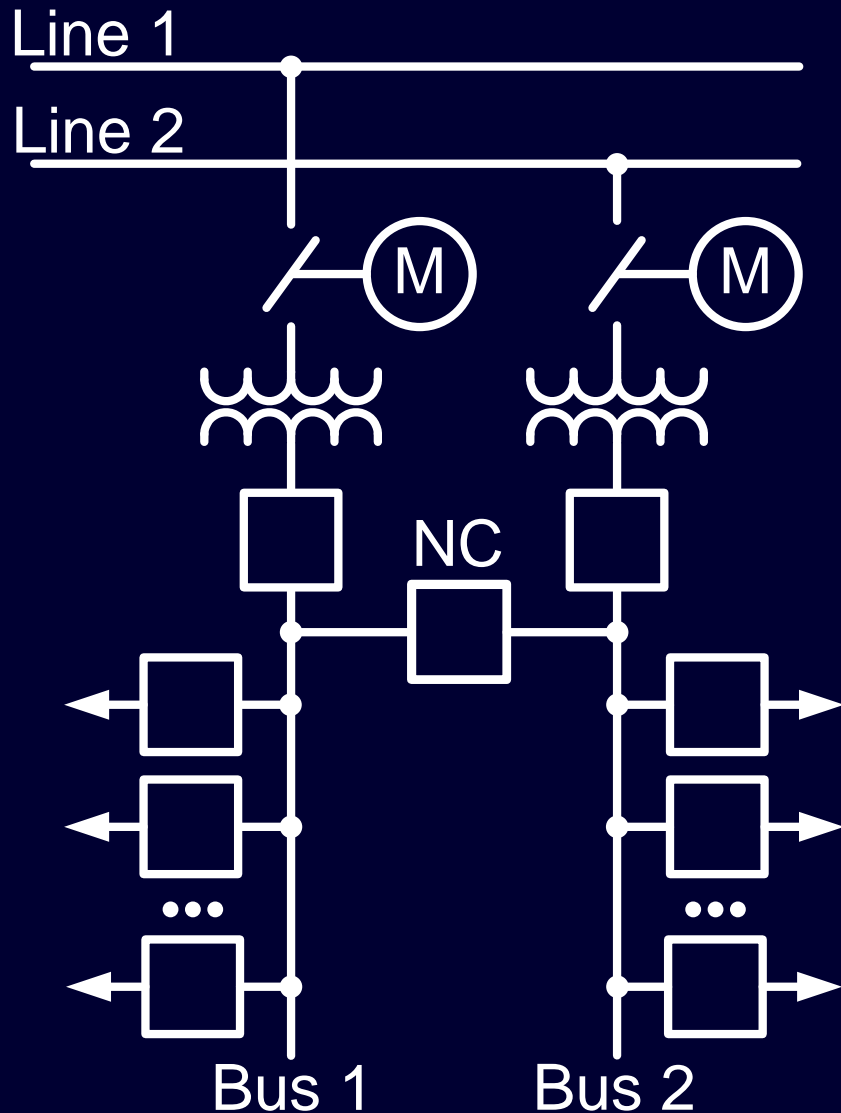


Practice of Tapping Loads

- Sparse loads along line right of way
- 230 and 115 kV lines between 50 and 300 km
- Often as many as five taps
- LV of 13.8 to 44 kV
- 83 to 125 MVA transformers, grounded or ungrounded on HV side
- Audio-tone channels from taps

Typical Tapped Station

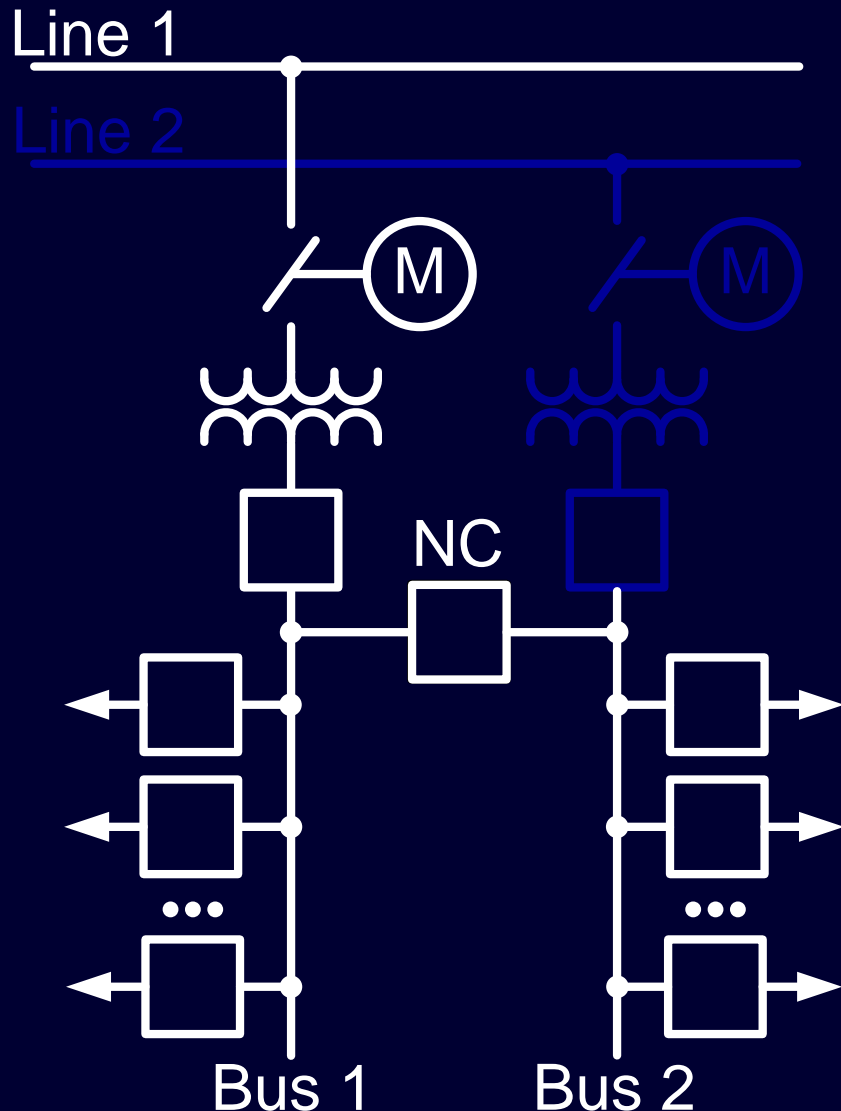
Dual Element Spot Network



- No HV breakers
- Feeders can be paralleled on same CB

Typical Tapped Station

Dual Element Spot Network

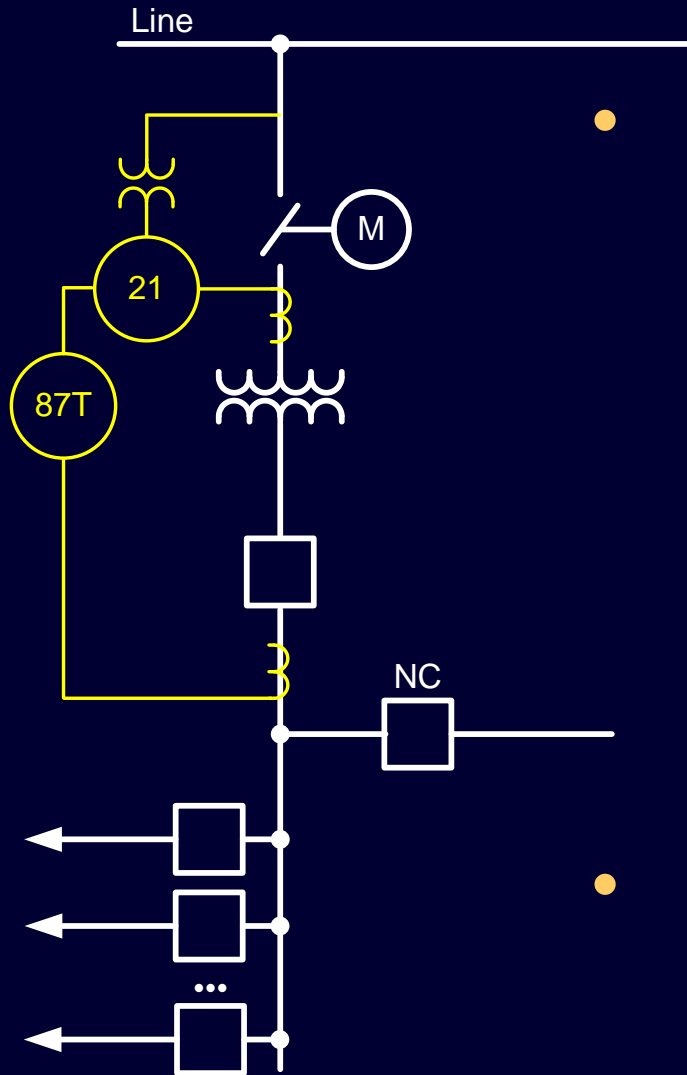


- No HV breakers
- Feeders can be paralleled on same CB
- Transformers rated to carry total load
- Uninterrupted load service for line or transformer faults

Protection for Tapped Stations

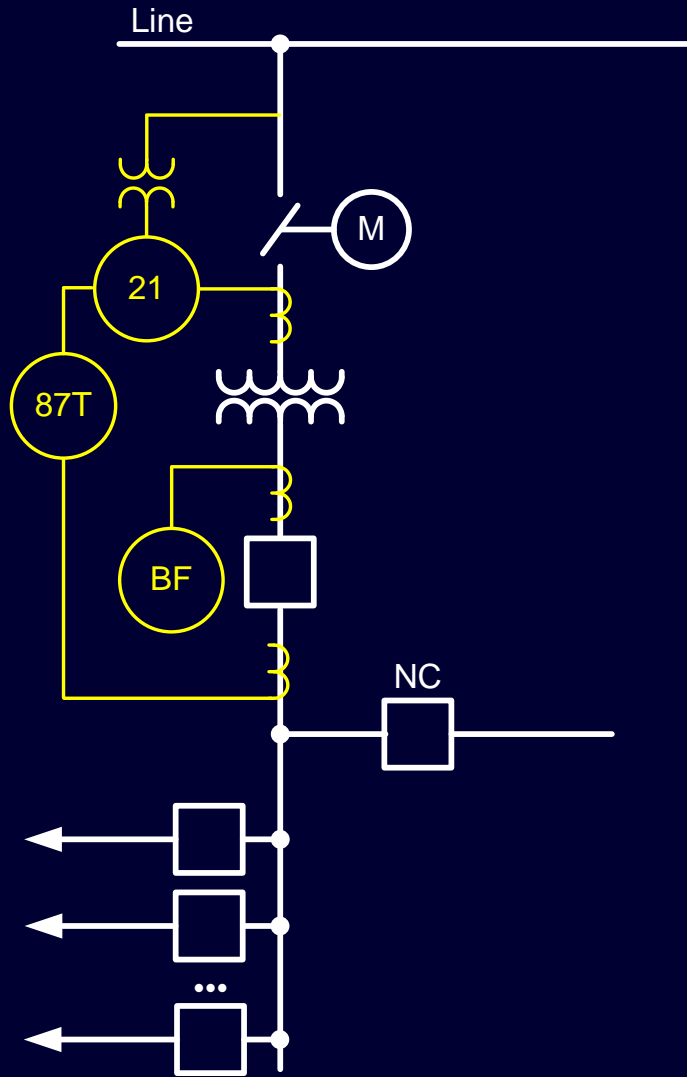
- No HV breakers – tapped stations are part of bulk electric system (BES)
- Protection must be BES-class
 - ◆ Dual-redundant schemes for dependability
 - ◆ Breaker failure protection with DTT
 - ◆ Protection security is very important (misoperation takes line out of service)

Transformer and Line Protection



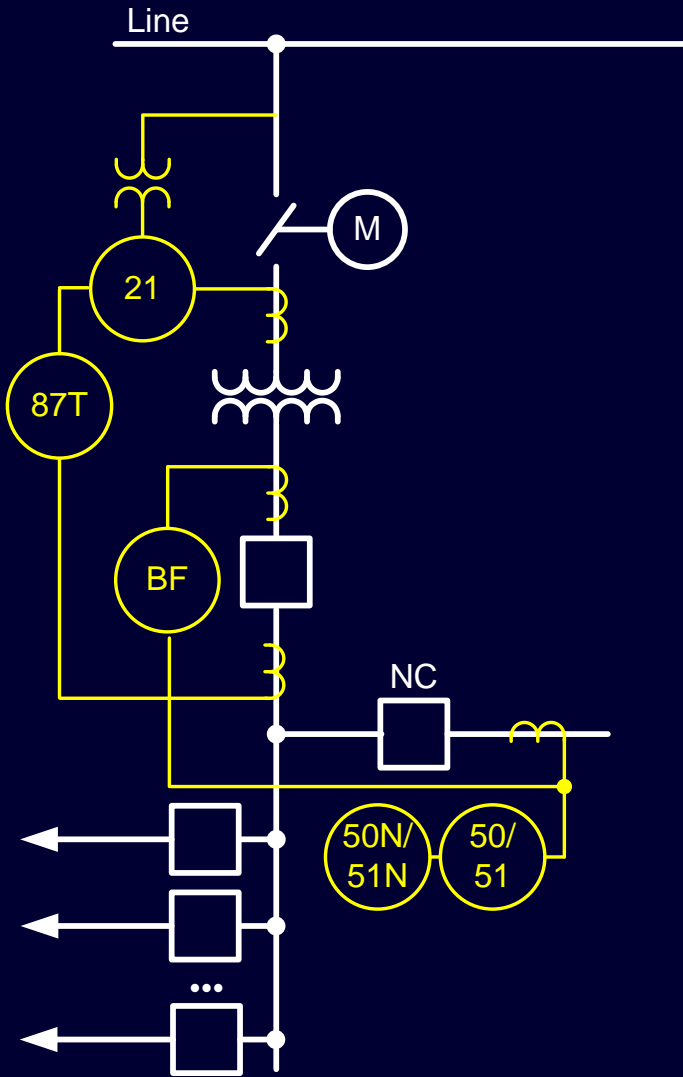
- Transformer protection
 - ◆ Trips and initiates BF for LV CB
 - ◆ Opens MOD
 - ◆ Sends DTT to line terminal
 - ◆ Seals DTT with current to prevent / allow AR
- Line protection – cascades DTT to other taps and terminals, AR

Breaker Failure and Line Protection



- Initiates on transformer and bus faults
- Trips bus-tie breaker
- Sends DTT to line terminal
- Opens MOD when current subsides

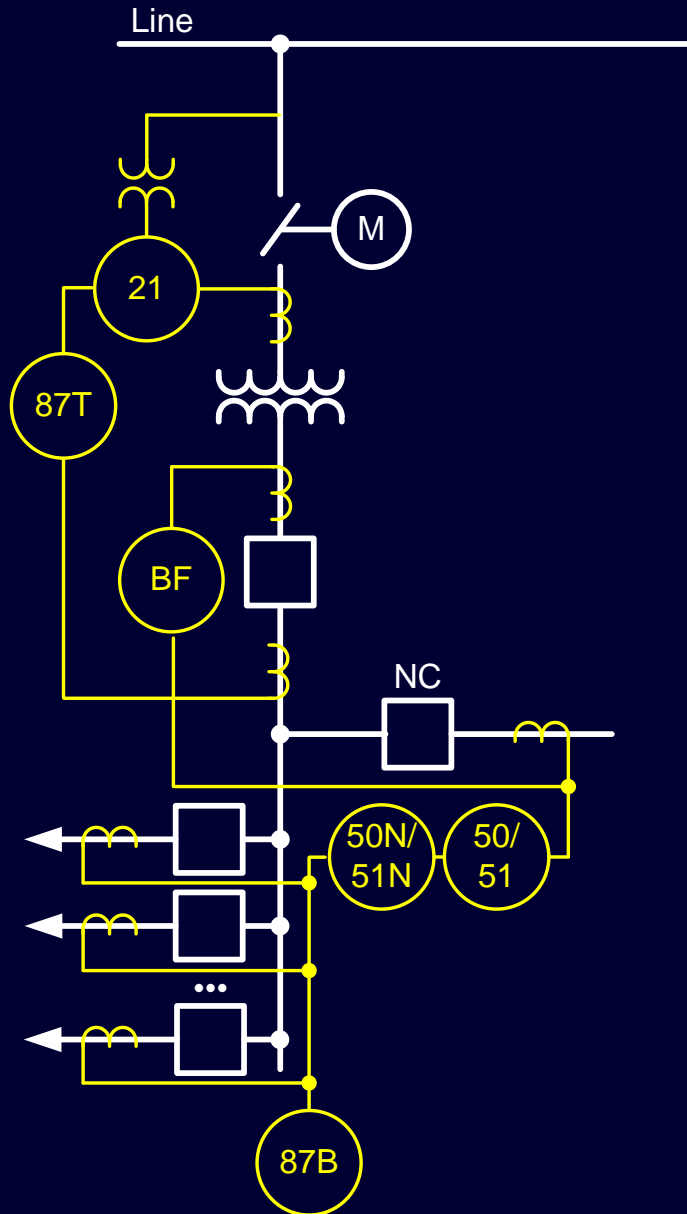
Bus and Feeder Backup



- Trips LV and tie CBs
- Has time-coordinated overcurrent elements
- Can use instantaneous elements for directionality (line vs. LV faults)

Bus Protection

- Zone-interlocked
- Bus differential



Line Protection

Challenges and Solutions

Difficulty seeing
line faults from
tapped stations

DTT from main line terminals

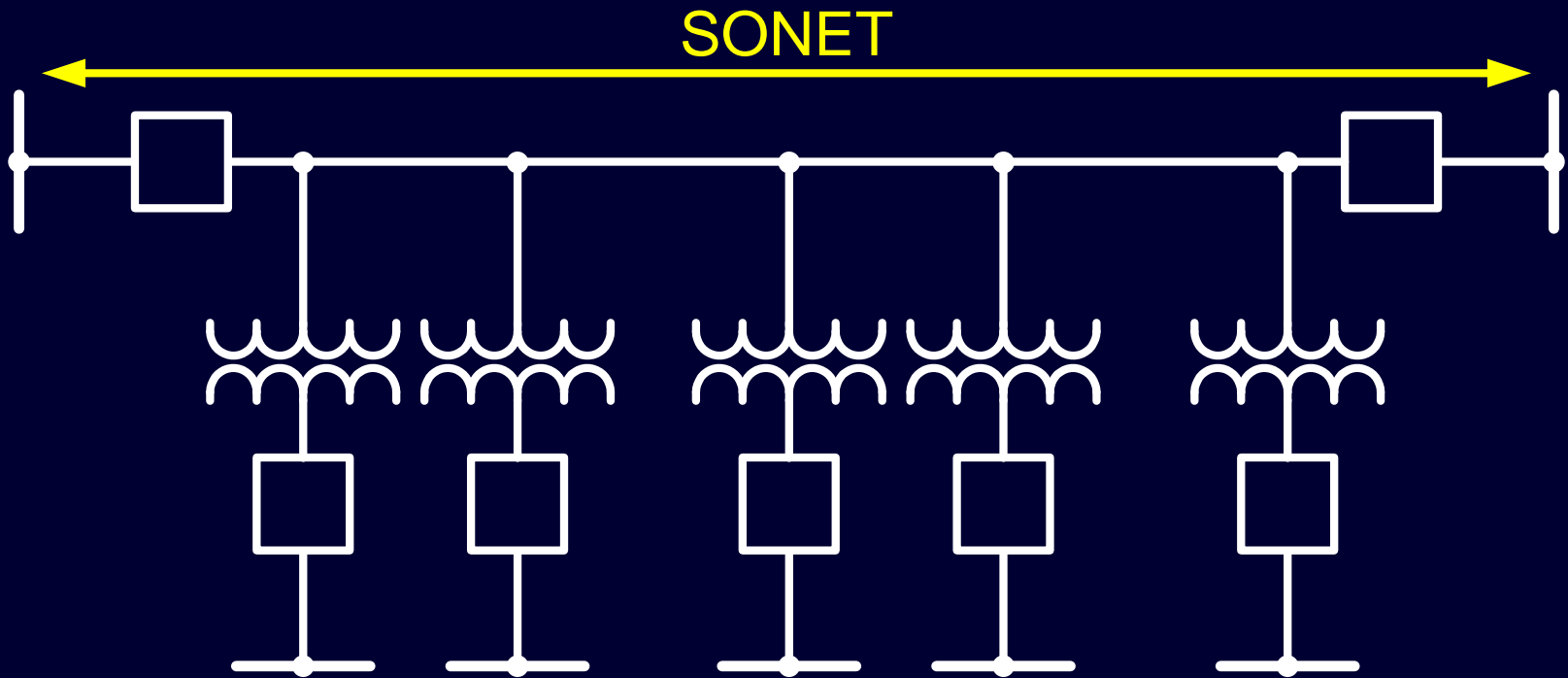
No HV breakers

Trip and reclose line on
transformer and
LV BF operations

Seven-terminal
87L relays
not available

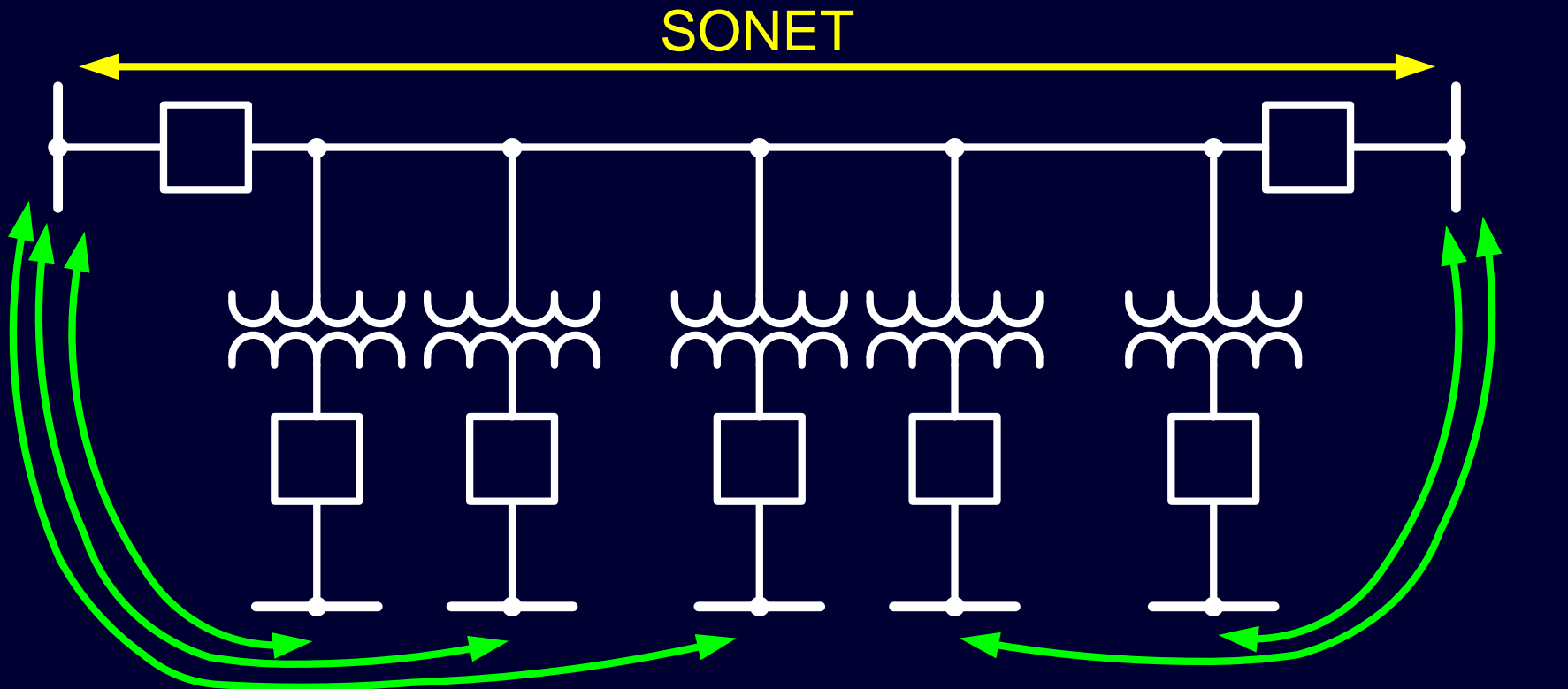
Partial line current
differential applications

Line Protection Channels



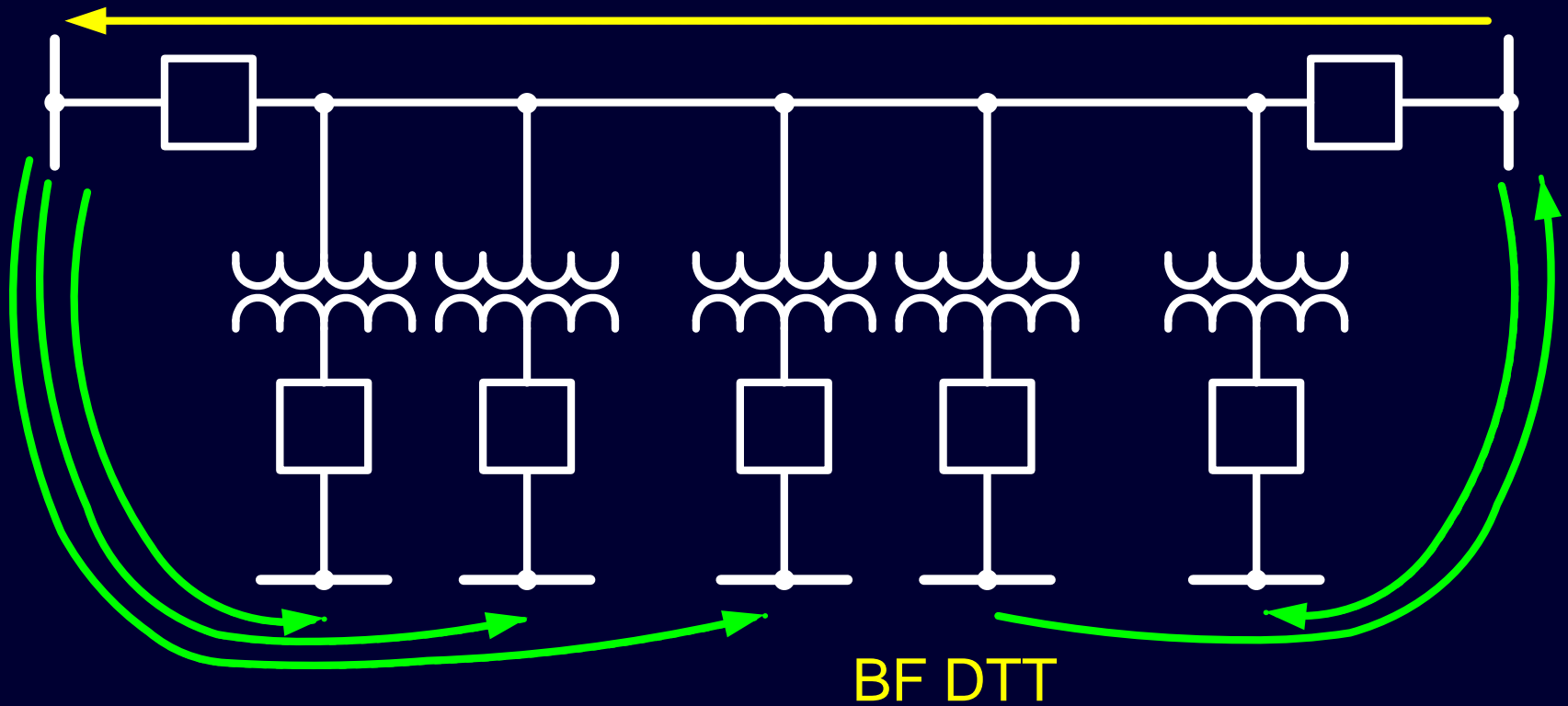
- Dual-redundant multiplexers
- Redundant, diverse, but static paths
- IEEE C37.94 interface for POTT / DCB and 87L

Line Protection Channels



- Dual-redundant channels
 - Channel to one terminal only
 - Need to cascade signals (e.g., DTT)
- Audio Tone Over Leased Lines

Cascading DTT Signals



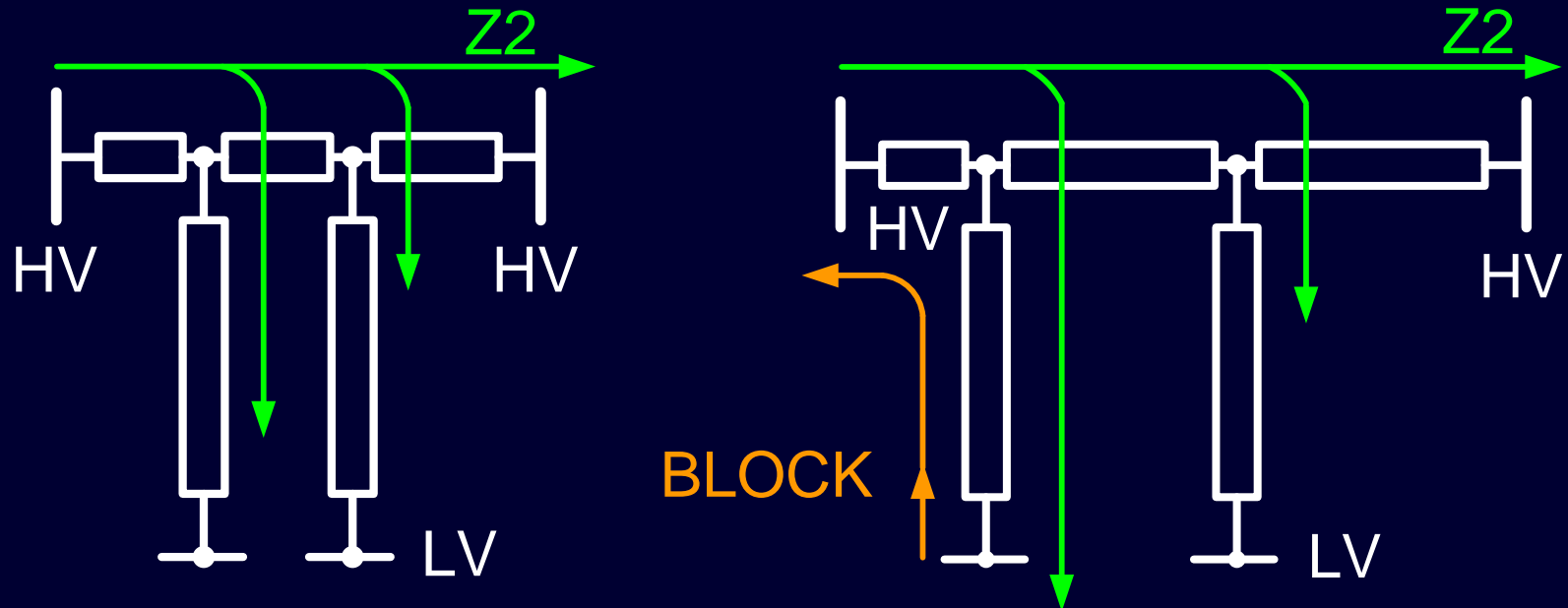
Line Protection Philosophy

- Dual-redundant schemes
(2 POTT / DCB or POTT / DCB and 87L)
- Tripping from underreaching Z1
- 67N and Z2 as overreaching elements
- Blocking signals from taps if Z2 reach coordination cannot be achieved
- Distance supervision for 87LP if set to sensitive, 87LG otherwise

Distance Elements

- Zone 1 reach
 - ◆ Short of LV buses
 - ◆ Short of remote terminal
- Zone 2 reach
 - ◆ Beyond remote terminal
 - ◆ Short of LV buses
- Security concern for transformer inrush
 - ◆ OC supervision
 - ◆ Harmonic blocking

Distance Elements

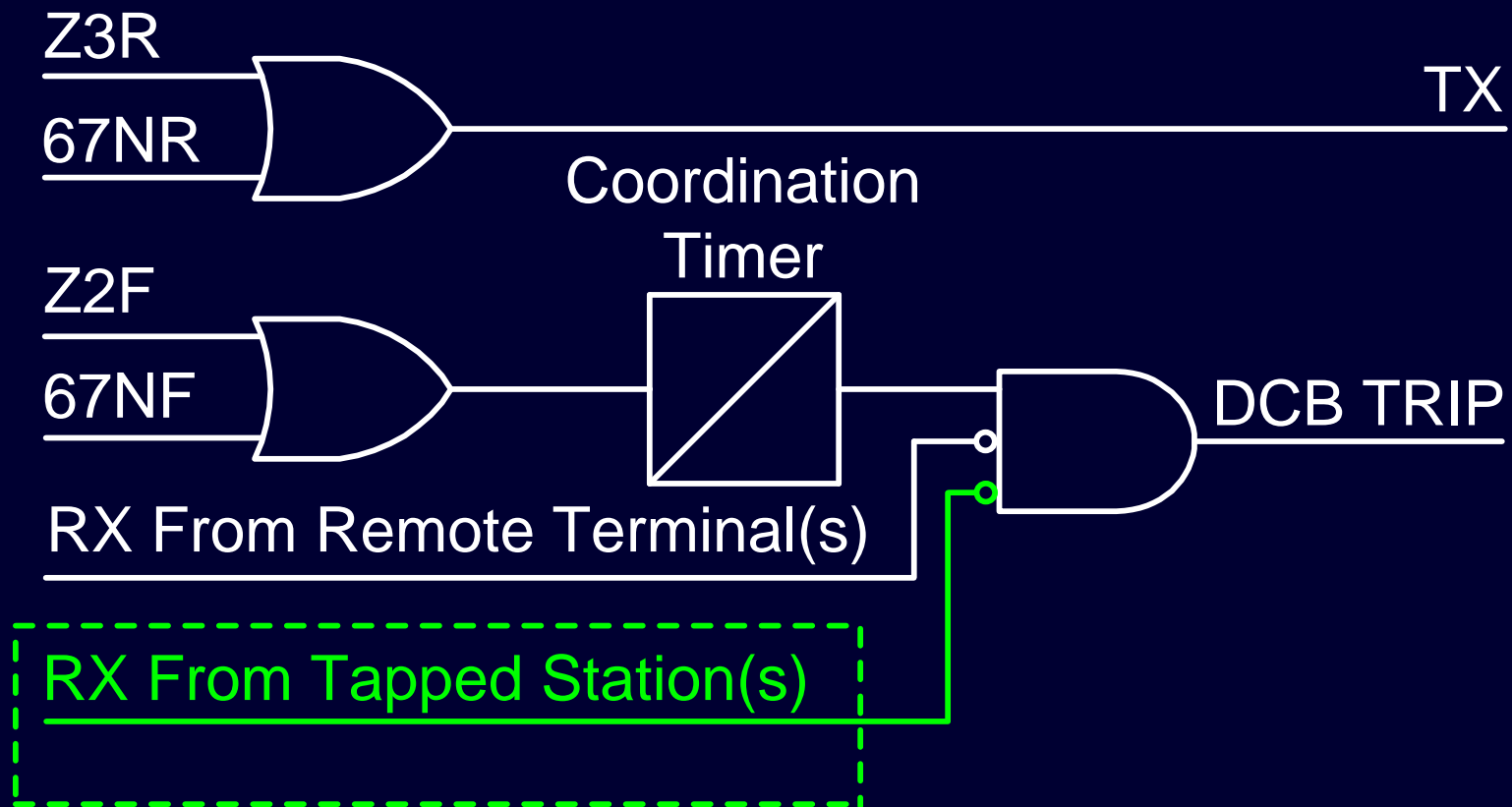


- Transformer connections and mutual coupling impact $3I_0$ flow (infeed effect)
- Short-circuit studies to validate reach

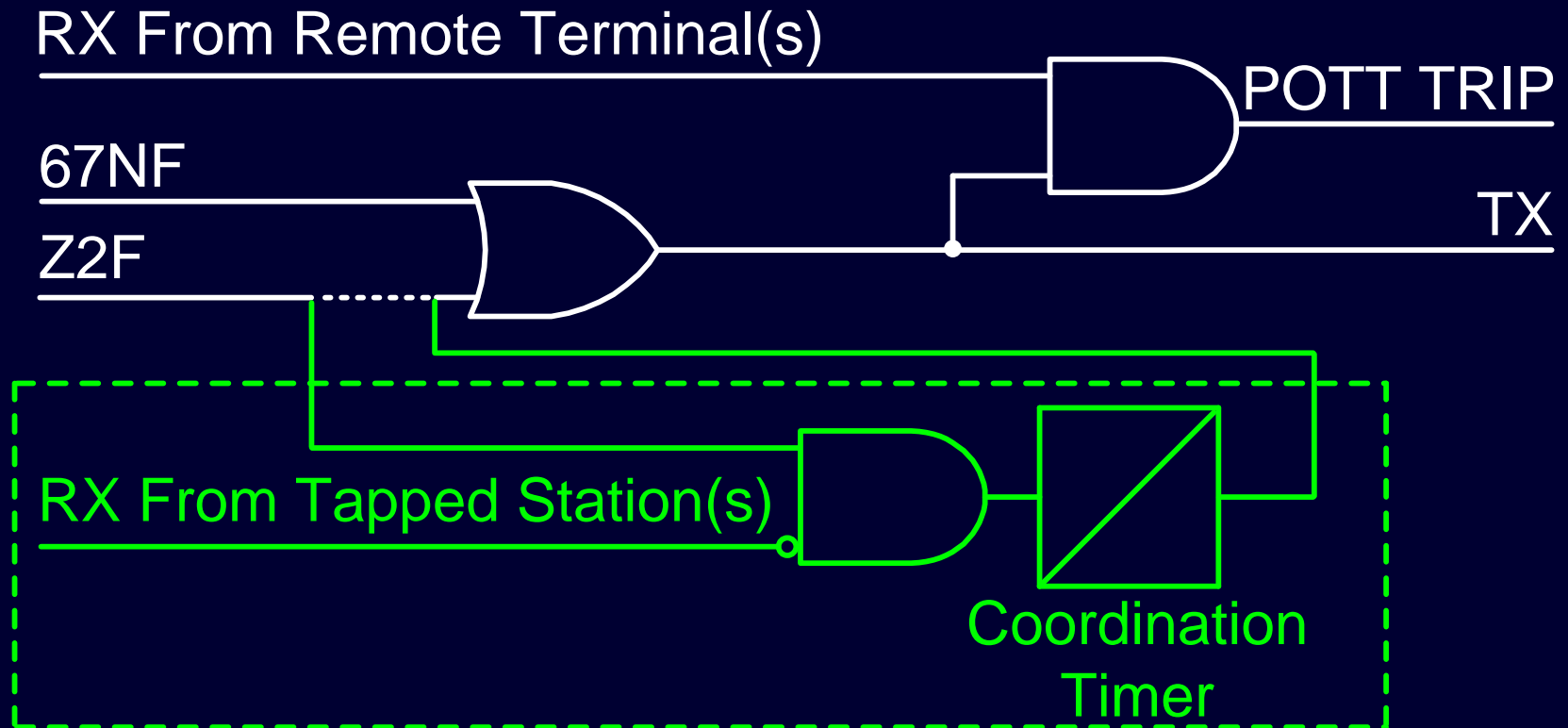
Directional Comparison Schemes

- POTT is preferred scheme
- DCB used for three-terminal lines and with PLC
- 67NT and Z2 used as overreaching elements
- Extra blocking logic from taps that violate Z2 reach coordination

DCB Logic



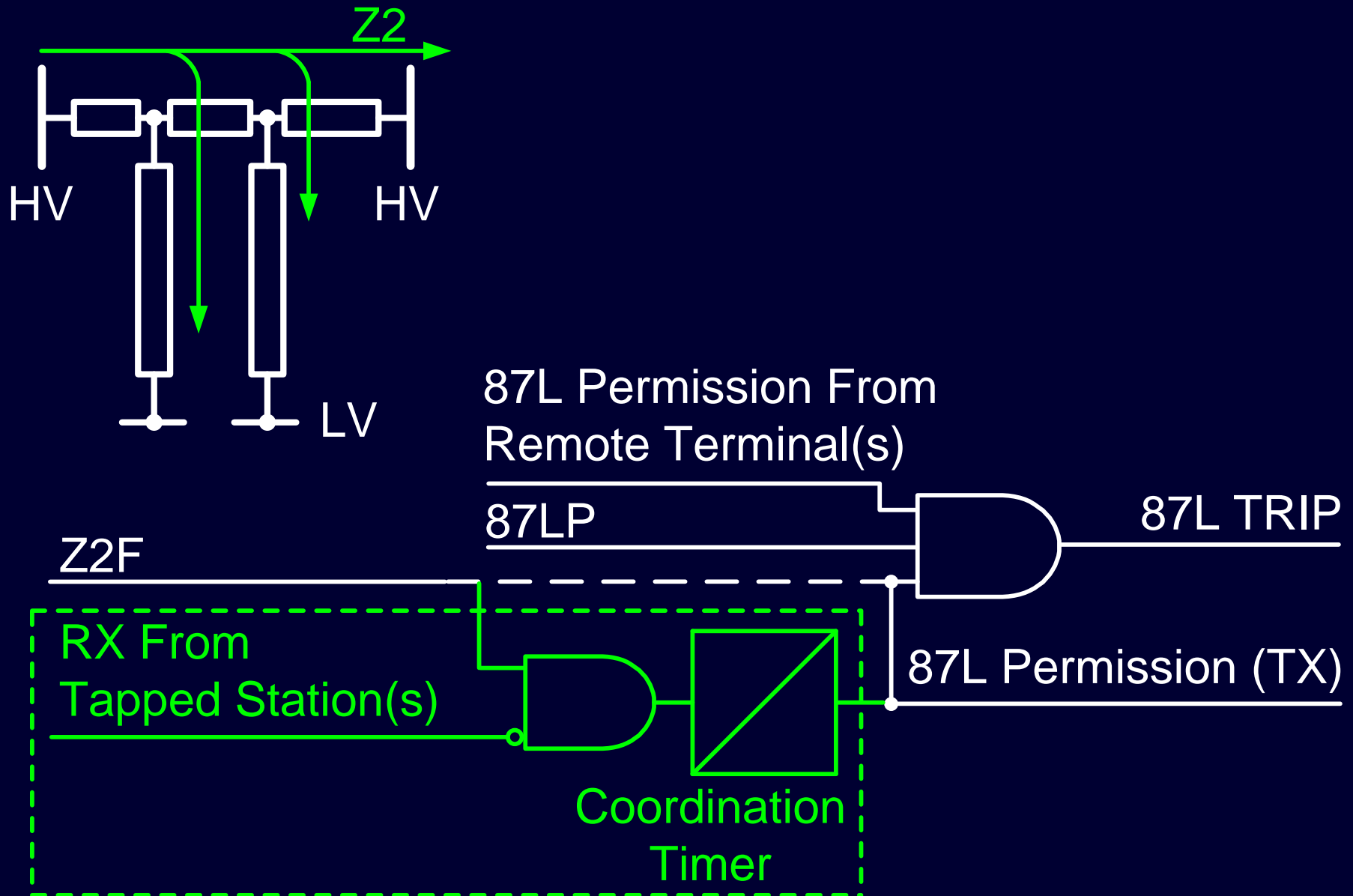
POTT Logic



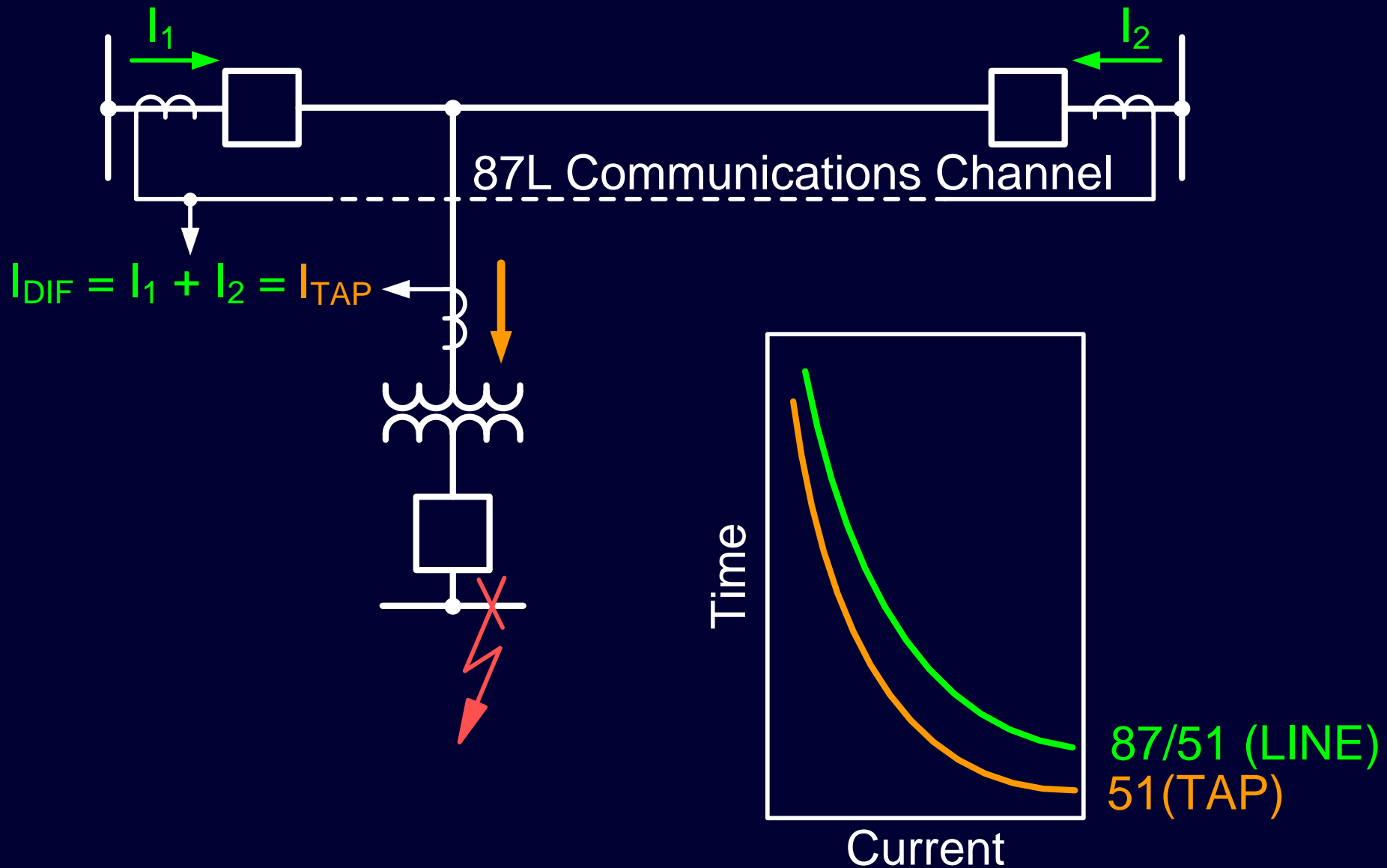
87L Elements

- Unmeasured current requires desensitizing 87L elements
- Phase elements (87LP)
 - ◆ Increased OC pickup
 - ◆ Distance supervision
- Ground elements (87LG / 87LQ) have increased OC pickup
- Extra sensitivity via time-coordinated 87L

Distance Supervision



Time-Coordinated 87L



Autoreclosing on Line Faults

- All LV breakers tripped to prevent backfeed
- All loads served via parallel transformers and line
- AR allowed if all tap currents subside
- Transformer inrush when energizing line (MODs remain closed)
- LV breakers close automatically on synchronism check

Autoreclosing on Transformer Faults

- All LV breakers tripped to prevent backfeed
- MOD operated to open
- AR allowed if all tap currents subside
- Transformer inrush when energizing line (other MODs remain closed)
- LV breakers close automatically on synchronism check

Summary

- DESN tapped stations provide good reliability of supply and operational flexibility
- Lack of HV (line-side) breakers exposes BES to issues in LV system
- Tapped station protection must follow BES-class standards
- Common protection schemes can be successfully applied to tapped lines

Questions?

