Transmission Line Setting Calculations – Beyond the Cookbook Part II

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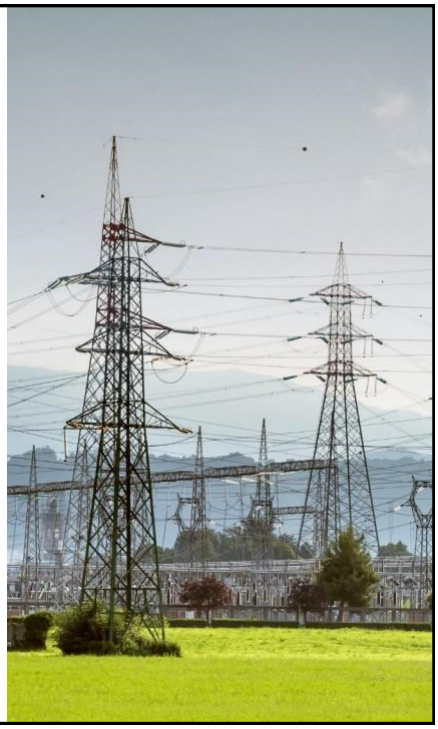
Beyond the Cookbook Part I Overview

- Serves as guide for inexperienced or out-of-practice engineers
- Explains two “knobs” engineers must adjust
  - Sensitivity
  - Delay
- Details only a few notable topics outside other traditional guides

Cookbook Part II Digs Deeper

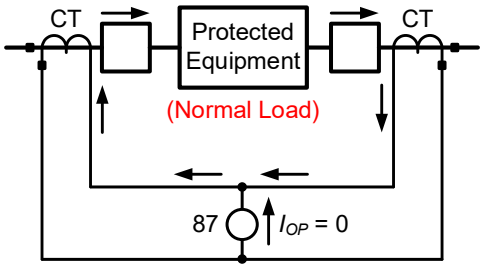
- This presentation covers
  - Line current differential (87L)
  - Three-terminal line protection
  - Source impedance ratio (SIR) guidelines
  - Inverter-based resources (IBRs)
- The paper also covers
  - Switch onto fault (SOTF)
  - Dependability during loss of protection (LOP)



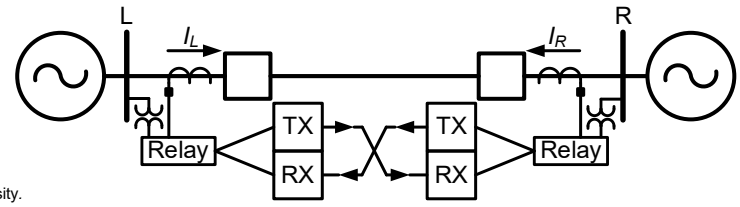
Line current differential

Current differential

Traditional 87



87L



ePROT 407: Transmission Line Protection, SEL University.

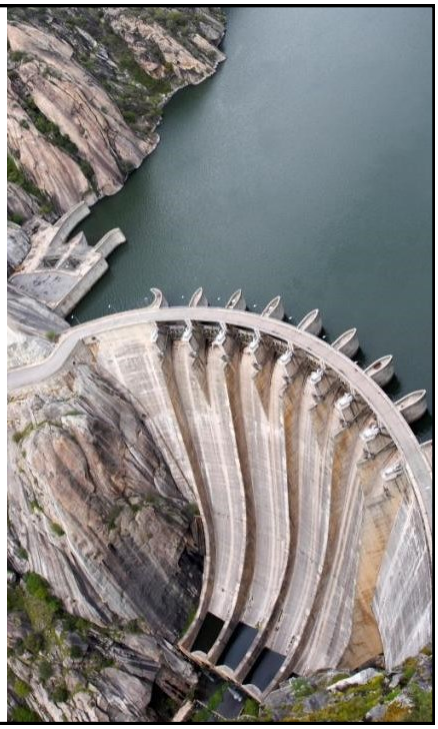
87L
Protective Elements

Fault Type	87LP (Per Phase)	87L (Negative Sequence)	87LG (Zero Sequence)
SLG	X	X	X
PH-PH-G	X	X	X
PH-PH	X	X	
3-PH	X		

X = Sensitive coverage for high-resistance faults

Setting 87LP pickups

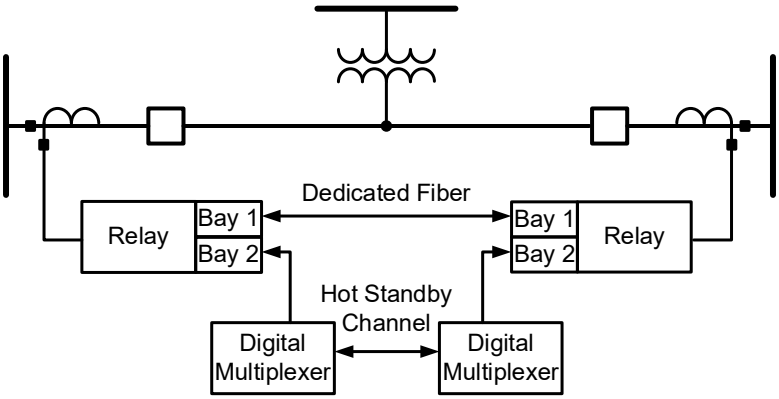
- Dependability check
  - 2.0–3.0 margin for internal faults
  - Can be met by any of 87L elements
- Security check
  - 87LP: desirable to be greater than load at 110%–120%
  - 87LG and 87LQ: greater than 10% WE rating



87LG and 87LQ elements

- Can be set less than load; 0.10–0.20 pu is good starting point
- Used to supplement 87LP
  - 87LG for ground faults
  - 87LQ for unbalanced faults
- May not be available in all relays

87L with load taps



Distribution transformers must be modeled; system models may not include tapped transformers that do not contribute fault current

SEL-411L Advanced Line Differential Protection, Automation, and Control System Instruction Manual. Available selinc.com.

87L with load taps

Security check method

Set pickups to 1.25–1.5 times maximum through current

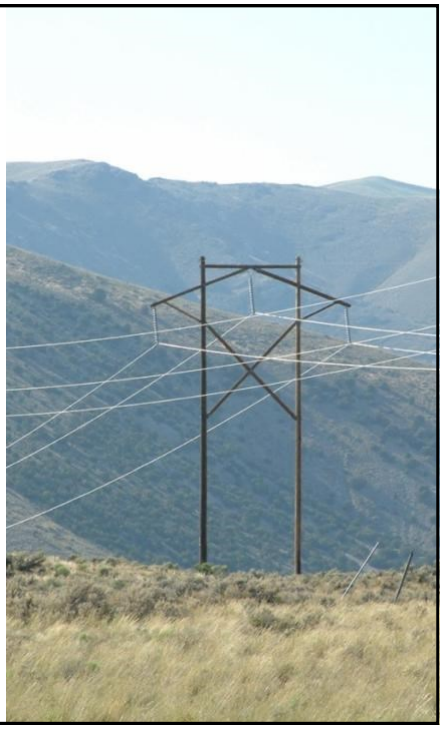
- Full load
- Transformer inrush
- Low-side faults

87L with load taps

Zero-sequence isolation

- 87LG cannot detect ground faults through transformers with zero-sequence isolation; no additional considerations needed
- 87LQ can still detect faults through transformers with zero-sequence isolation; can be
  - Checked using same method as 87LP

    or
  - Disabled due to security concerns from inrush



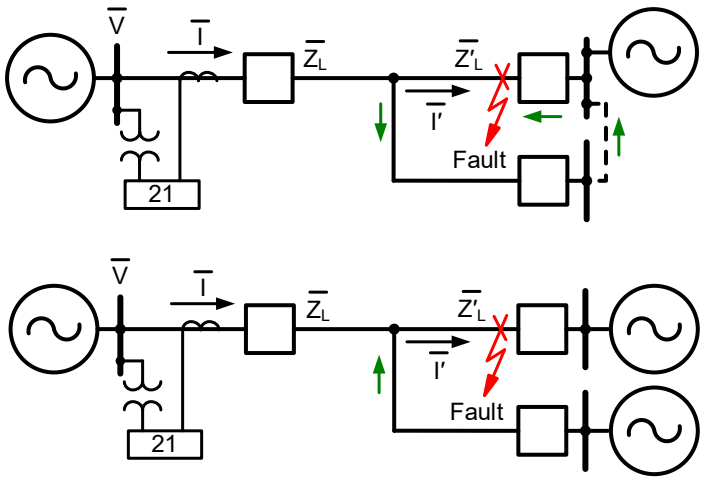
Three-terminal line protection

Three-terminal line protection

Outfeed: $Z_{APP} < Z_L + Z'_L$

$$Z_{APP} = Z_L + \frac{I'}{I} Z'_L$$

Infeed: $Z_{APP} > Z_L + Z'_L$



Three-terminal line protection

General rules still apply

- Underreaching elements underreach both remote terminals
- Overreaching elements overreach both remote terminals

Additional considerations

- Must take apparent impedance into account when setting distance elements
- Must take additional current source into account when determining worst-case fault currents

Communication-based schemes on three-terminal lines

87L

- Simplest
- Every relay sees the total current

DCB

- Simple, block sent to both remote relays
- Applications with outfeed are a problem

POTT

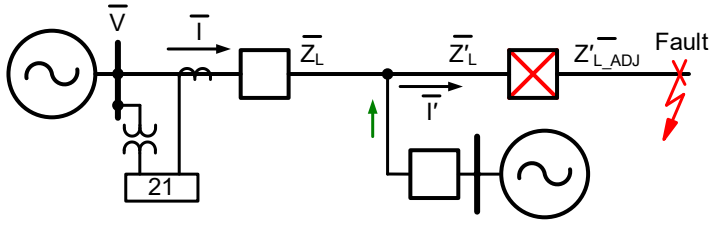
- Requires permissive signal from both remote relays
- Applications with a weak terminal are a problem

PUTT and DUTT

- Requires permissive signal from only one remote relay
- Applications without Zone 1 overlap are a problem

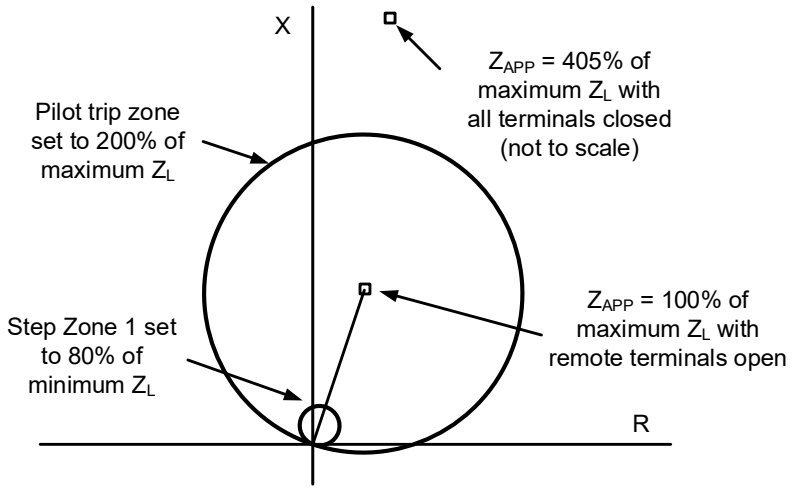
Three-terminal breaker failure coverage

- Overreaching protection would have to cover protected line and adjacent circuit **with infeed**
- Breaker failure direct transfer trip strongly recommended



Three-terminal sequential tripping

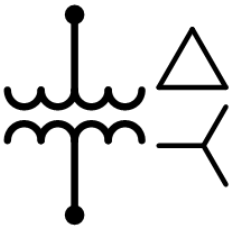
Real-world example



Weak terminals on three-terminal lines

Intermittent power generation

Another terminal provides a shorter path to fault



Blocking-only terminals for large load transformers

SIR guidelines

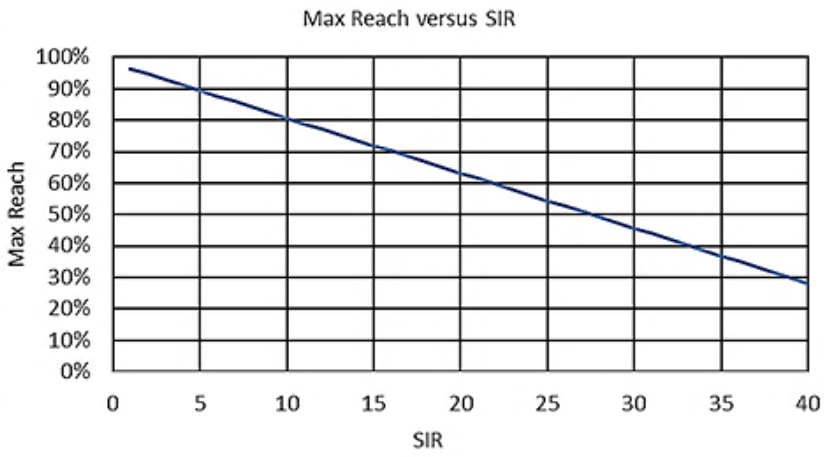
SIR guidelines

- Determine if line is electrically short
- Set Zone 1 reach based on SIR
  - SIR > 10, start pulling back reach
  - Length of line versus weak system

$$SIR = \frac{Z1_{SOURCE}}{Z1_{LINE}}$$

$$Reach_{MAX} = 1 - ERROR_{PU}\left(SIR + 1\right)$$

SIR guidelines



*Assuming 1.75% steady-state error

SIR guidelines

- Simple to calculate and use
- Reach is the knob we tweak
- Set Zone 1 protection to underreach
- Consider this example: pulling reach back from 80% to 60%
  - Acceptable to trip for 60.1% of line
  - Acceptable to trip for 99.9% of line
  - Unacceptable to trip for 100.1% of line

SIR guidelines
Fault detectors

- Weak system, not physically short
  - SIR < 10 less than N-0
  - SIR > 30 less than N-1
- Checks include
  - Dependability: less than N-0 fault current
  - Security: greater than N-1 fault current

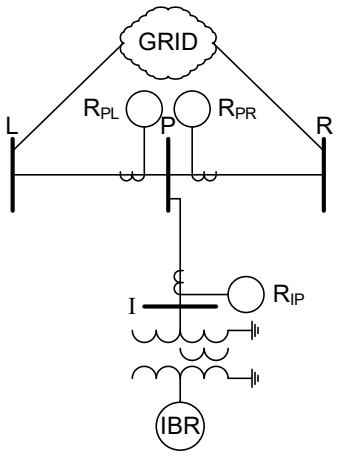
Line protection near IBRs

IBRs
Unconventional sources

- Includes solar, wind, and battery
- Contributes less fault current
- Control systems suppress negative-sequence quantities
- Impacts fault type identification logic and directional elements for unbalanced faults

IBRs
Ground fault protection

- Negative-sequence voltage polarized elements (32Q) have been preferred over zero-sequence voltage polarized elements (32V)
- IBR-sourced lines usually have strong ground source
- Authors recommend using 32V for IBR-sourced lines



IBRs
Phase fault protection

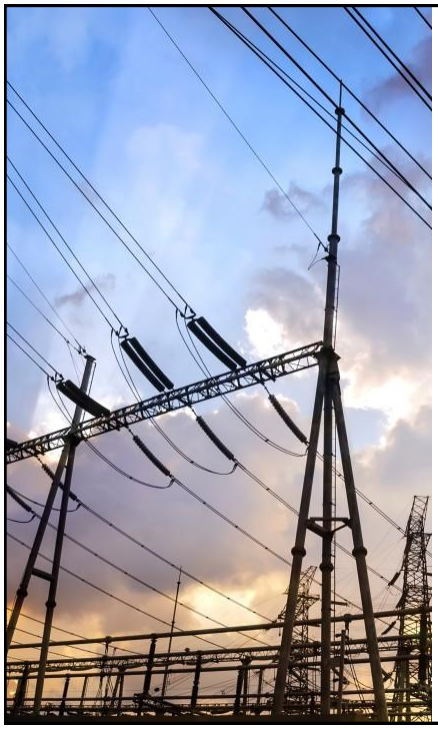
- Unbalanced phase faults must be addressed even if using 32V
- For security, set negative-sequence supervision greater than expected IBR contribution
- Ensure dependability
  - 87L protection
  - Voltage-based weak feed tripping
  - Time-delayed 27 elements

IBRs
Future developments

- Performance standards are pending
- Future IBR control algorithms may be updated to inject negative-sequence current under fault conditions
- Will likely always be period of uncontrolled response lasting as long as 2.5 cycles

Conclusion

- 87L
  - Apply 87LG or 87LQ to improve sensitivity to unbalanced faults
  - Perform security checks when tap loads are in the 87L zone
- Three-terminal line protection
  - Set reaches using Z_{APP} minimum and Z_{APP} maximum
  - Recognize when sequential tripping is necessary
- SIR guidelines
  - Reduce reach for medium to high SIRs
  - Use fault detectors for N-1 weak applications
- IBRs
  - Set negative-sequence current supervision greater than expected IBR contribution
  - Use zero-sequence quantities for ground directional elements



Questions?