Protection in an IBR World

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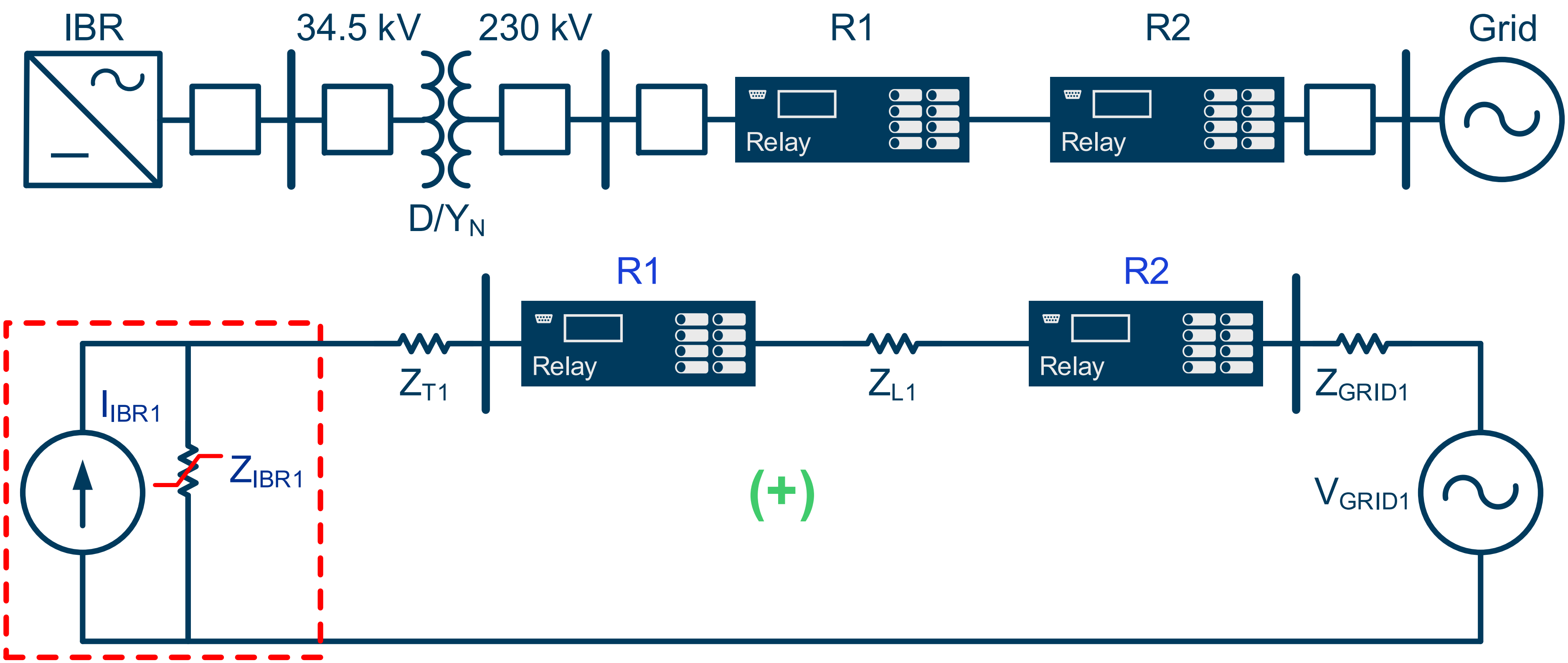
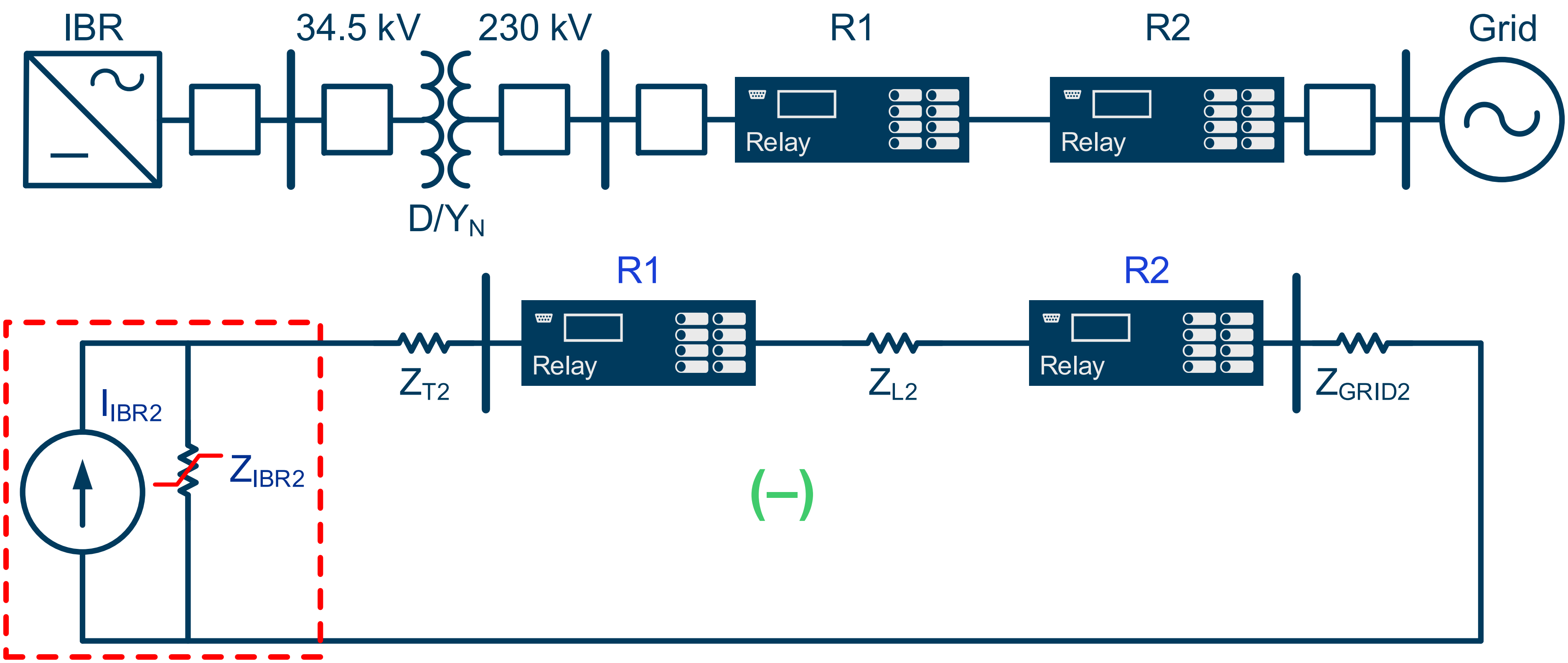
Overview

- IBR sequence network
- IBR fault characteristics
- Protection element security challenges and solutions
- Dependability evaluation
- Resources

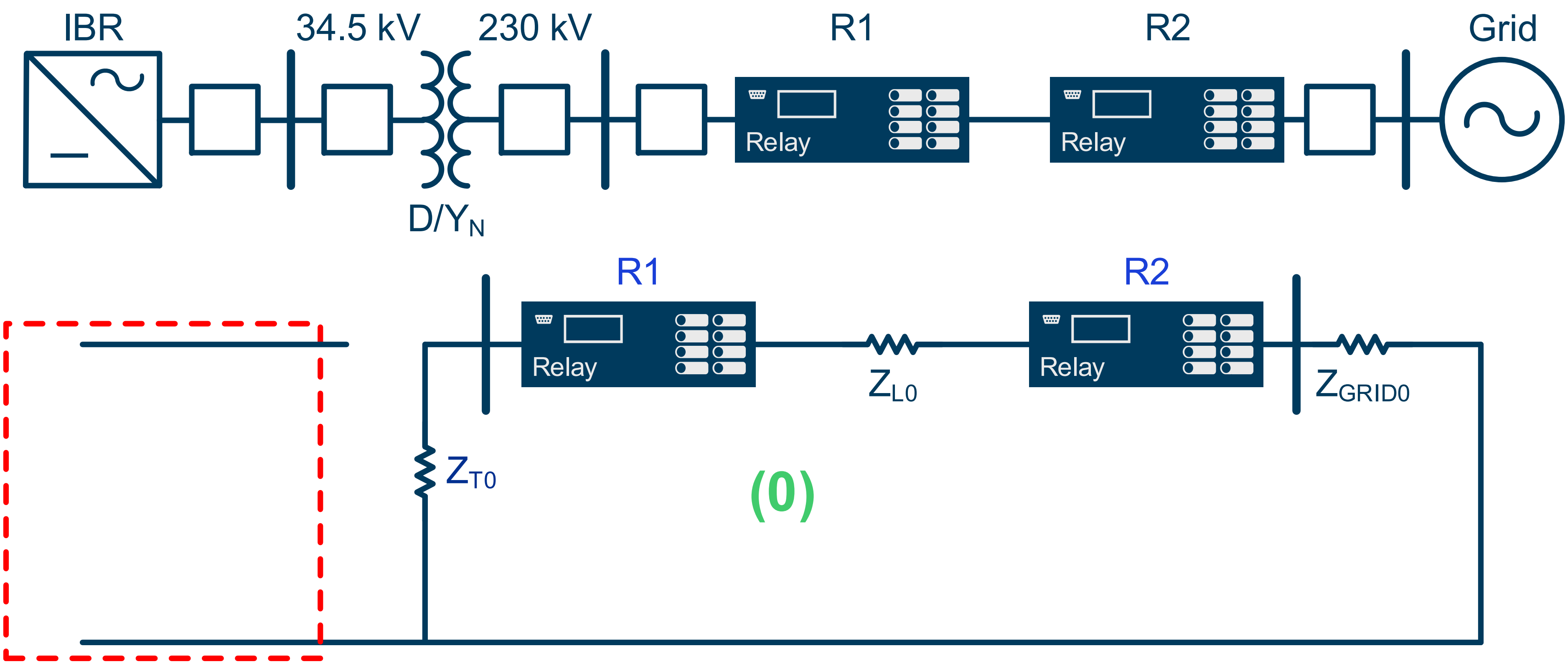
IBR sequence networks



IBR sequence networks



IBR sequence networks



Fault current

- **Conventional source** – Function of fixed impedance values
- **IBR source** – Function of proprietary control schemes

Fault current characteristics

SEQUENCE CURRENT (I1) AND (I2)

- **Conventional source**
  - Frequency changes slowly due to high inertia
  - Current magnitude is generally high
- **IBR source**
  - Frequency can change suddenly due to low or no inertia
  - Current magnitude is low

Fault current characteristics

SEQUENCE CURRENT (I0)

- **Conventional source**
  - Frequency changes slowly due to high inertia
  - Current magnitude is generally high
- **IBR source**
  - I0 is not produced
  - Path for I0 current from conventional source exists through grounded transformer

Fault voltage characteristics

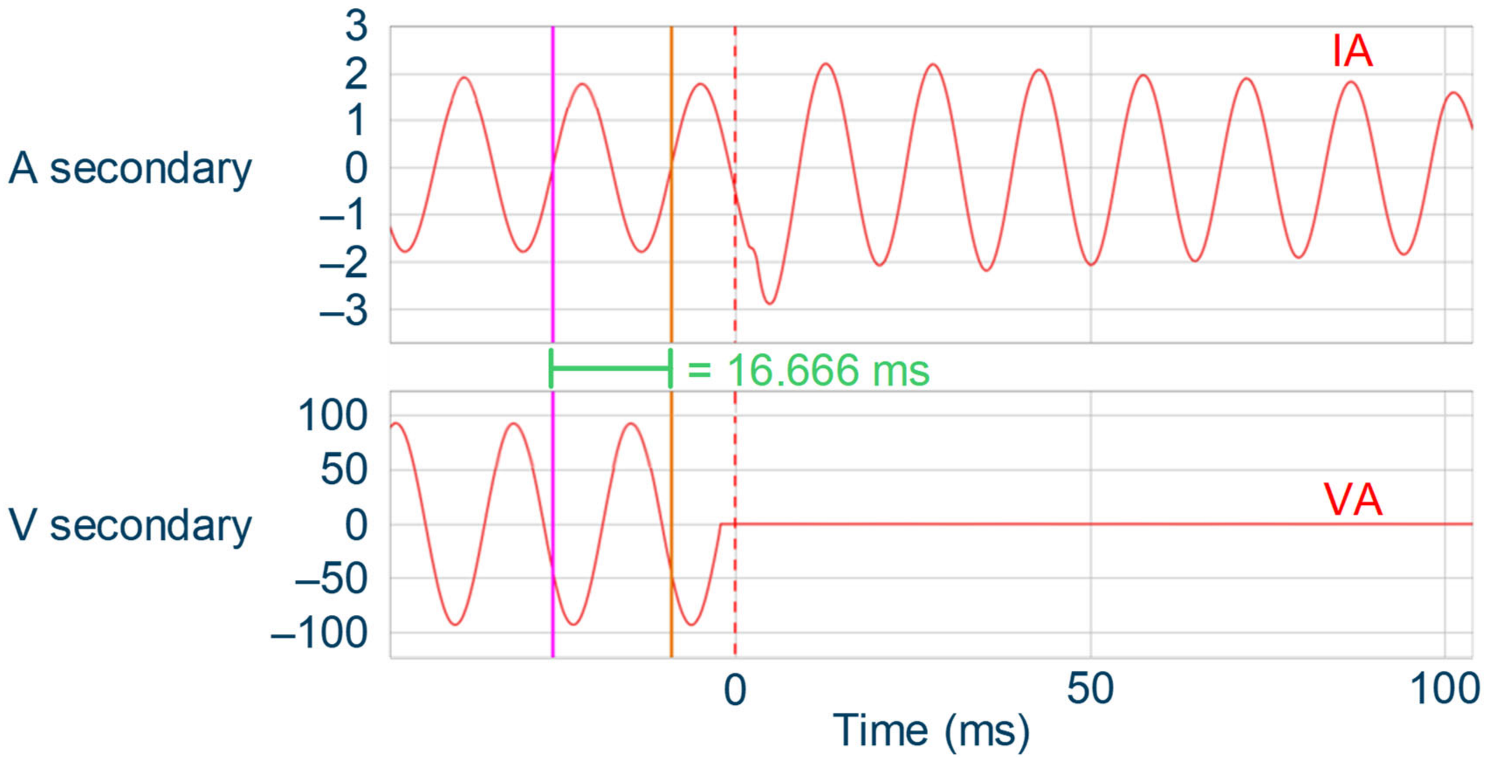
- **Conventional source**
  - Source impedance is generally small
  - Fault loop voltage is dependent on fault location
- **IBR source**
  - Source impedance is very large
  - Fault loop voltage is typically small and less impacted by fault location

Issues for Transmission Line Relays

- Memory Polarization
  (Low or No Inertia = High ROCOF)
- Faulted Phase Identification Logic (FIDS)
  (Erratic behavior of 3I2 relative to 3I0)
- Directional Element Performance
  (Erratic behavior of 3I2 relative to 3V2)
- Apparent Impedance Oscillates
  (Underreach and overreach issues)

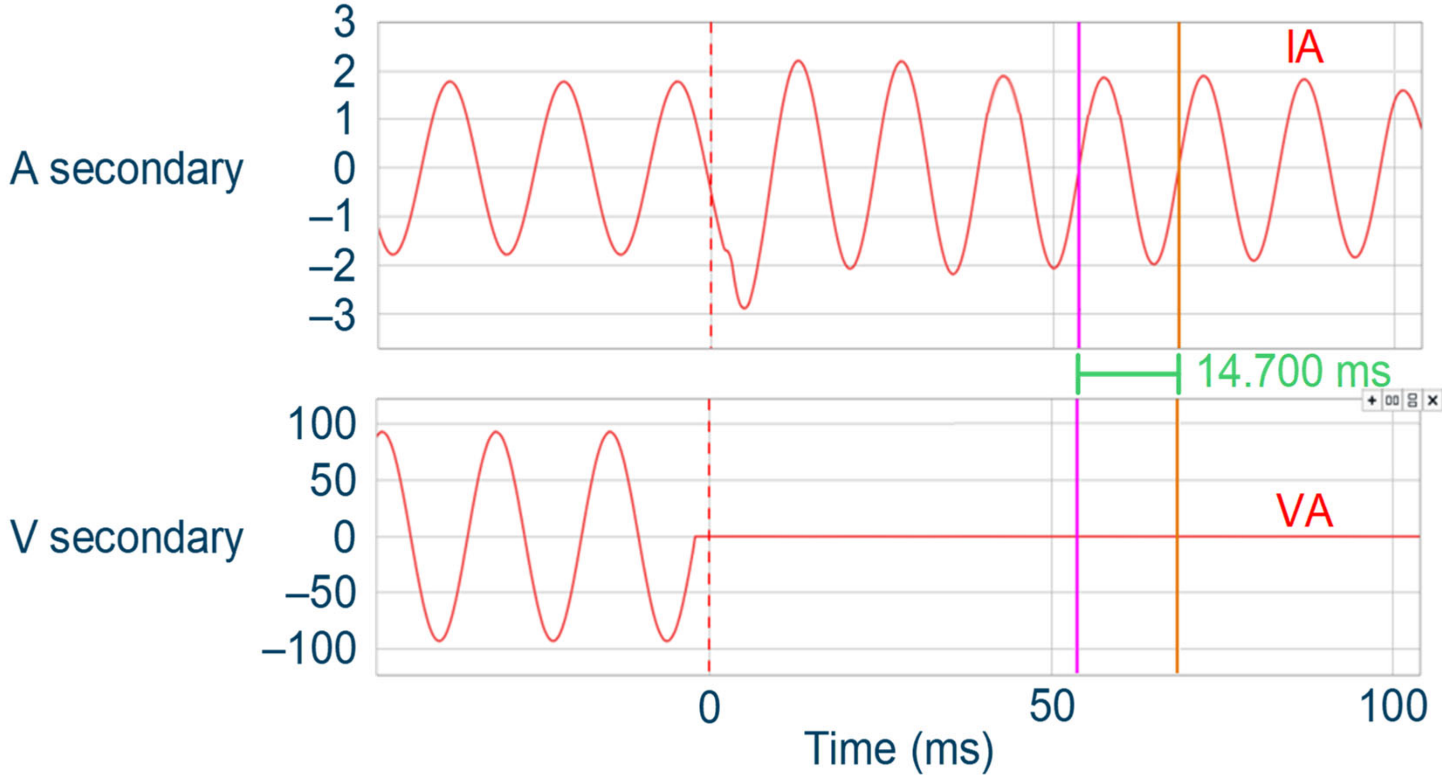
Memory - IBR only source – reverse direction

R2 – GRID BUS 3P FAULT (TYPE 3) 60 HZ TO 68 HZ



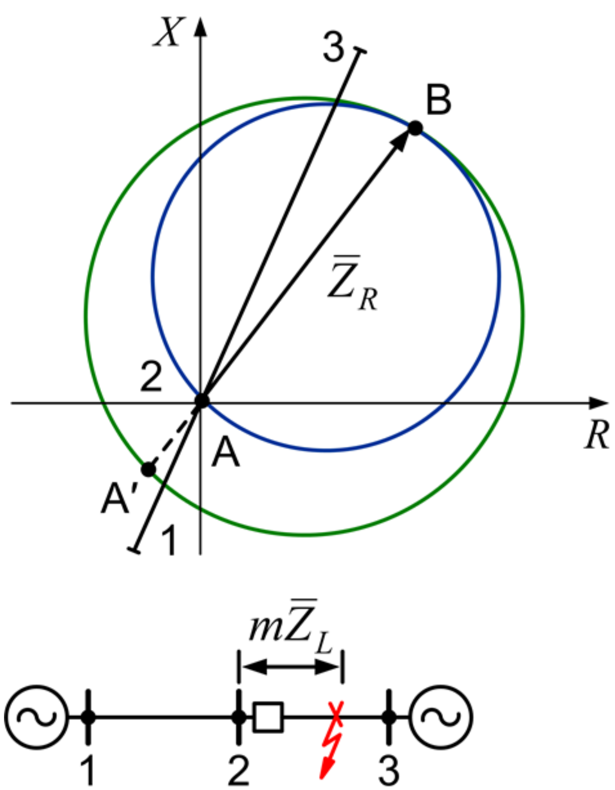
Memory - IBR only source – reverse direction

R2 – GRID BUS 3P FAULT (TYPE 3) 60 HZ TO 68 HZ

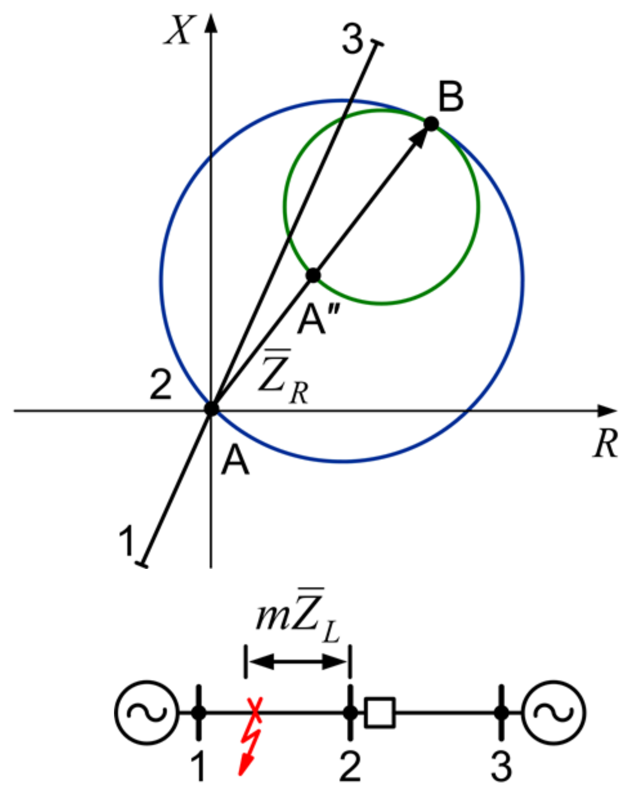


Dynamic Mho Behavior (Memory Polarized)

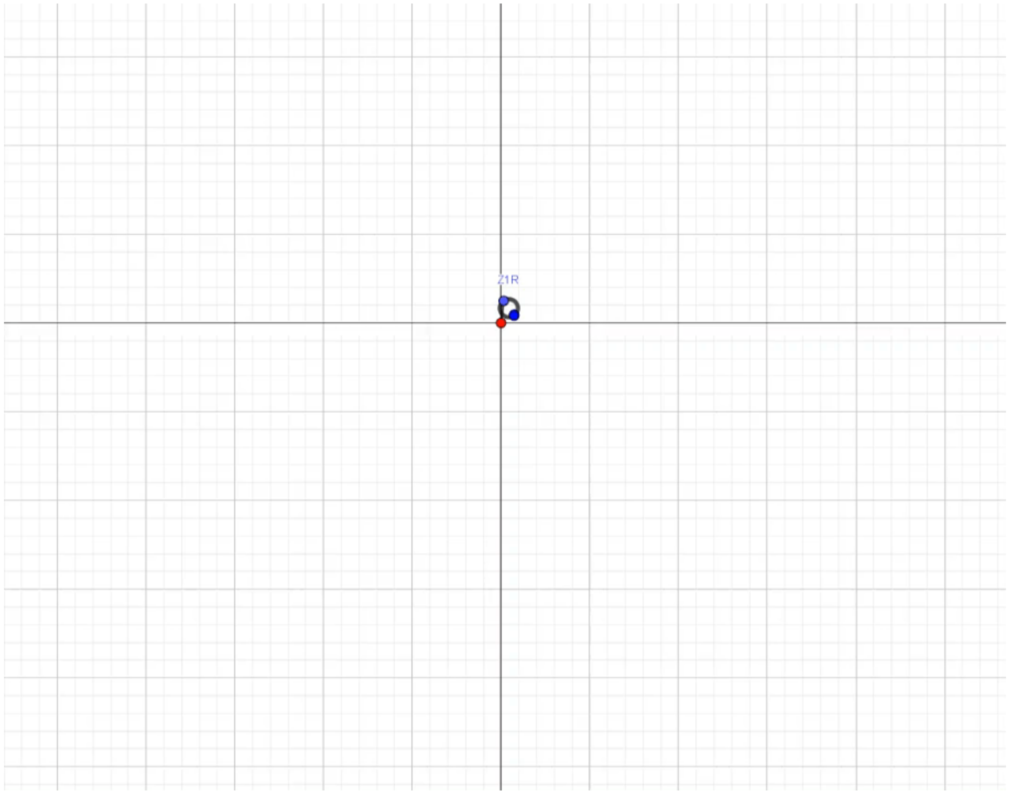
- **Forward Fault**
  Expansion



- **Reverse Fault**
  Contraction



Memory polarized 21



IBR fed fault security

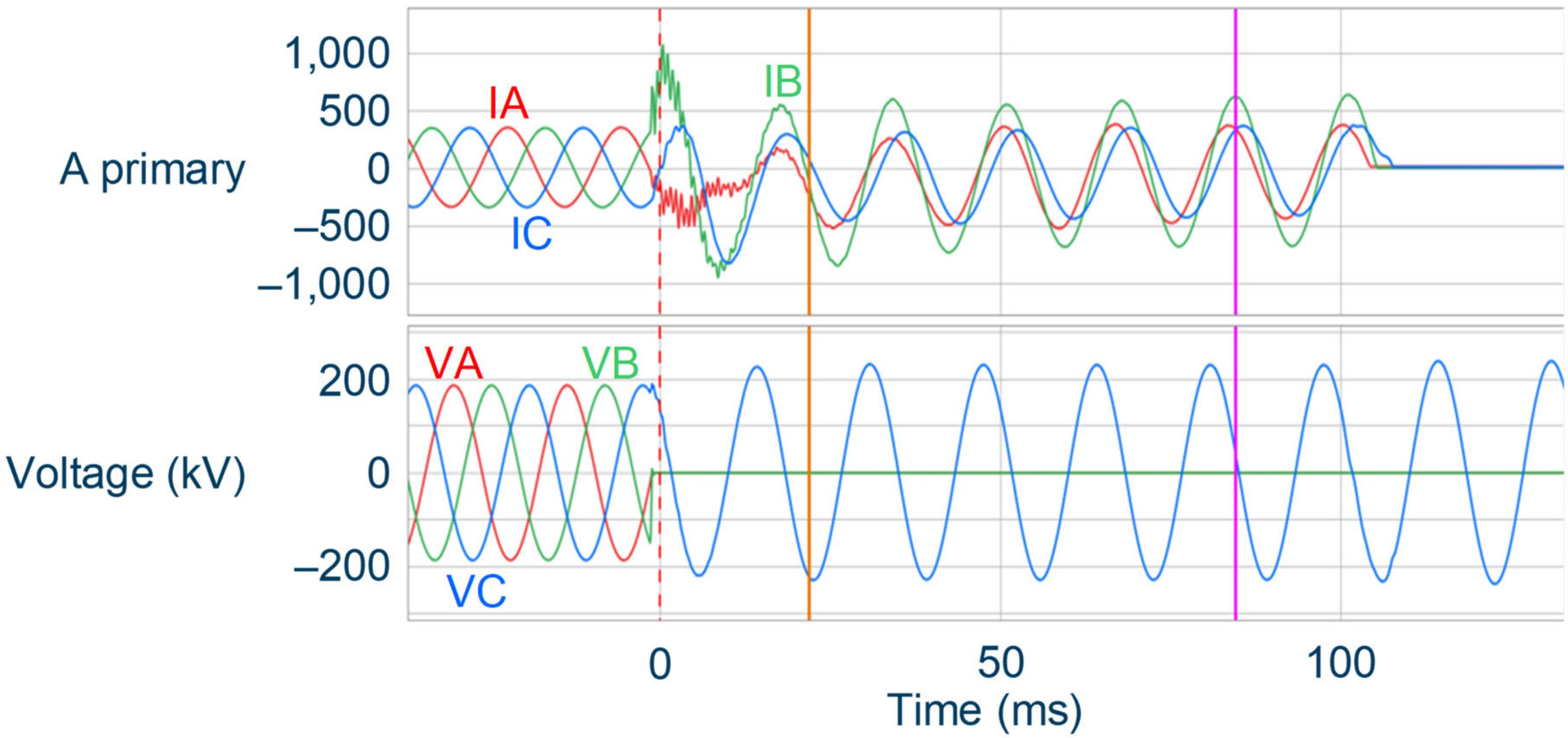
SEQUENCE CURRENT (I1)

Challenge –
Positive sequence voltage memory polarized elements can lose directionality for 3P faults

Solution –
Block 21P elements for low magnitude 3P faults

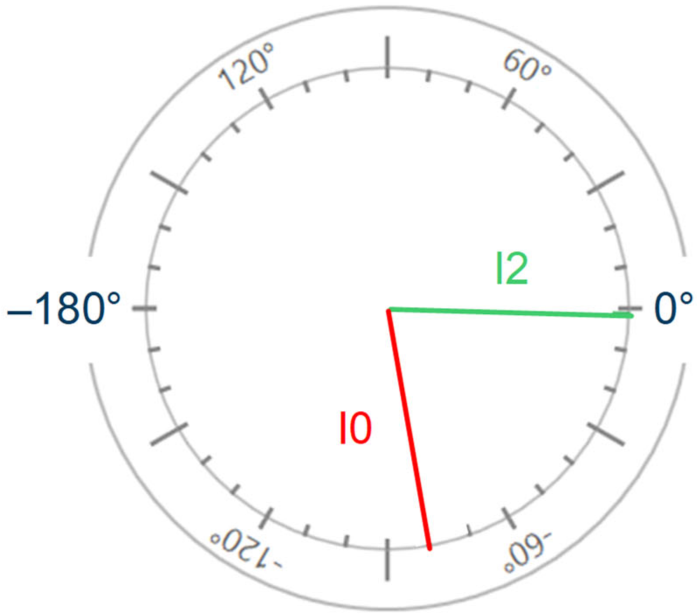
IBR only source – reverse direction

R2 – GRID BUS PPG FAULT (TYPE 4)

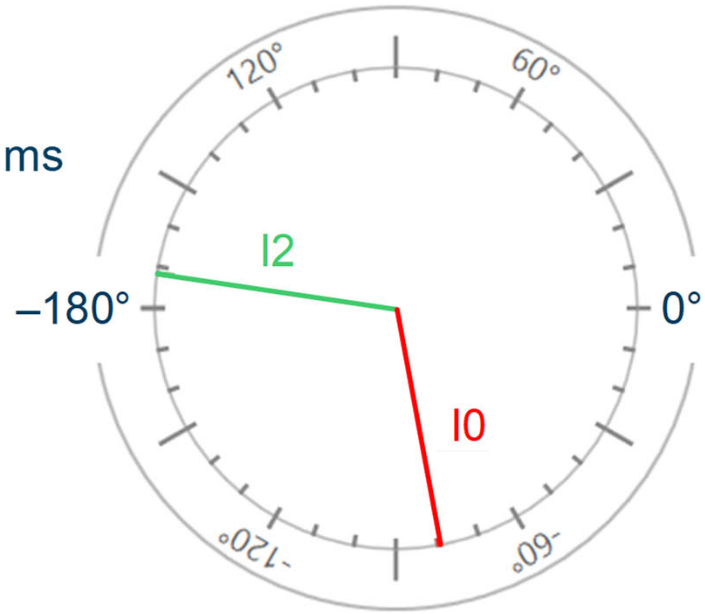


IBR only source – reverse direction

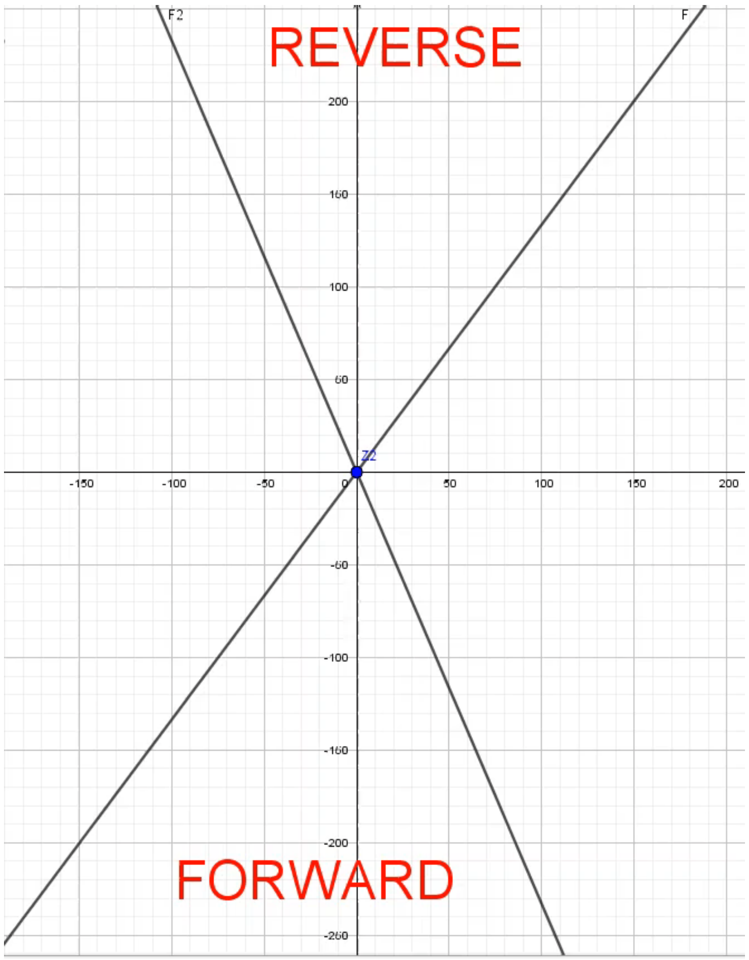
R2 – GRID BUS PPG FAULT (TYPE 4)



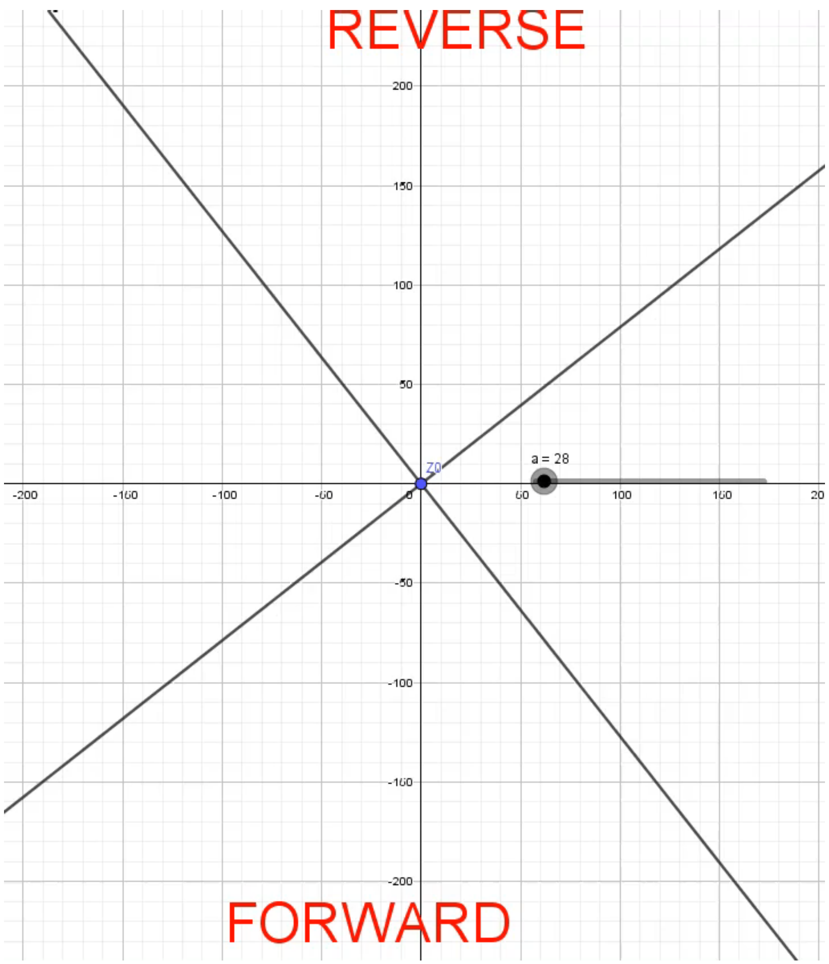
Delta T = 60 ms



Z2 is erratic



Z0 is stable



IBR fed fault security

Sequence Current (I2)

CHALLENGES

- Z2 directional elements can lose directionality
- Current based FIDS logic can declare incorrect fault types

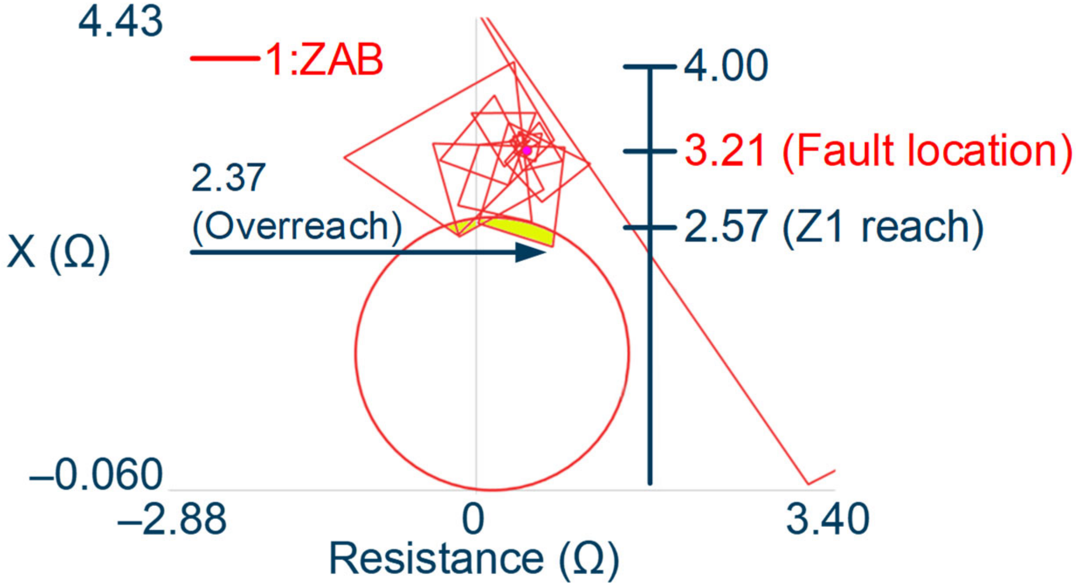
SOLUTIONS

- Block Z2 directional element and current based FIDS for low current magnitude faults
- Use Z0 directional elements for ground faults
- Utilize voltage-based FIDS for PG faults

IBR only source – forward direction

R1 – GRID BUS PPG FAULT (TYPE 4)

Apparent impedance oscillates significantly



IBR apparent impedance oscillations

Challenges

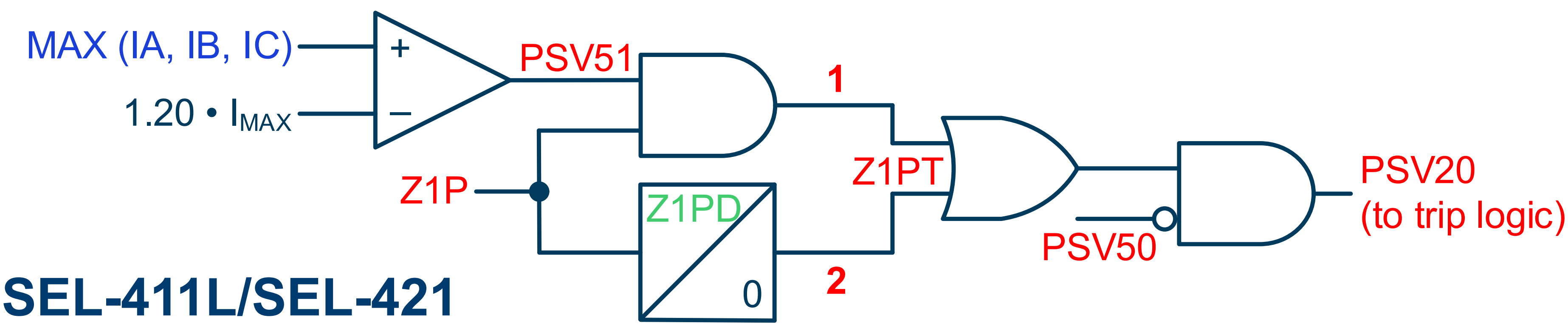
- Potential overreach for Zone 1 (security)
- Potential underreach for Zone 2 backup (dependability)

Solutions

- Use PU timers for Zone 1 security
- Use DO timers for Zone 2 dependability

21P Zone 1 security

- Path 1 is for fast operation for 3P, PP, and PPG faults fed by conventional system
- Path 2 is for secure operation for PP and PPG faults fed by IBR only

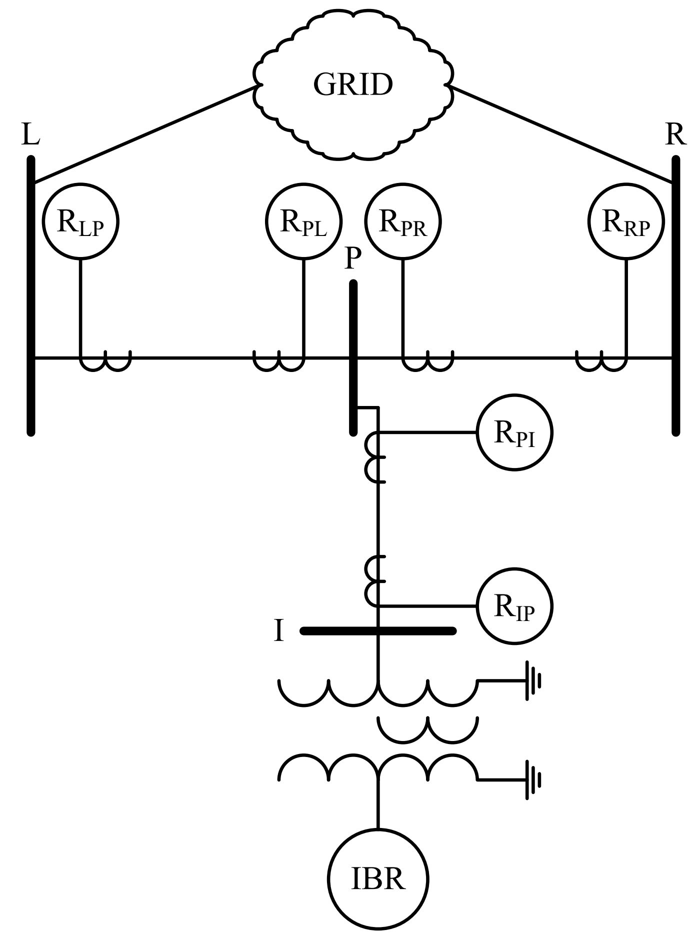


SEL-411L/SEL-421

Note: PSV50 blocks only if the fault is balanced, and the current is low

When do favorable conditions occur?

- There is infeed from conventional sources
- Type 3 IBR feeds unbalanced faults
- There is adequate penetration of IBRs that provide coherent I2 signal, (IEEE 2800)



Favorable conditions

- $I1 > I_{MAX}$ for 3P faults
- $3I2 > I_{MAX}$ for PP, PPG, and PG faults
- $3I2 < I_{MAX}$ and Voltage FIDS enabled (SEL-400 series) for PG faults

Determine IBR fault current contribution

USED FOR OVERCURRENT SUPERVISION

$$I_{MAX} = 1.30 \cdot \frac{S_{IBR}}{\sqrt{3} \cdot V_{HV} \cdot CTR}$$

Negative-sequence current supervision

$$50FP = 1.25 \cdot I_{MAX}$$

$$50RP = 1.00 \cdot I_{MAX}$$

↓

Secures Z2 and FIDS logic for unbalanced faults

Protection schemes

- Line current differential
  - 87LP, 87LG – good performance
  - 87LQ – set pickup at 1.25 • I_{MAX}
- POTT
  - Enable echo keying and ECTT
  - Includes voltage FIDS (SEL-400 series only)
- DCB
  - Dependability at IBR terminal is limited

Better dependability

Implementation

SEL Application Guide Volume I AG2021-37

Applying SEL Relays in Systems With Inverter-Based Resources

Ryan McDaniel, Ritwik Chowdhury, Karl Zimmerman, and Brett Cockerham

Available for download at selinc.com

Additional Resources

Transmission Line Protection for Systems With Inverter-Based Resources

Ritwik Chowdhury and Normann Fischer, *Schweitzer Engineering Laboratories, Inc.*

https://selinc.com/api/download/133824/?lang=en

Distance Elements for Line Protection Applications Near Unconventional Sources

Bogdan Kasztenny
Schweitzer Engineering Laboratories, Inc.

https://selinc.com/api/download/134587/?lang=en

Transmission Line Setting Calculations – Beyond the Cookbook Part II

Michael Thompson, Daniel Heidfeld, and Dalton Oakes, *Schweitzer Engineering Laboratories, Inc.*

https://selinc.com/api/download/135493/?lang=en

Conclusion

1. Use line current differential scheme
2. Apply weak infeed echo with POTT scheme
3. Improve directional element settings
   - Apply 32V to utilize strong IBR plant transformer if there is no mutual coupling
   - Increase 50FP and 50RP settings
     - Improved directionality, especially for phase-to-phase faults in which 32Q may be the only element to provide directionality
     - Voltage-based FIDS logic when IBR sources current
   - Add overcurrent supervision for directional security for three-phase faults

Conclusion

4. Distance elements
   - Phase Zone 1 security using fault detectors (i.e., overcurrent supervision)
   - Zone 1 security using CVT transient blocking logic
   - Step-distance Zone 2 dependability using dropout timer
   - Extend Zone 1 at strong terminal for tie-line applications
5. Ground time-overcurrent for ground fault backup
6. Time-delayed undervoltage backup, especially for phase faults

Guidance is independent of IBR type or controls and may be applied to existing relays with minor setting adjustments

IBRs

Future developments

- Performance standards are finally available
- IBR control algorithms updated to inject negative-sequence current under fault conditions will start penetrating the system
- Will likely always be period of uncontrolled response lasting as long as 2.5 cycles
- Guidelines for applying relays in an IBR world are not mature

Questions?