PNM Approach to Protecting Overcompensated High-Voltage Lines

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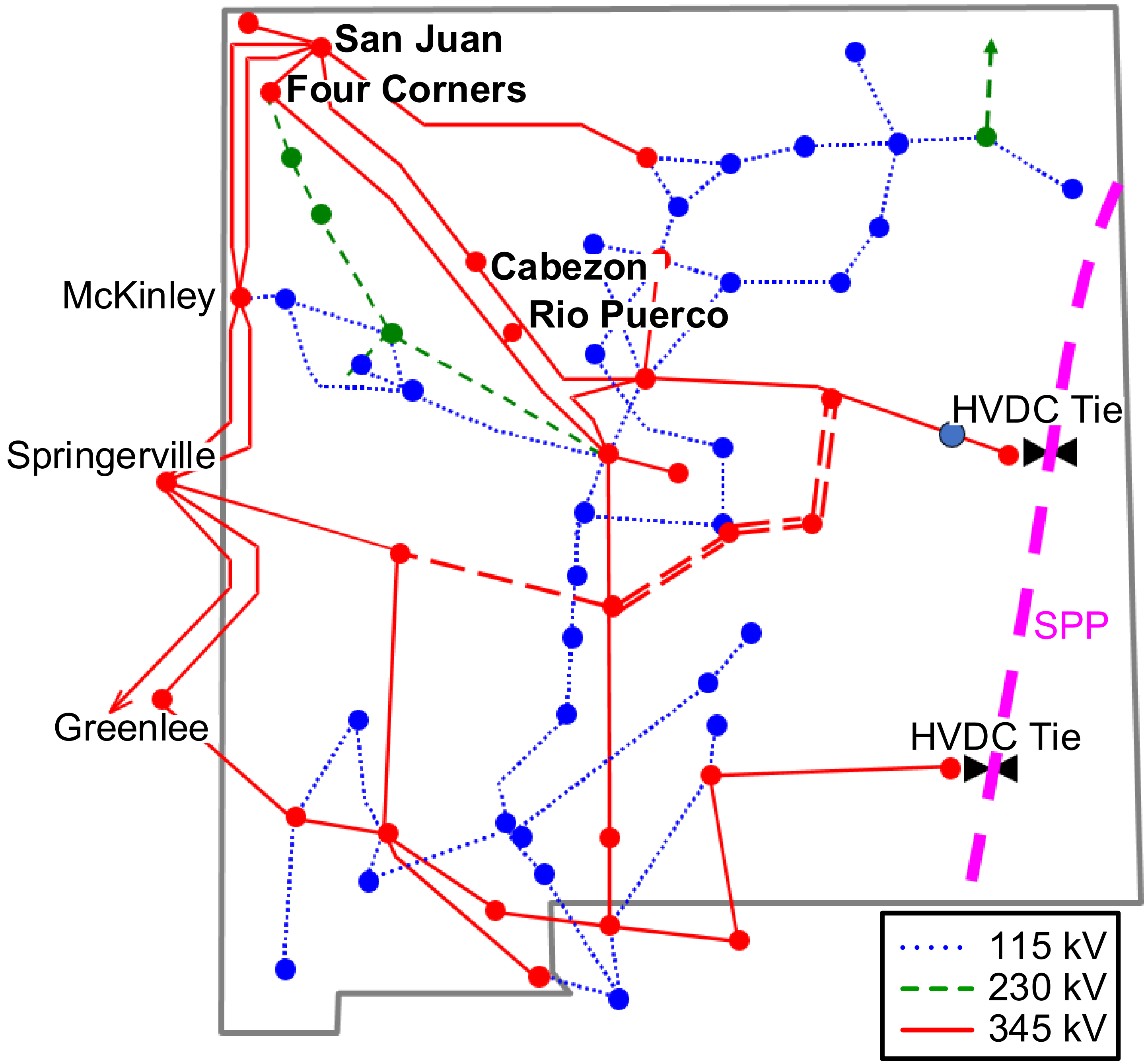
Introduction

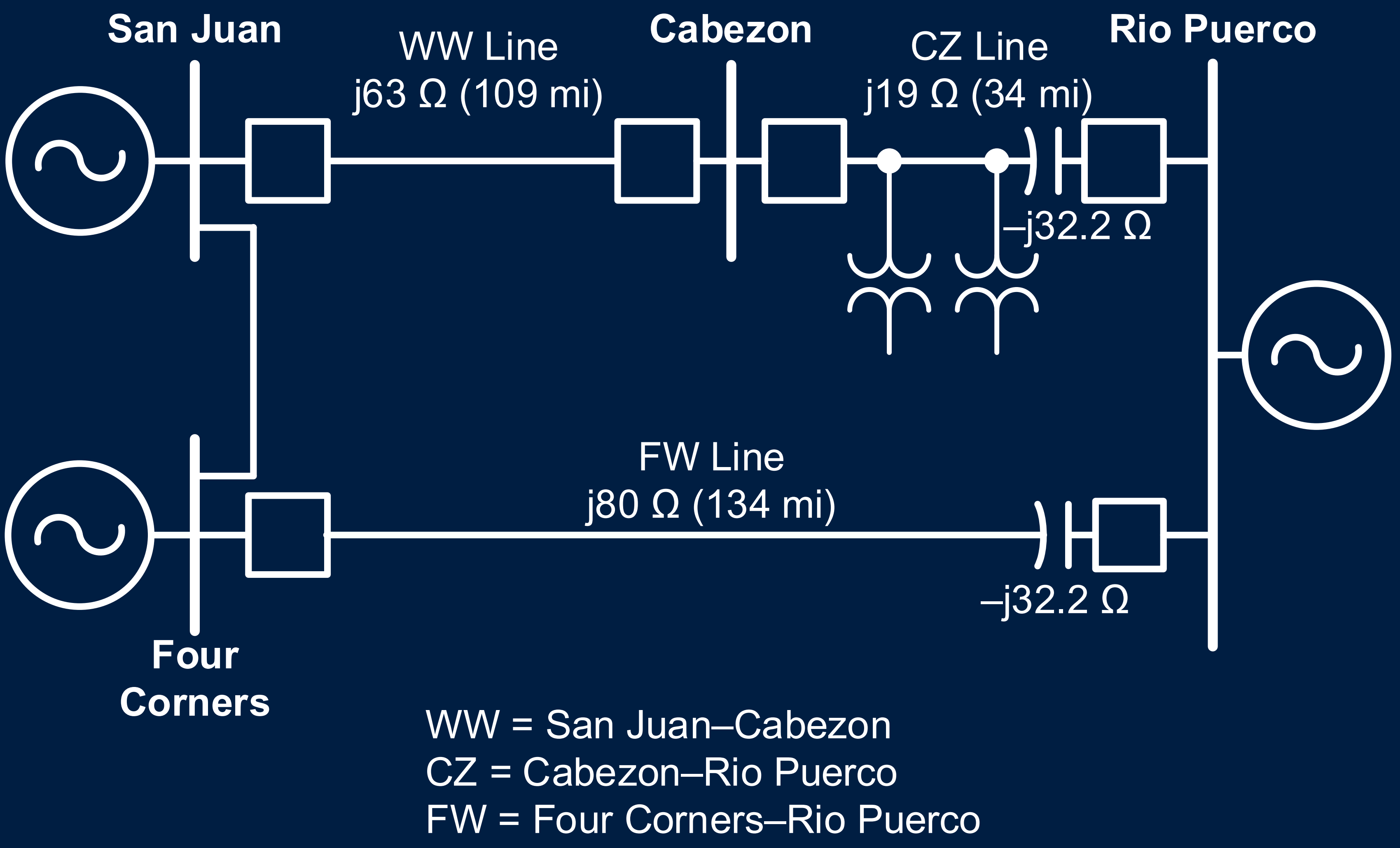
- Overview of PNM system
- Cabezon project summary
- PNM protection standards
- Series-compensated lines and protection challenges
- PNM protection scheme
- Laboratory tests and field events
- Conclusion

PNM System



- 14,388 mi of transmission lines
- 69–230 kV primary voltage
- 46 kV subtransmission
- Large generation at San Juan, Four Corners substations

Cabezon Project Summary



- Compensation for Cabezon–Rio Puerco line is 170%
- Typical PNM compensation is 40–50%
- Shunt reactor provides reactive compensation

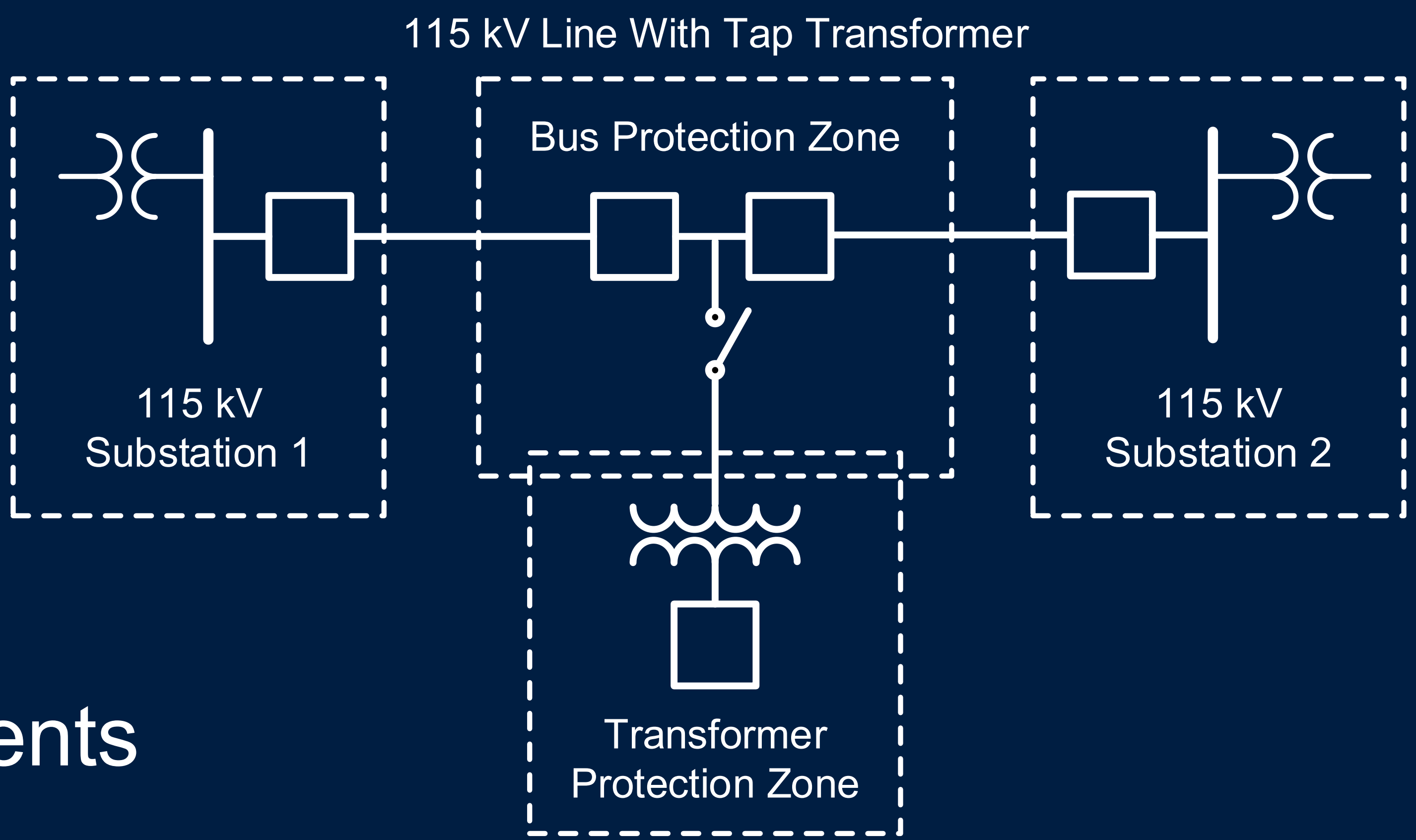
PNM Line Protection Standards

- Two relays at 115 kV and 230 kV and three relays at 345 kV
- Line current differential, POTT, and step-distance protection with backup overcurrent protection
- Quadrilateral distance protection for phase and ground
  - Z1 = 70–80% of line impedance
  - Z2 = POTT forward direction, step-distance delay of 20 cycles
  - Z3 = POTT reverse direction
  - Z4 = Breaker failure, forward direction, delay of 60 cycles

PNM Line Protection Standards

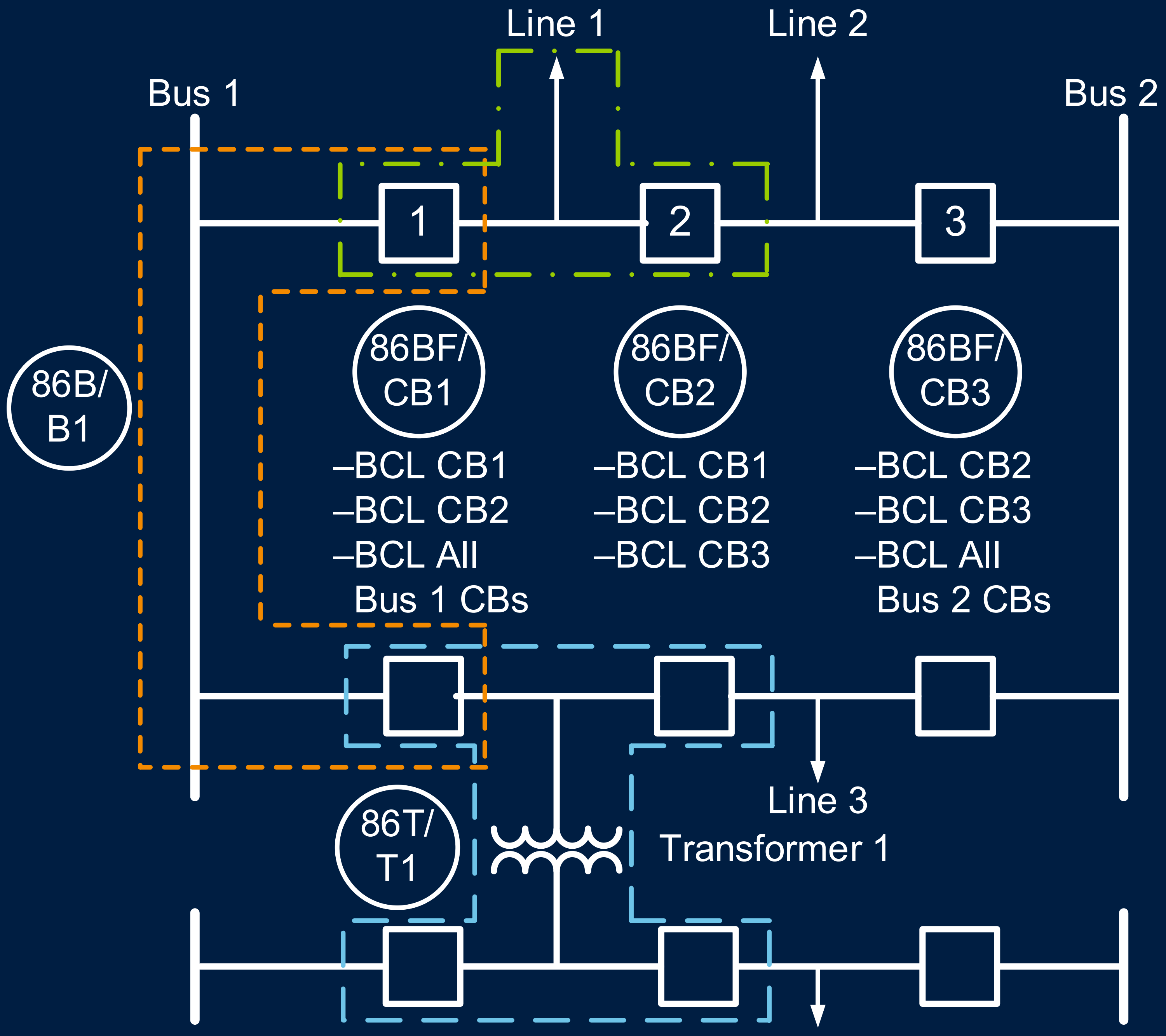
- Backup instantaneous overcurrent element (phase and ground) at 15–20% of line
- Remote bus ground fault delay of 0.3–0.5 seconds
- Three-pole tripping for most applications

PNM Line Protection Standards



- Differential protection uses positive-, negative-, and zero-sequence elements
- 115 kV lines use tapped load and do not use negative-sequence differential elements
- Future protection will include breakers at tapped substations, allowing system to be restored once transformer fault is cleared

PNM Protection Standards



CB1 BF (line and bus)

1. Line 1 R1, R2, R3
2. Bus 1 RX1, RX2

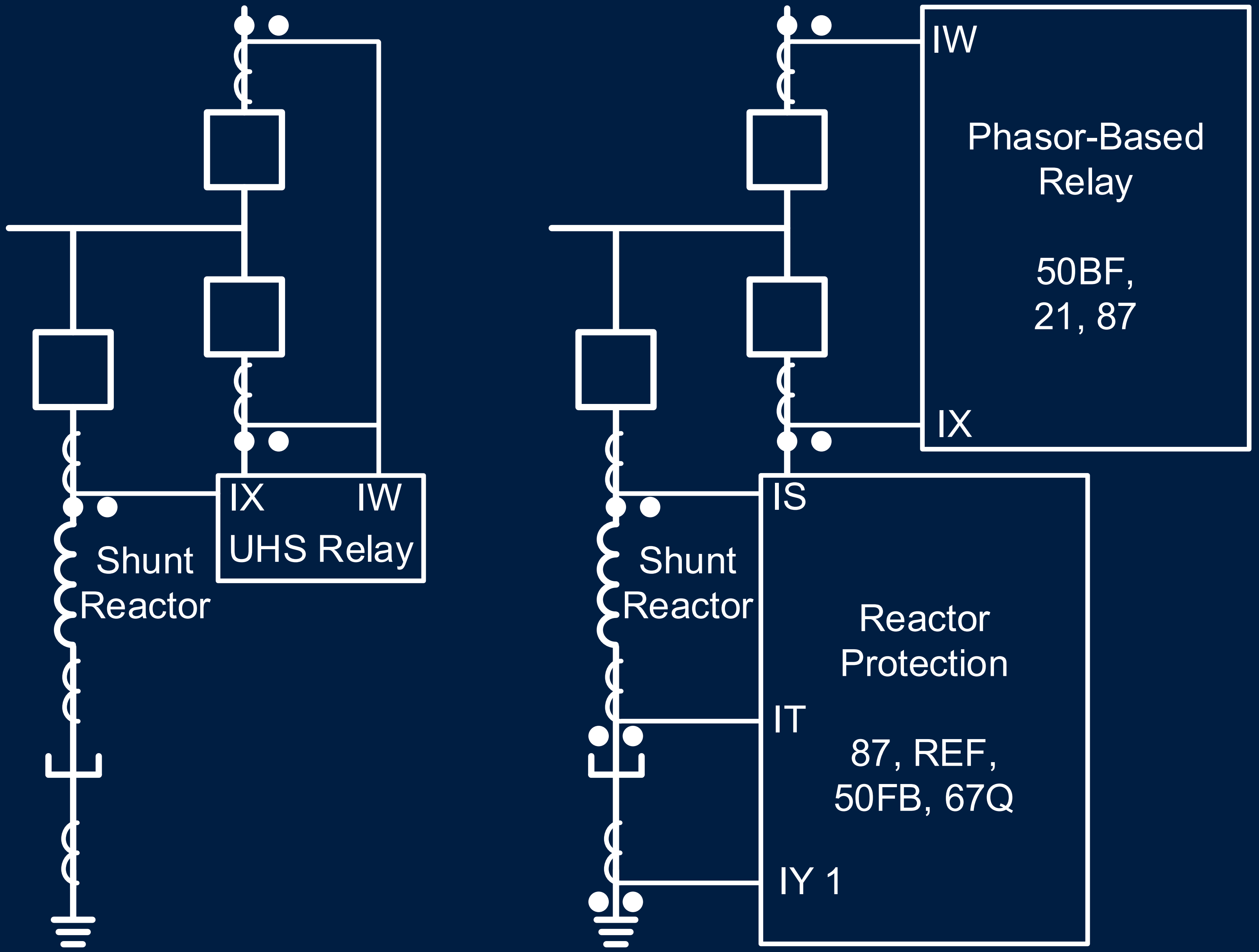
Line R1

1. Re-Trip CB1
2. Trip CB2
3. DTT R2, R3 Line 1
4. TTR Remote End
5. DTT RX1, RX2 Bus 1
6. Assert 86BF/CB1

Bus 1 R1

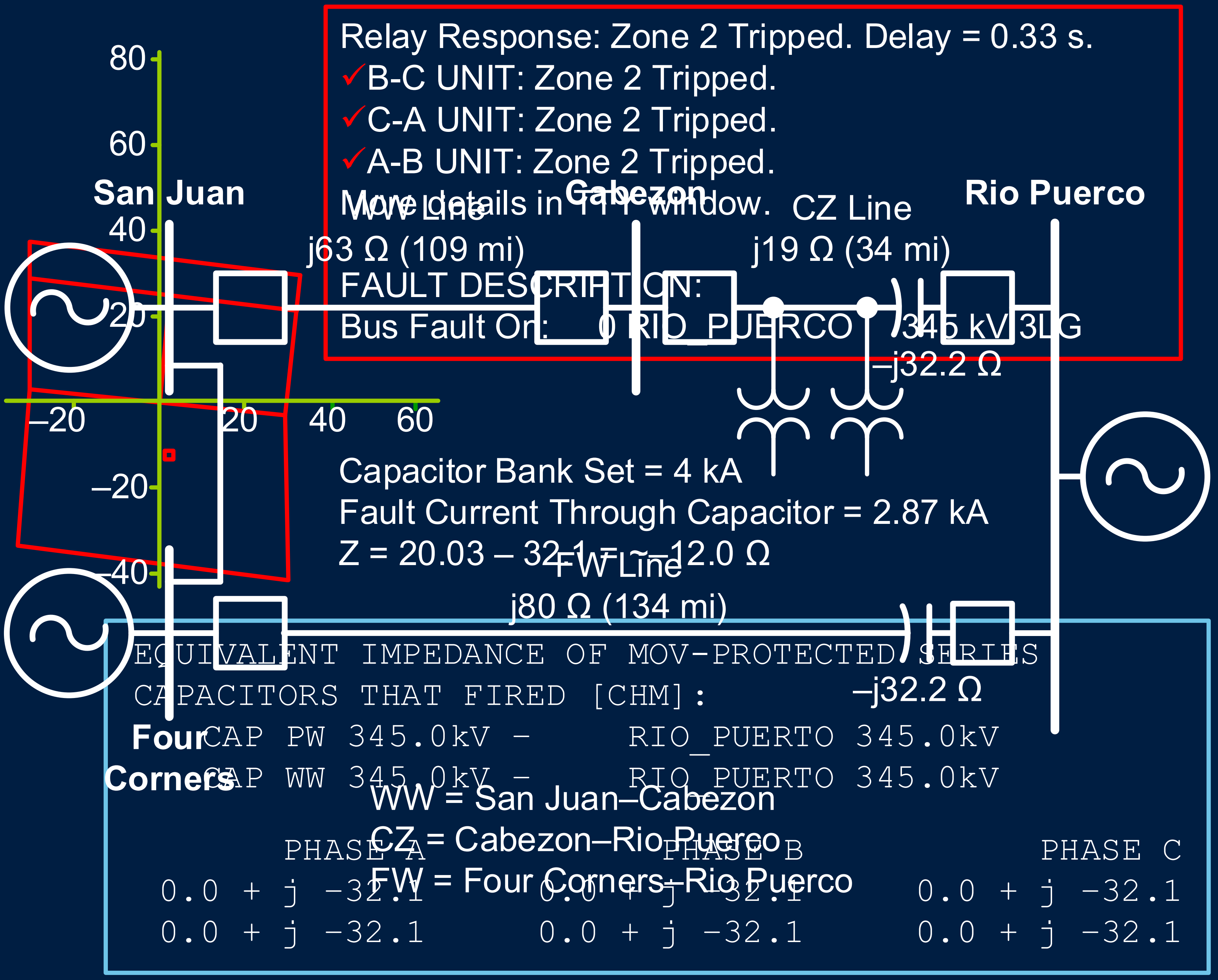
1. Re-Trip CB1
2. DTT RX2 Bus 1
3. DTT R1, R2, R3 Line 1
4. Assert 86BF/CB1

PNM Protection Standards



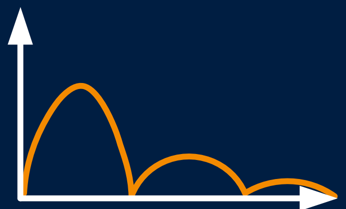
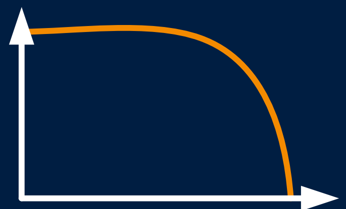
Compensated Lines and Challenges

- Current and voltage inversion
- Impedance estimation
- Differential protection



Phasor and Time-Domain Principles

Similarities and Differences

Algorithm	Phasors	Incremental Quantities	Traveling Waves
Signal spectrum of interest	40–70 Hz	0.5 kHz	100 kHz
Filtering			
Sampling	16 s/c	10 kHz	1 MHz
Line theory	VF = V – ZI	$V_F(t) = V(t) - \left(Ri(t) + L\frac{di(t)}{dt} \right)$	$i_{S(t)} \approx -i_{R(t-\tau)}$
Operating time	1 cycle	A few milliseconds	1–2 ms
Elements	Z1P, Z1G, 32G, 32Q, and more	TD21, TD32	TW87, TW32

Reach Selection

- Phasor-based protection
- Four quadrilateral zones
- POTT

- Line current differential settings
  - Positive-sequence current = 600 A
  - Maximum line loading 1,004 MVA = 1,680 A (600 A / 2,000 A = 0.3 pu)
  - Zero-sequence element = 10–15% unbalance (10% • 2,000 = 200 A = 0.1 pu)
  - Negative-sequence element = 25% of 500 A = 0.25 pu

Reach Selection – UHS Time Domain

- TD21
  - Phase and ground elements set to 75% and 70%, respectively
  - External series compensation = Y
- TD32
  - TD32ZF = 0.3 • strongest impedance for fault at remote bus
  - TD32ZR = 0.3 • line impedance including series capacitor

Reach Selection – UHS Time Domain

- POTT – TP67P and TP67G selected based on maximum incremental current caused by series capacitor switching
- TW87 – TP50P set above line charging current and below minimum remote bus fault current (select margin of 50–75%)

$$TP67G = \frac{1.25}{\sqrt{3}} \cdot \frac{VNOM}{\left|Z_{S1} + Z_{L1} + Z_{T1}\right|}$$

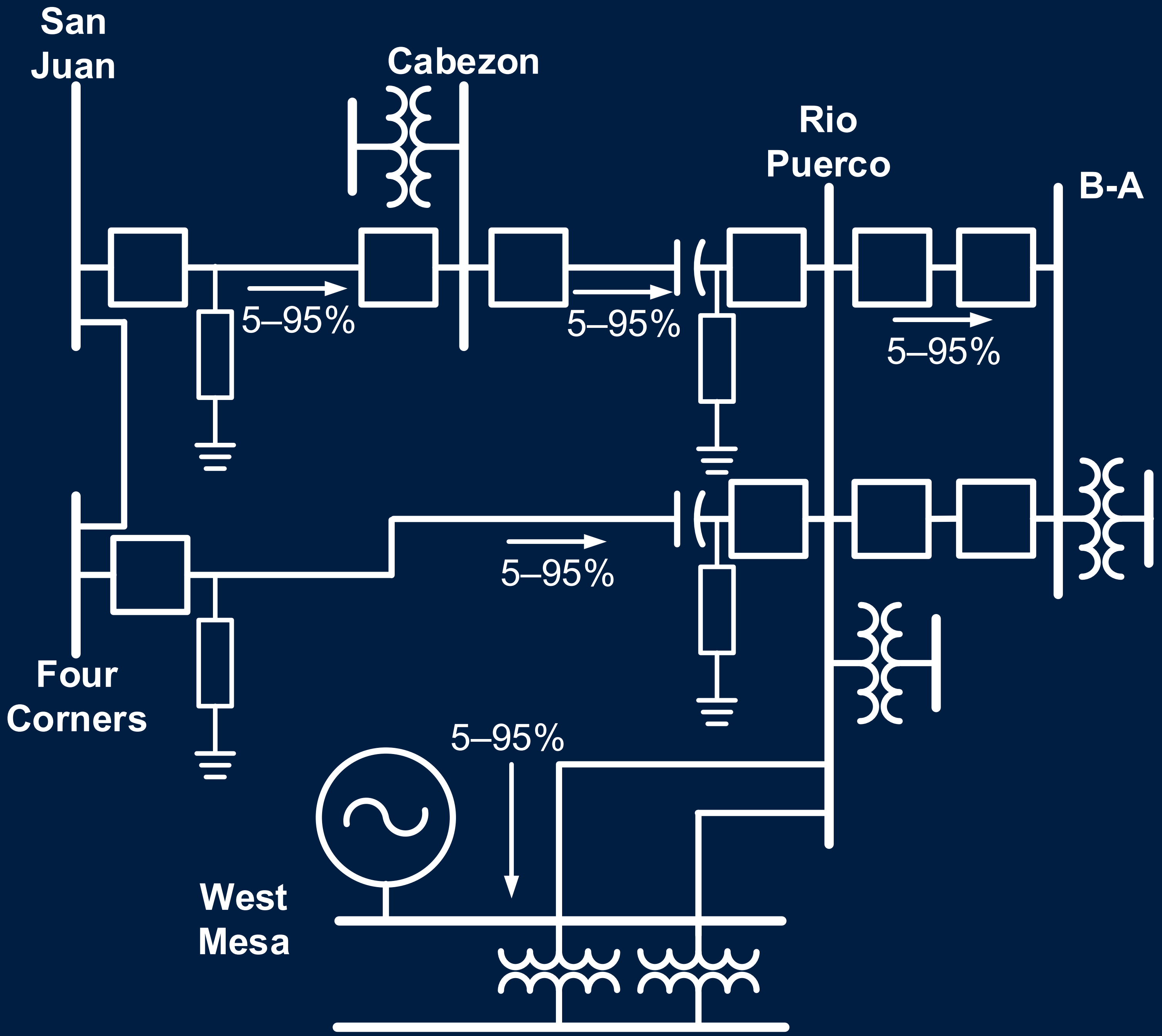
where:

Z_{S1} = strongest local source impedance
Z_{L1} = line impedance
Z_{T1} = strongest equivalent remote source impedance

$$TP67P = \sqrt{3} \cdot TP67G$$

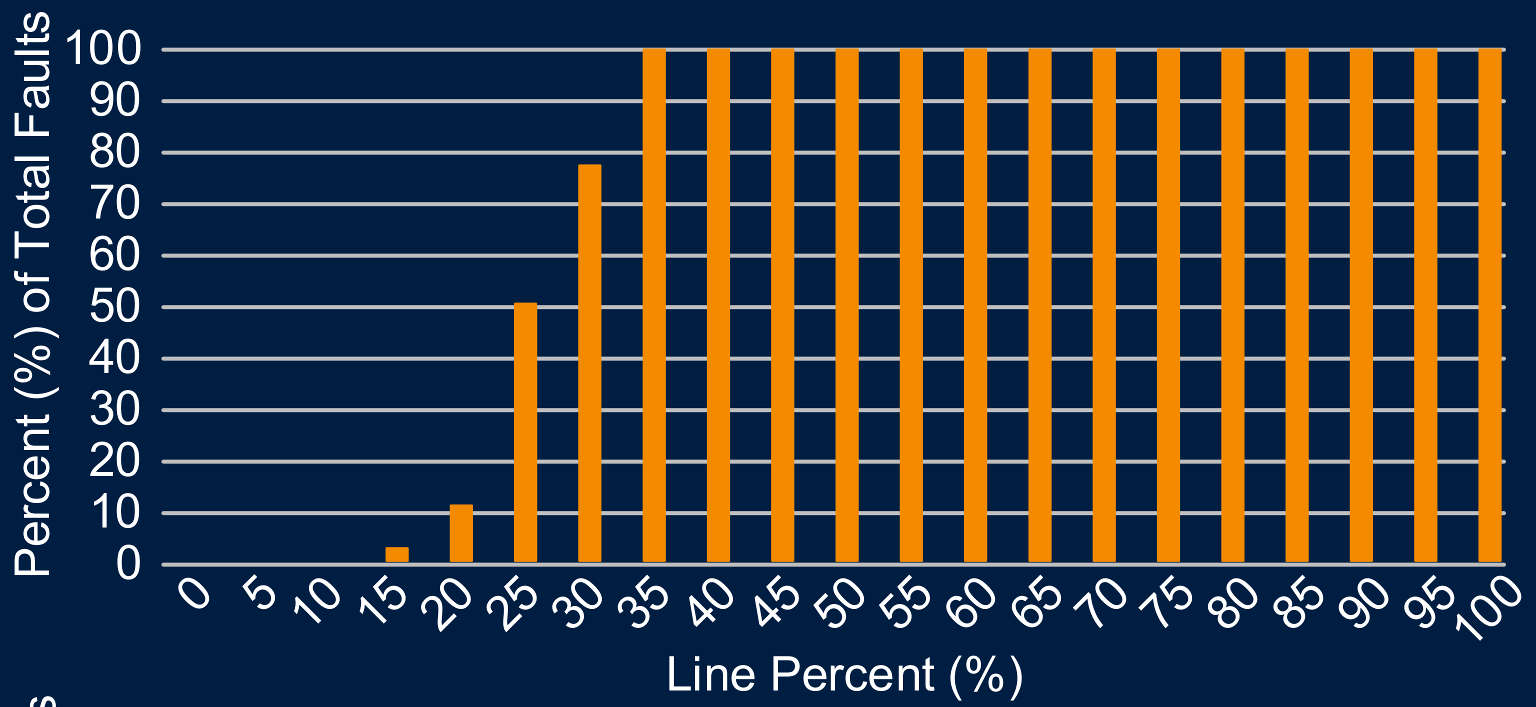
Lab Testing

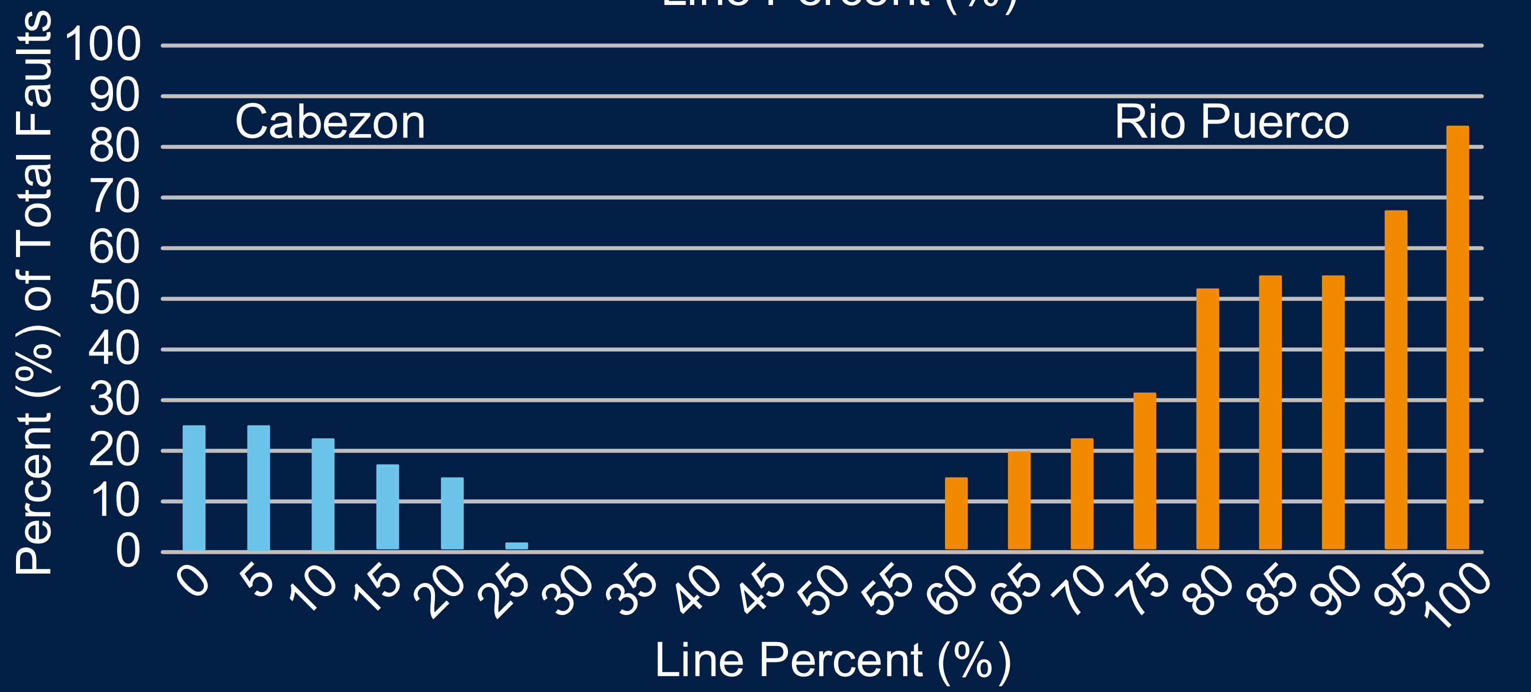
- Model system
- Test internal and external faults



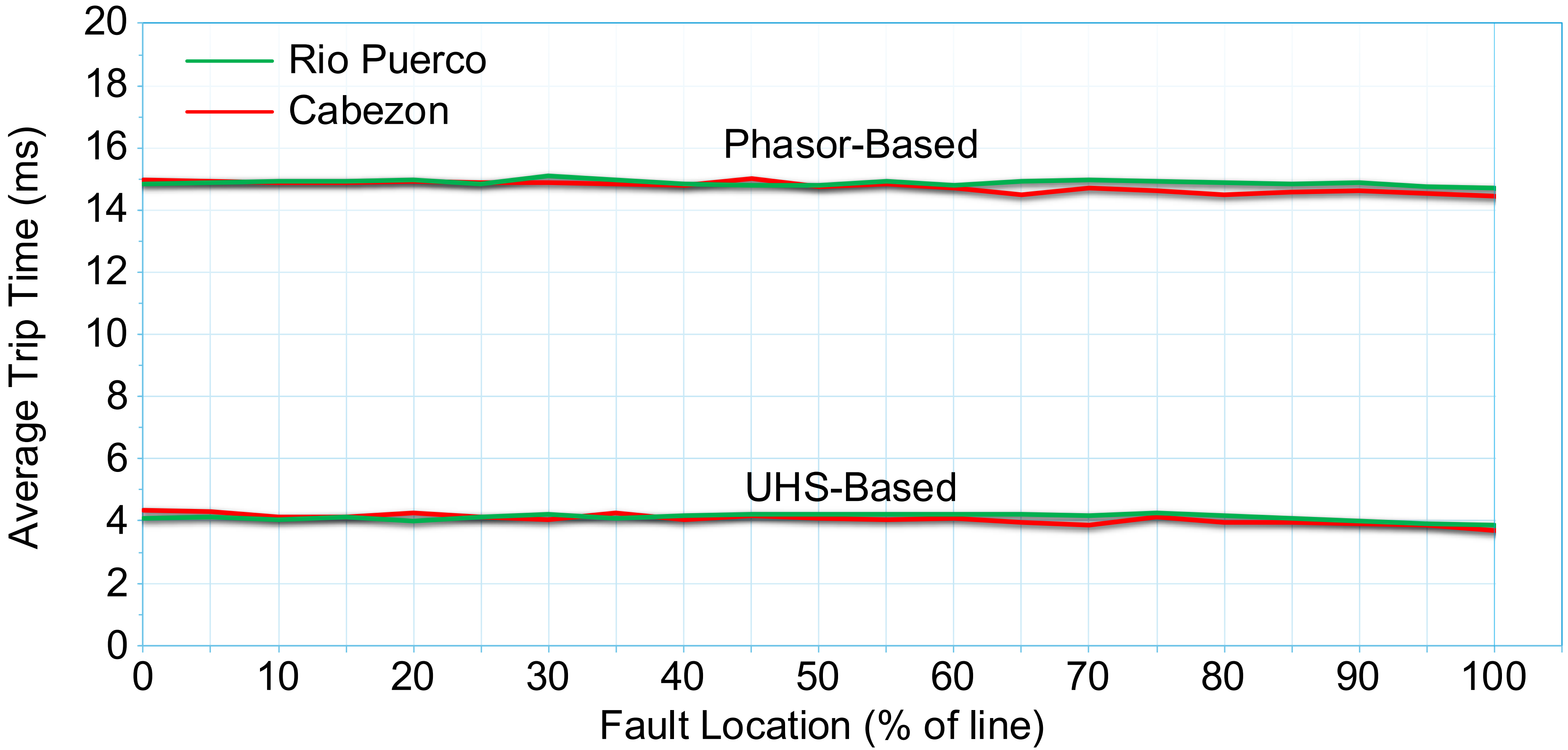
Lab Testing

- Phasor-based
- Time domain



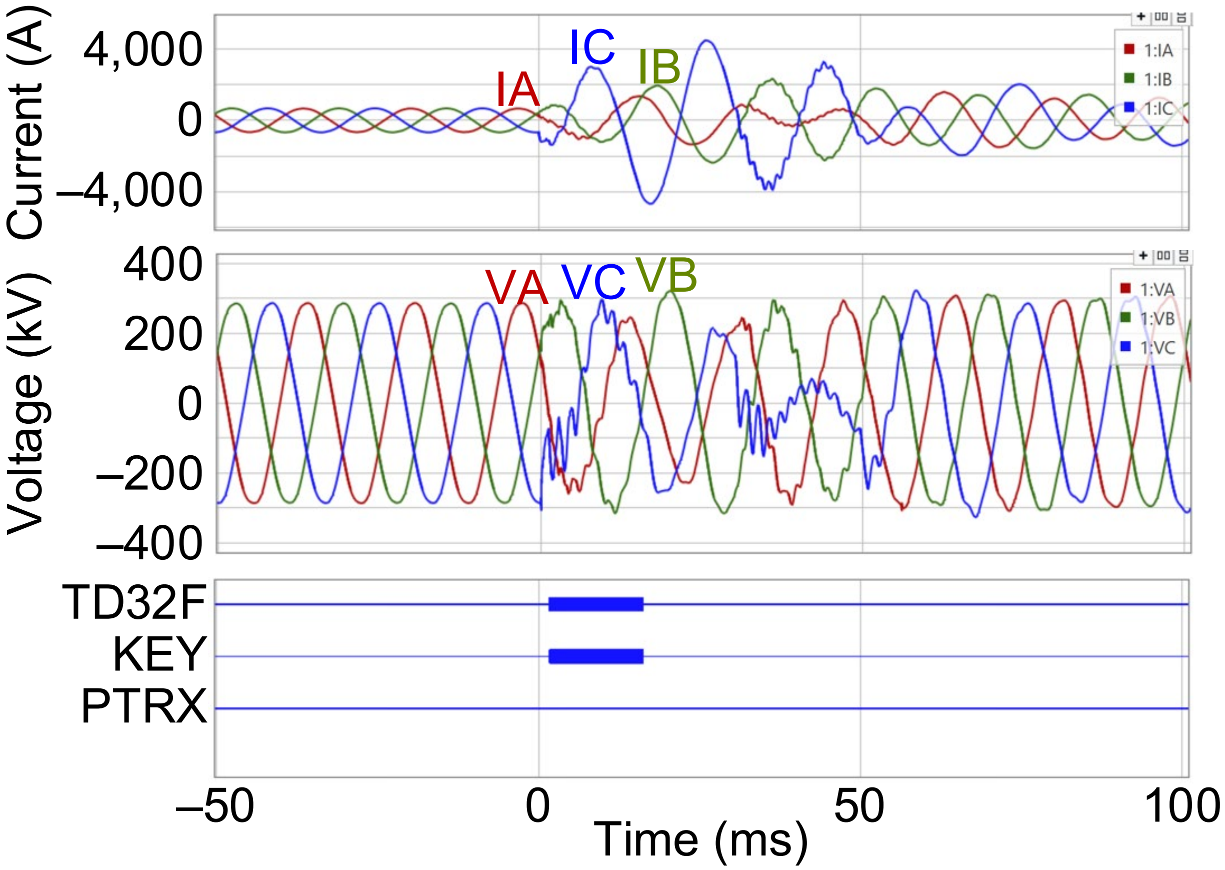


Results Summary



External Faults – Cabezon

Date	Fault Type	Location
10/2/2018	CG	Behind San Juan terminal
10/3/2018	CG	Behind San Juan terminal
8/13/2018	CG	Four Corners–Rio Puerco line



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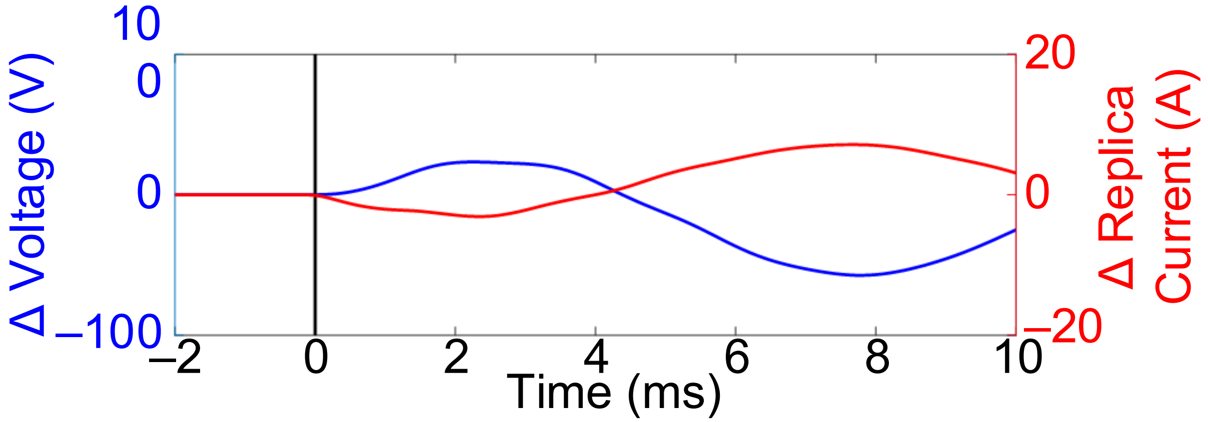

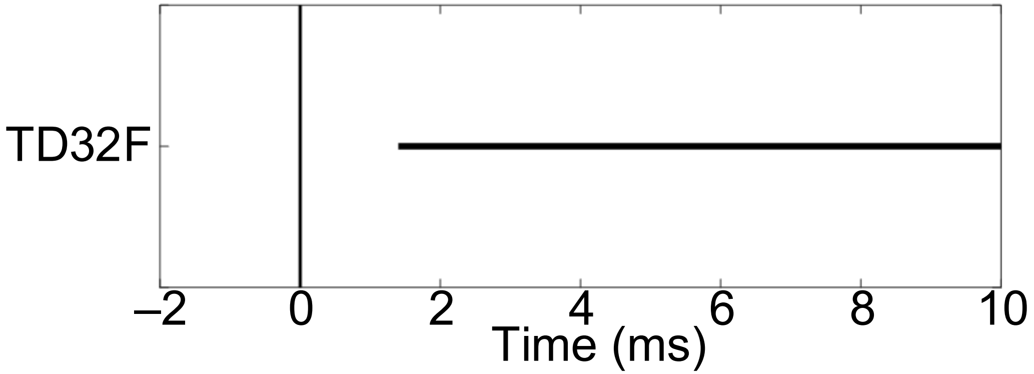

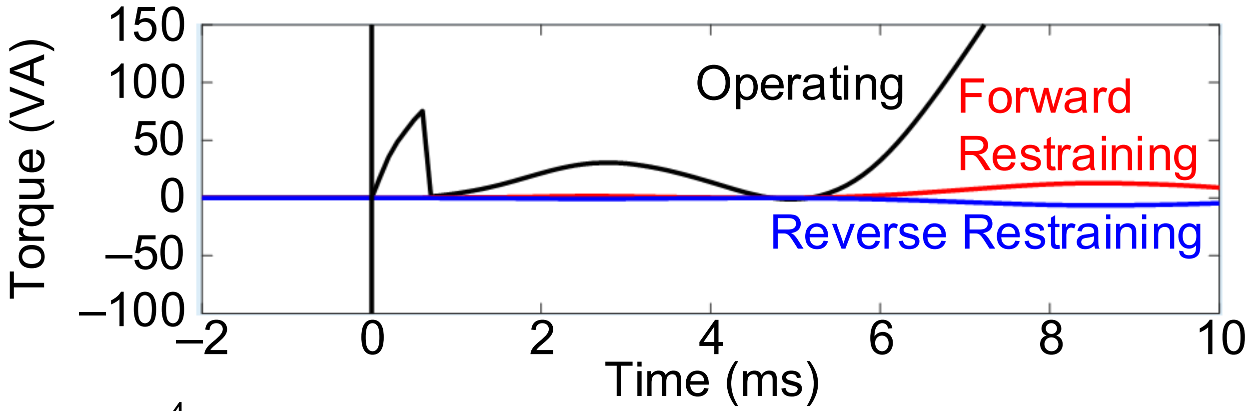

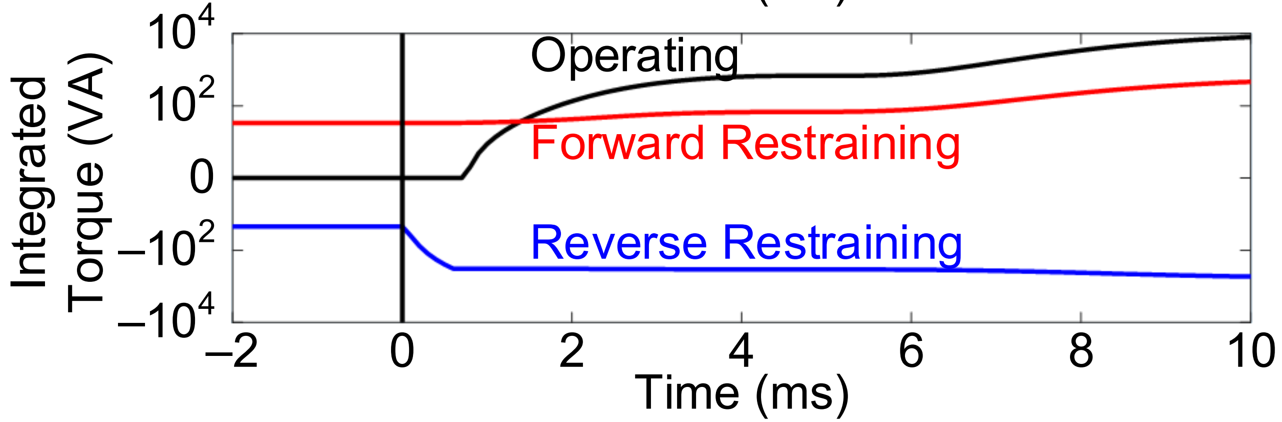

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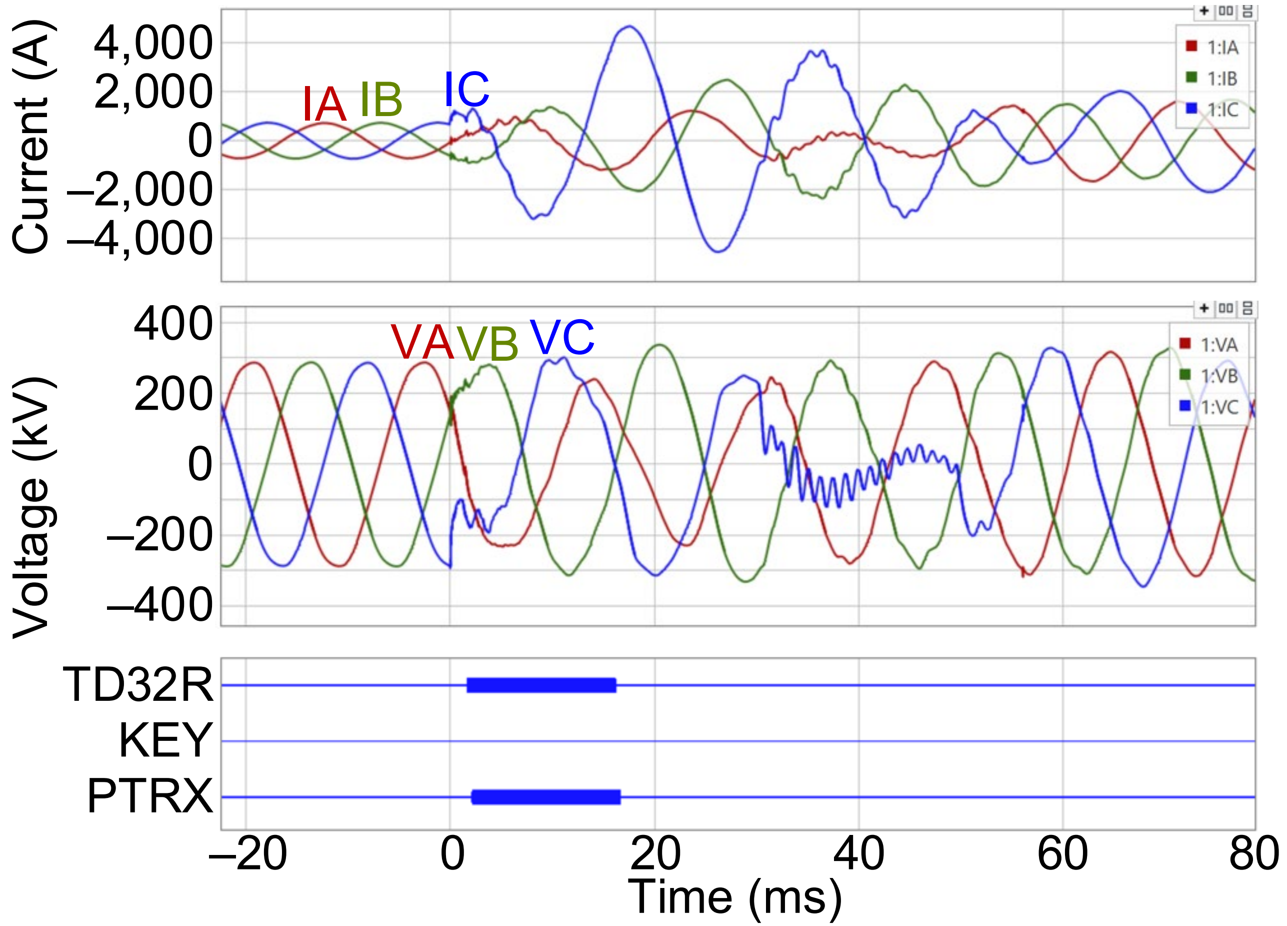

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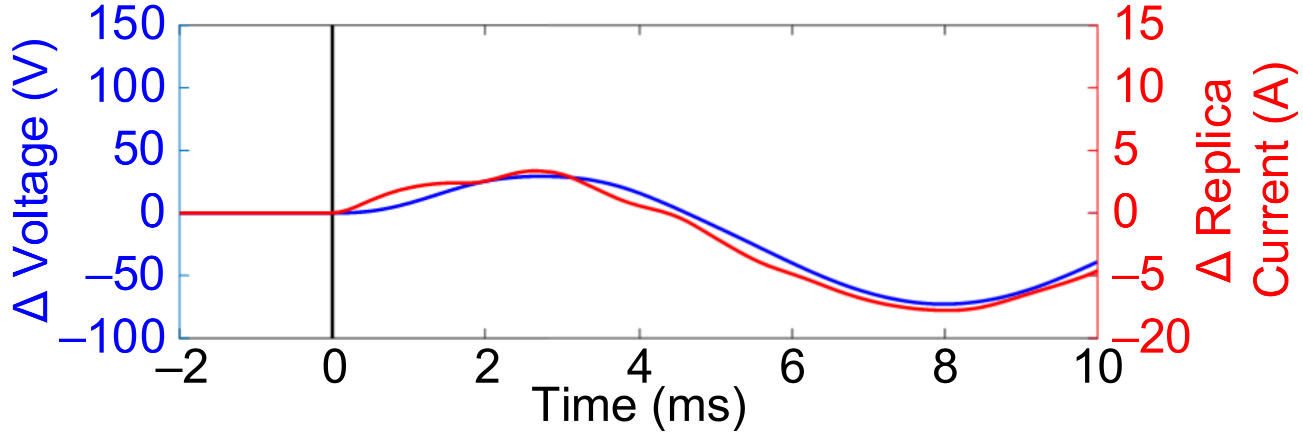
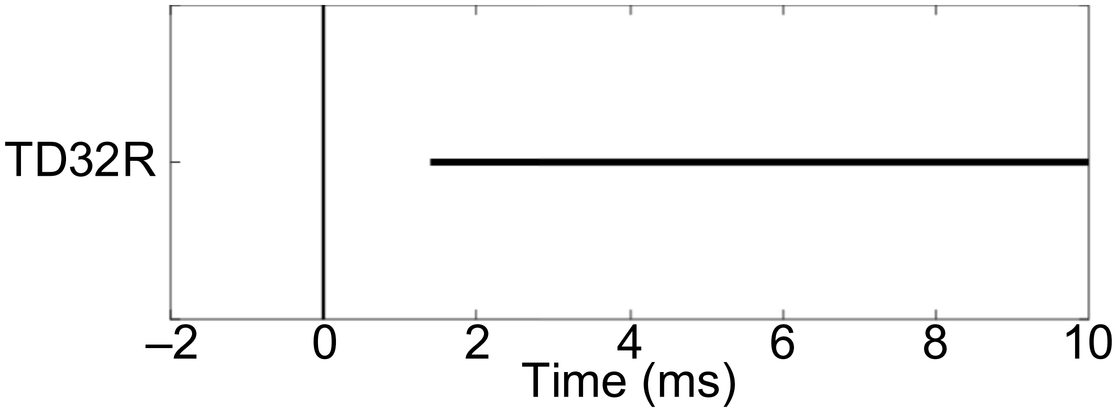
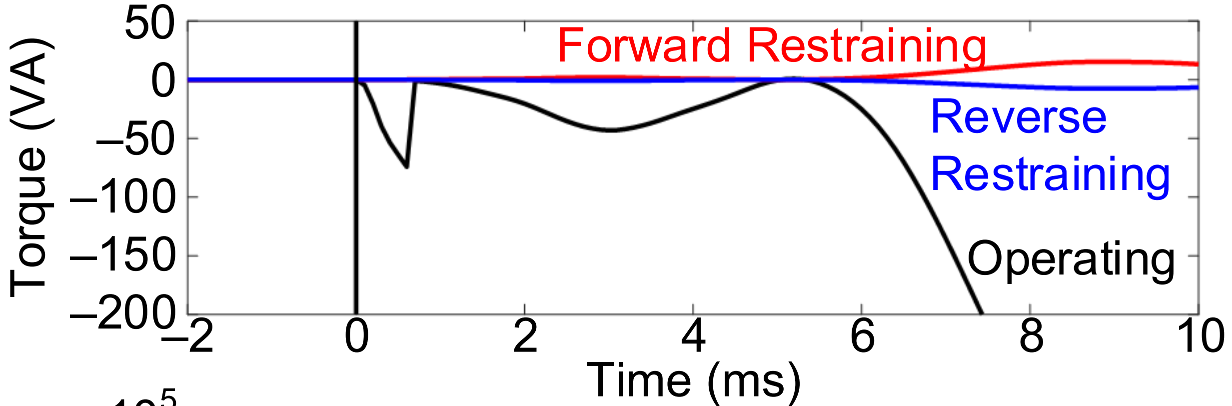
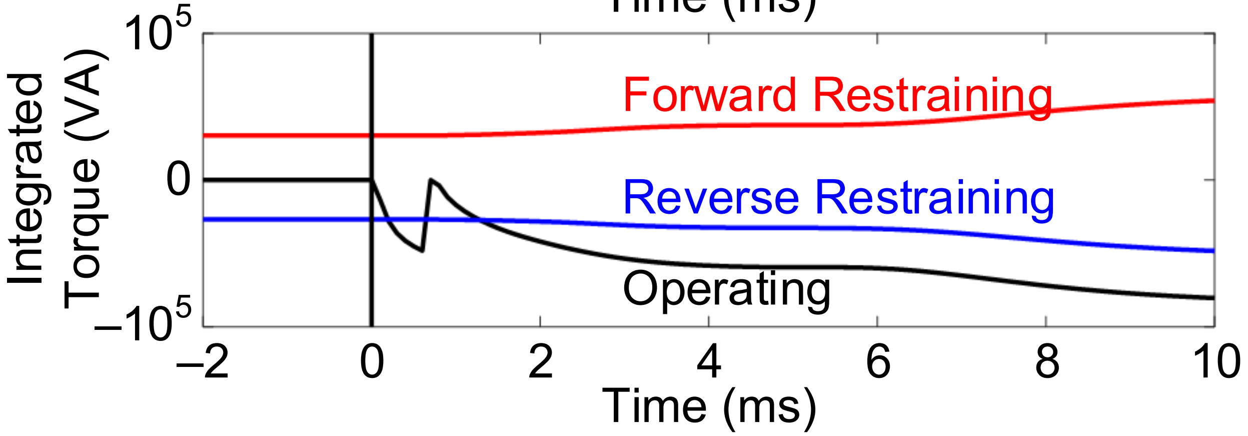


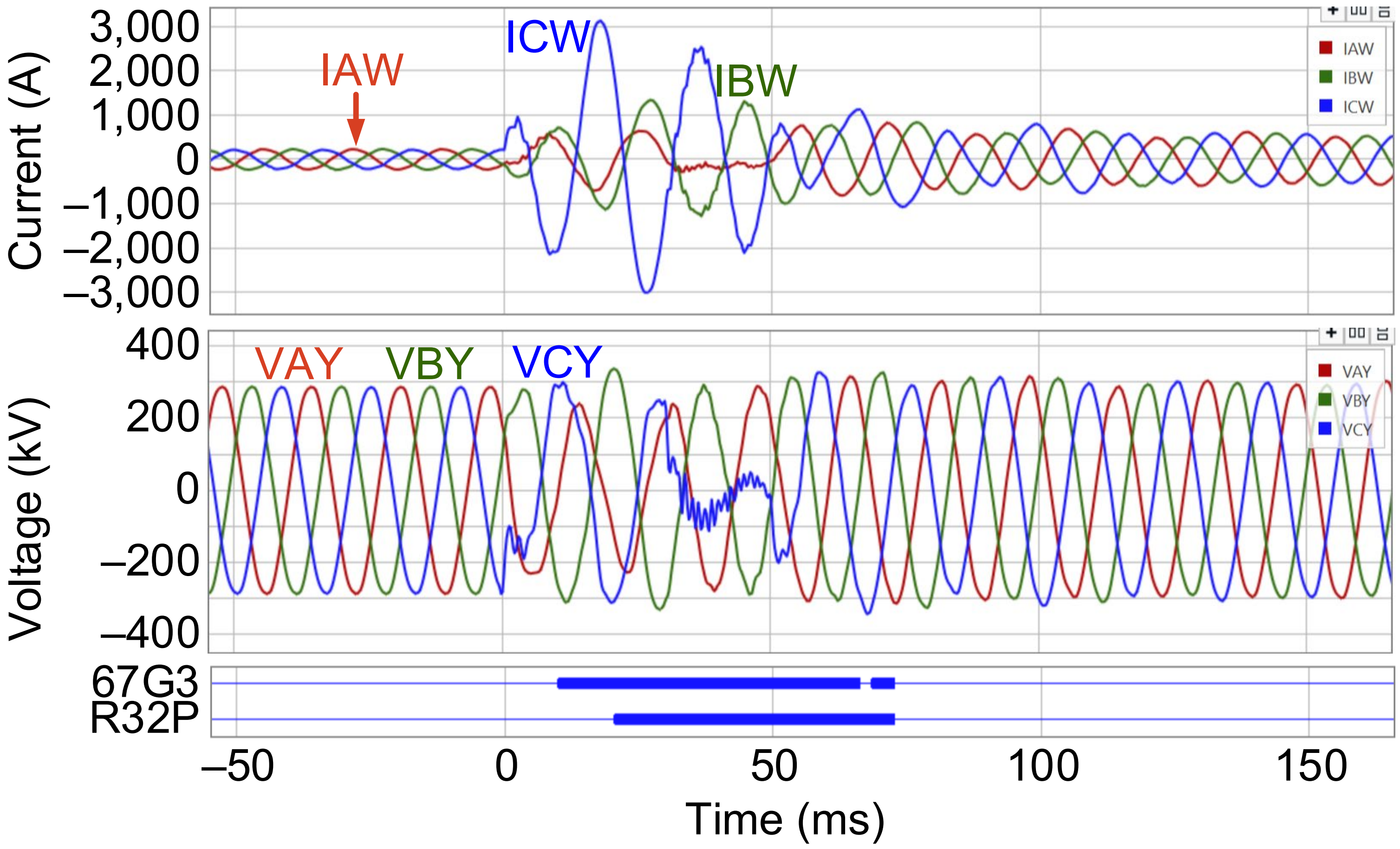




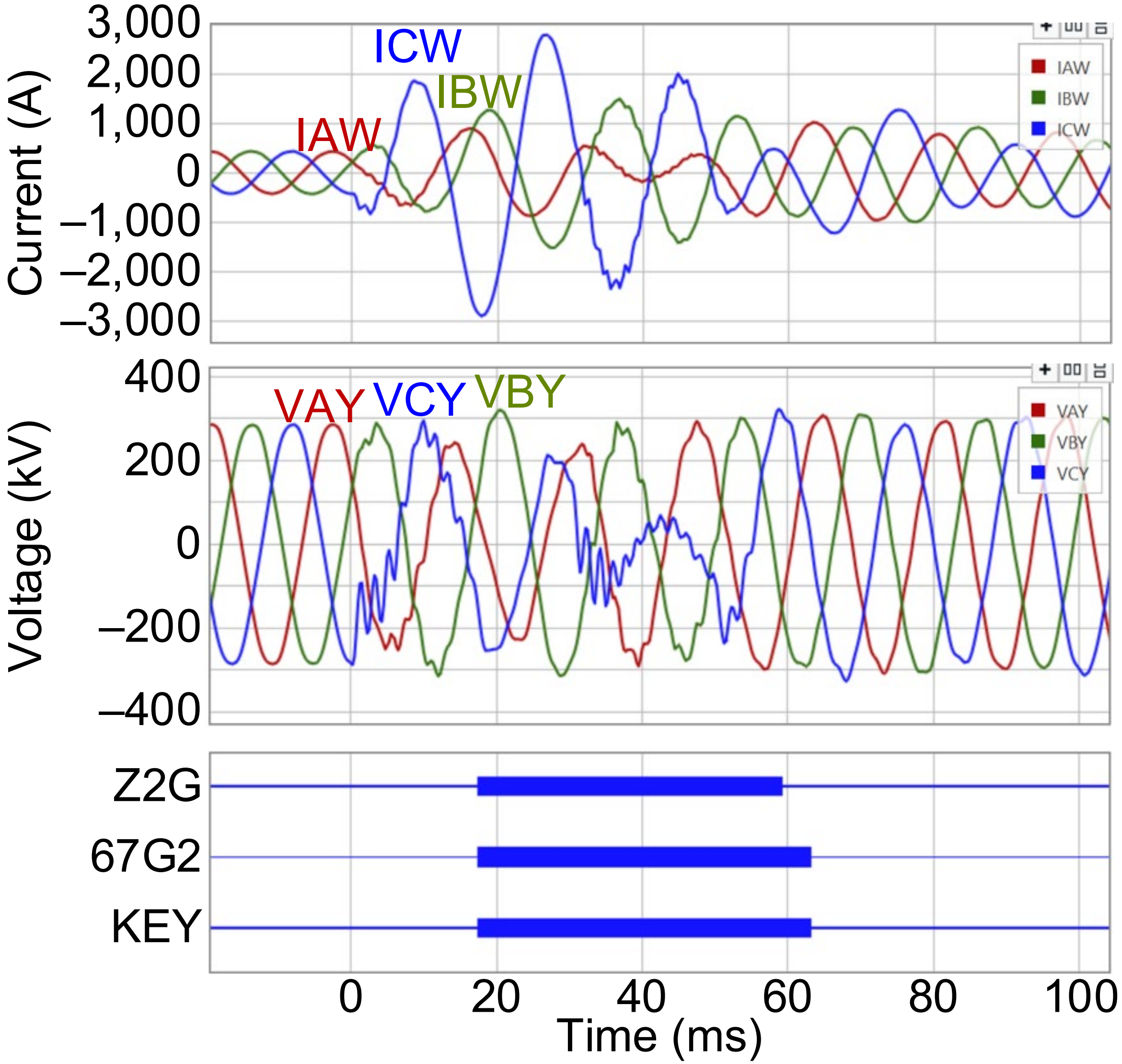


External Faults – 8/13/2018

Rio Puerco End



External Faults – 8/13/2018
Cabezon End



Conclusion

- 170% series-compensated line
- Protection challenges for series-compensated lines
- Phasor- and UHS-based relays
- PNM protection standards and set point selection
- Laboratory tests to validate set points
- Phasor-based relay operating time ~16 ms, UHS relay operating time ~2–4 ms
- Field event analysis verifying performance

Questions?