How RTDS and SEL Marked Historic Milestone in Power System Protection

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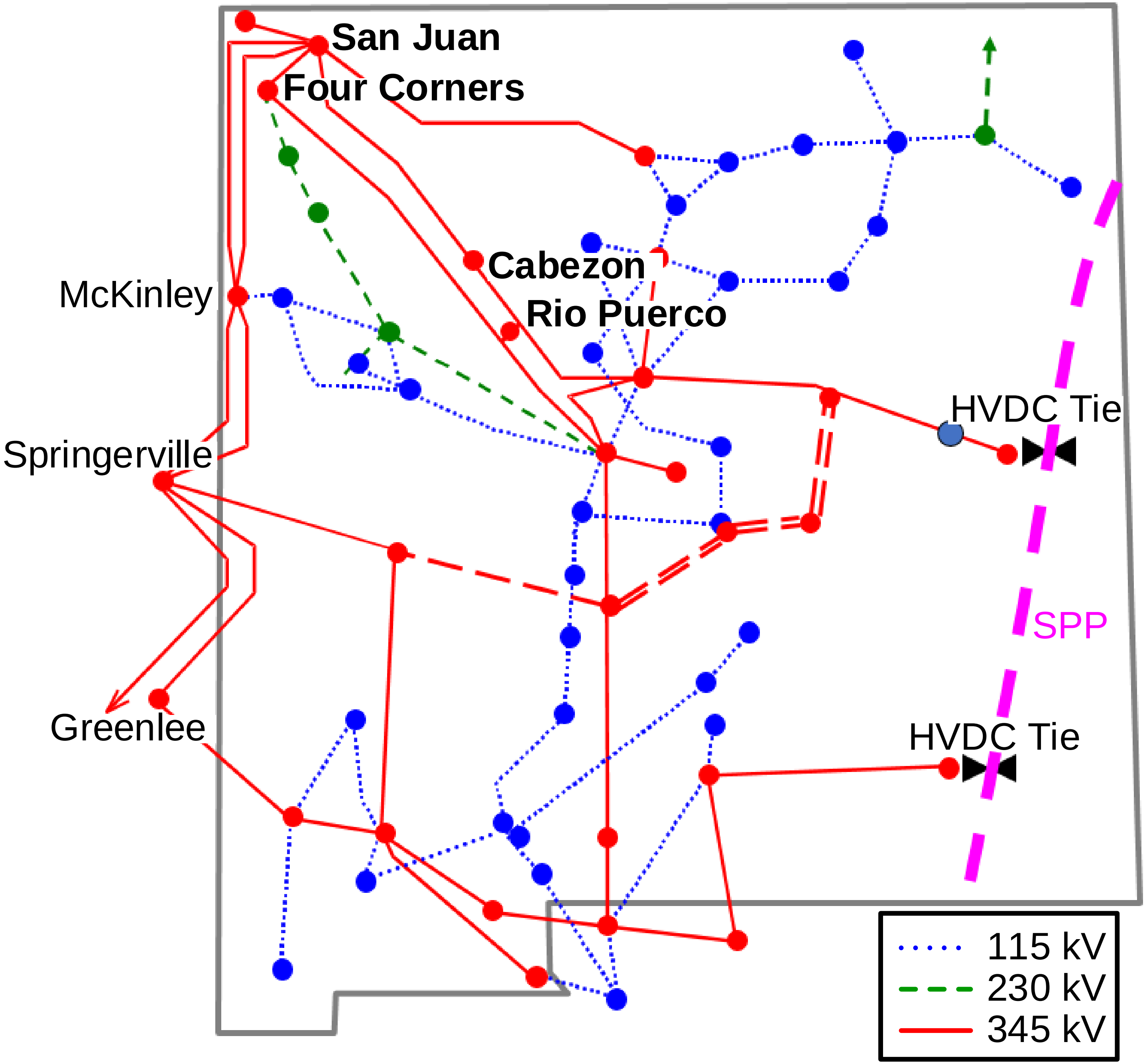
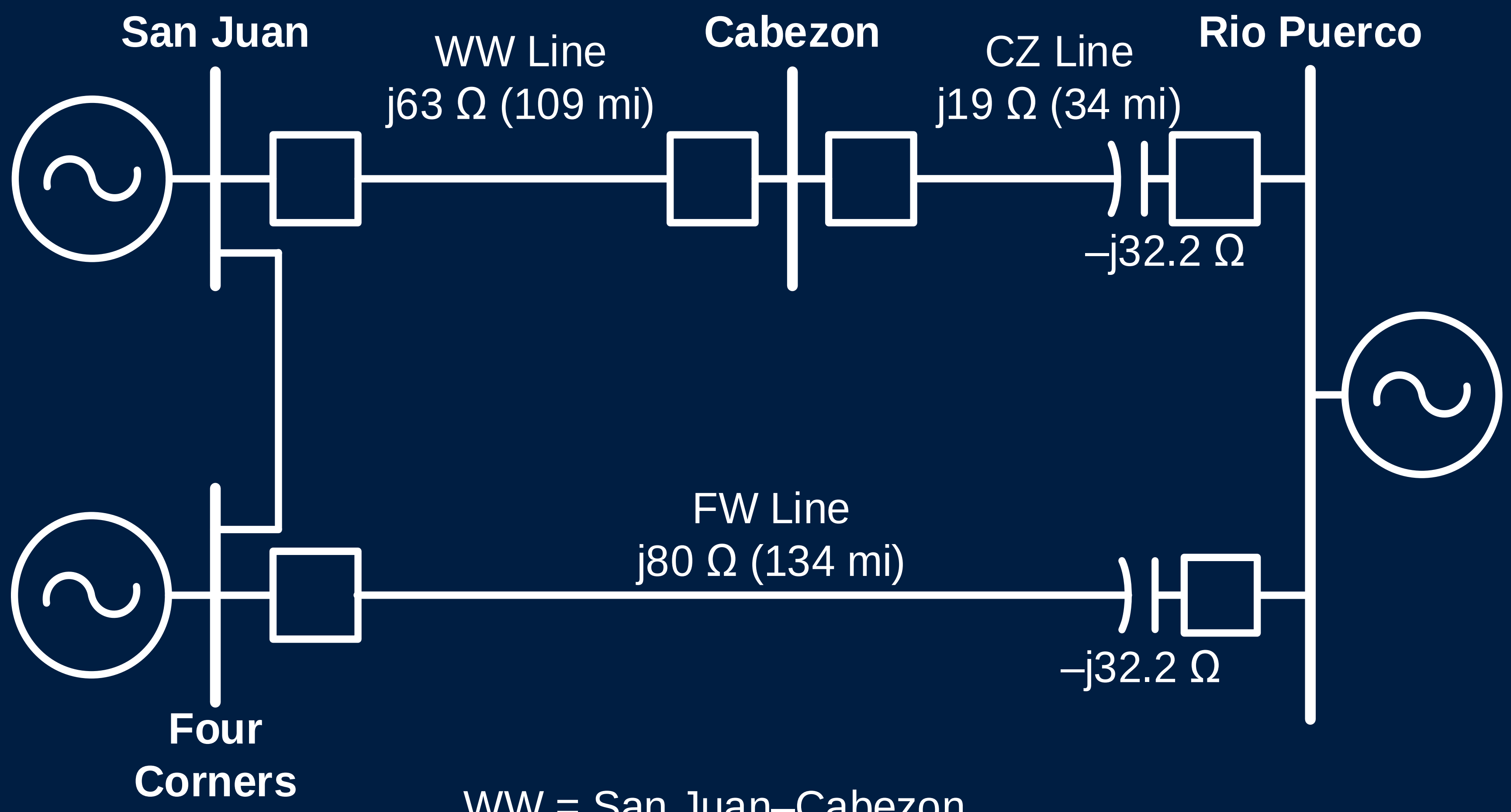


Public Service Company of New Mexico

- 14,388 mi of transmission lines
- 69 – 345 kV primary voltage
- 46 kV subtransmission
- Large generation at San Juan and Four Corners substations

Cabezon Project Summary



WW = San Juan–Cabezon
CZ = Cabezon–Rio Puerco
FW = Four Corners–Rio Puerco

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

Public Service Company of New Mexico (PNM) Transmission Challenge

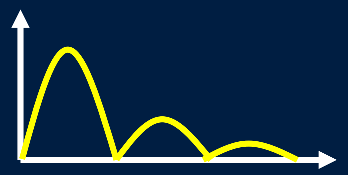
- 345 kV line split by new substation
- Series capacitor near one end
- Shorter part overcompensated $X_L - X_C < 0$
- Challenge for traditional protection
- *Simple* for the SEL-T400L $i = C\, dv / dt \quad dv = i / C\, dt$
- *dt* is so short, it is like the capacitor is not even there!

PNM’s Protective Relays Standard

- Phasor-Based
  - 87L
  - 21P / G Quadrilateral
  - 67P / G
- Time-Domain
  - TW87 / TW32
  - TD21 / TD32

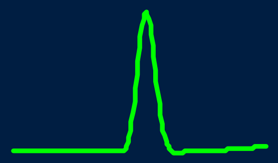
Phasor and Time-Domain Principles

Similarities and Differences

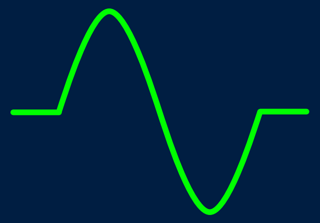
Algorithm	Phasors
Signal Spectrum of Interest	40–70 Hz
Filtering	
Sampling	8 / cycle
Line theory	$V_F = V - ZI$
Operating time	1 cycle
CT and PT requirements	Low

Ultra-High-Speed Line Protection Offered by Time-Domain Elements and Schemes

- Based on traveling waves
  - Differential scheme, TW87, 1–3 ms
  - Directional element, TW32, 0.1 ms



- Based on incremental quantities
  - Underreaching distance element, TD21, 2–6 ms
  - Directional element, TD32, 1.5 ms



Processing Interval Comparison

- RTDS time-step: typically 50 µs
- Relay processing intervals
  - Phasor-based: 8 samples per cycle (~2 ms)
  - Incremental quantity calculations: every 100 µs
  - Traveling-wave calculations: every 1 µs

SEL Engineering Services
RTDS and Relay Test Setup


RTDS ™
Real-Time Digital Simulator
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RTDS ™
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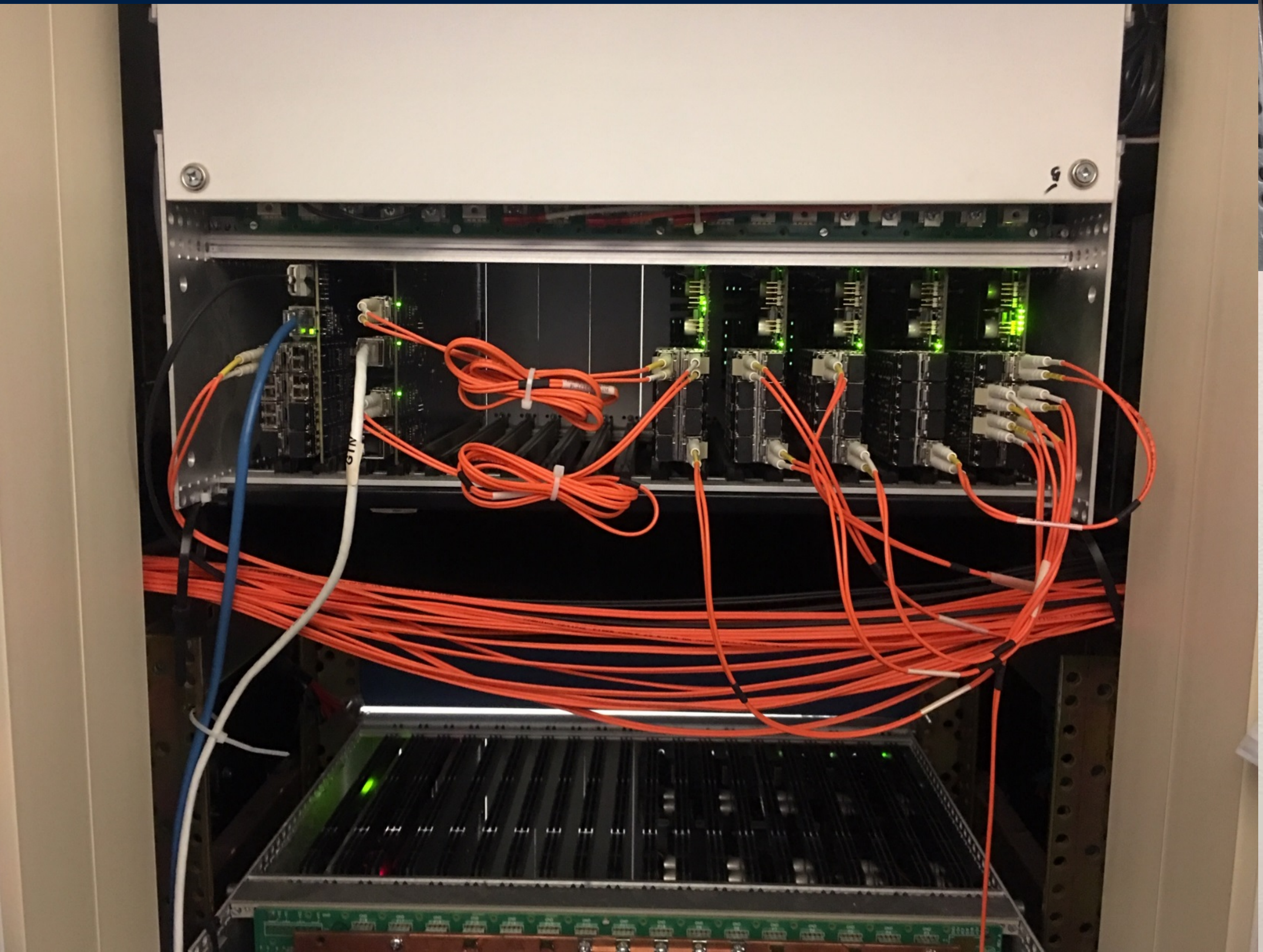
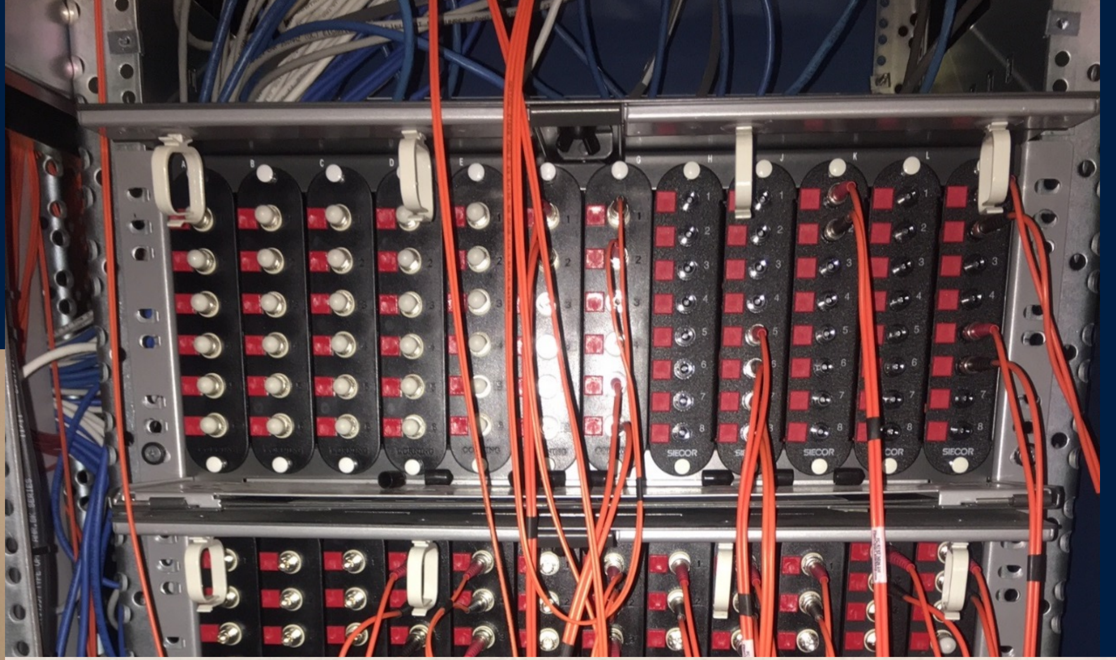
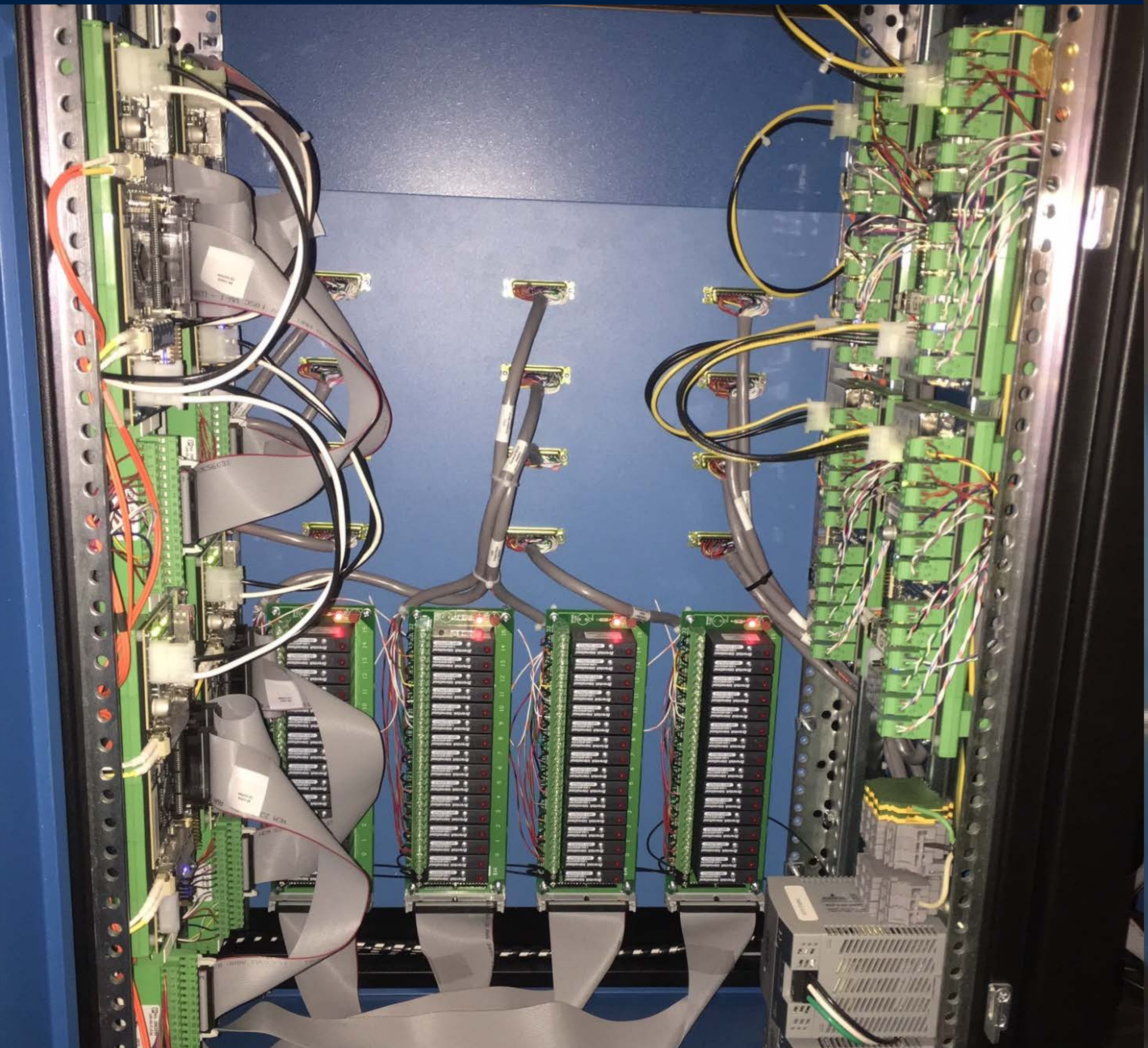
Fiber Connections





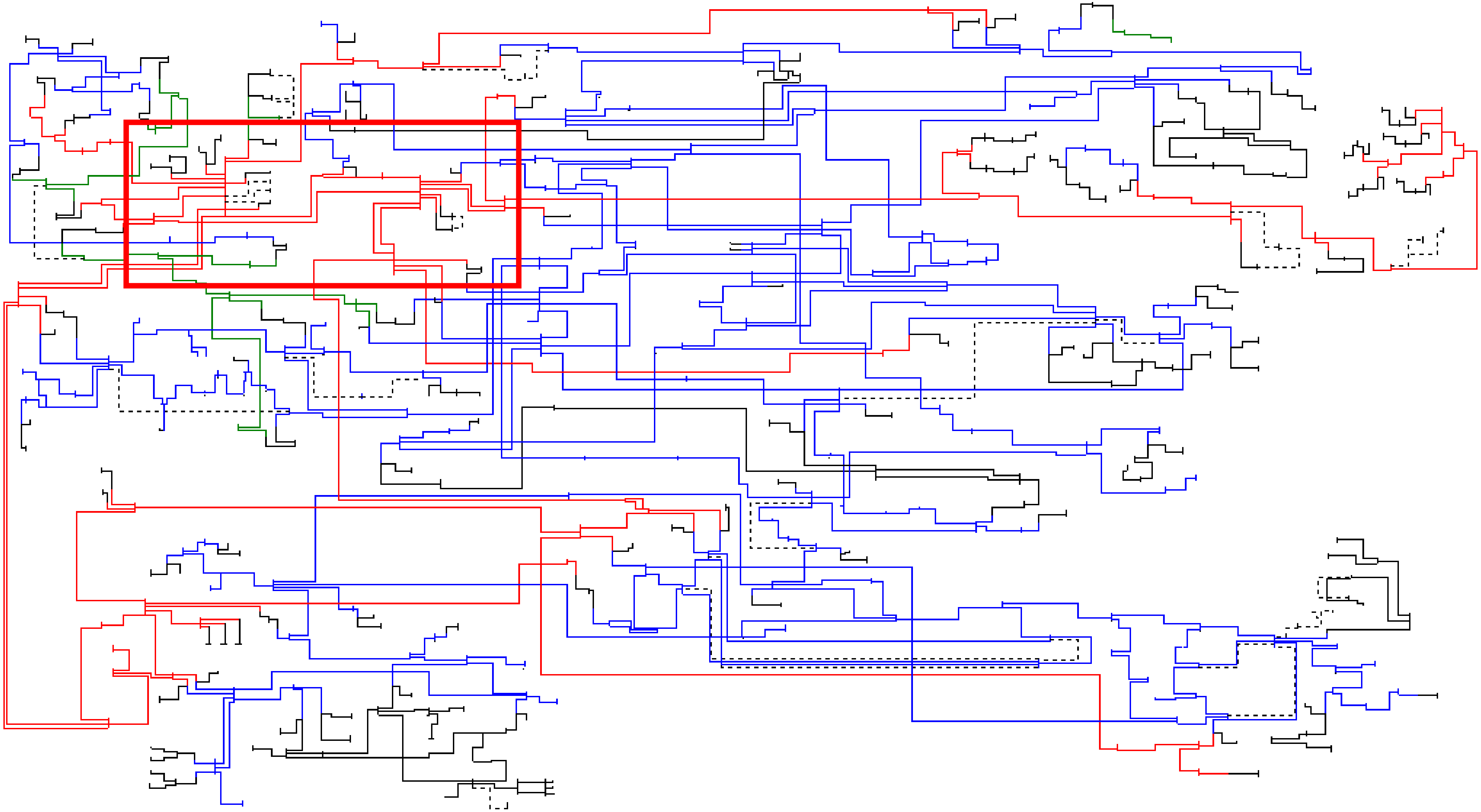
I / O Connections



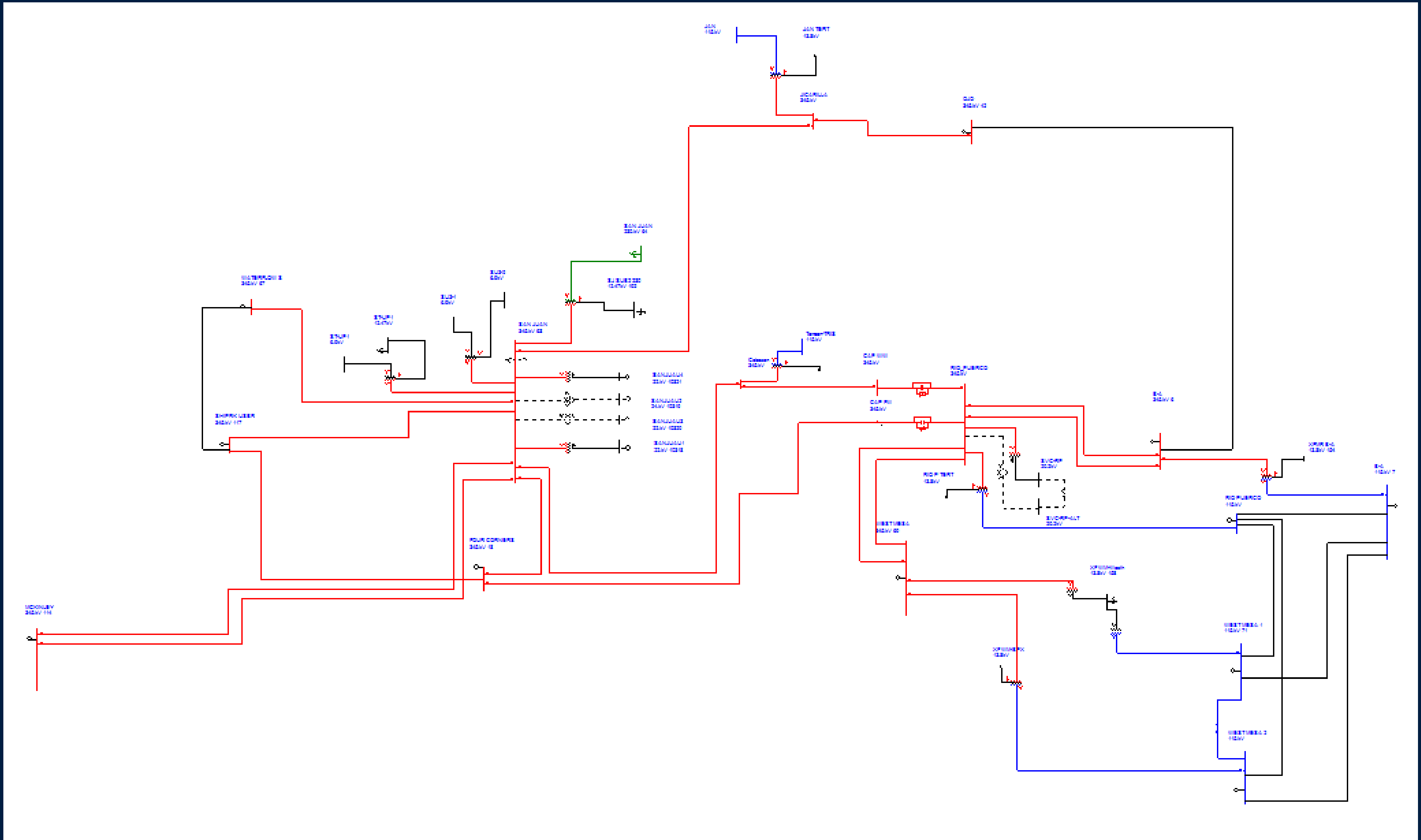
Relay Connections

Model Development

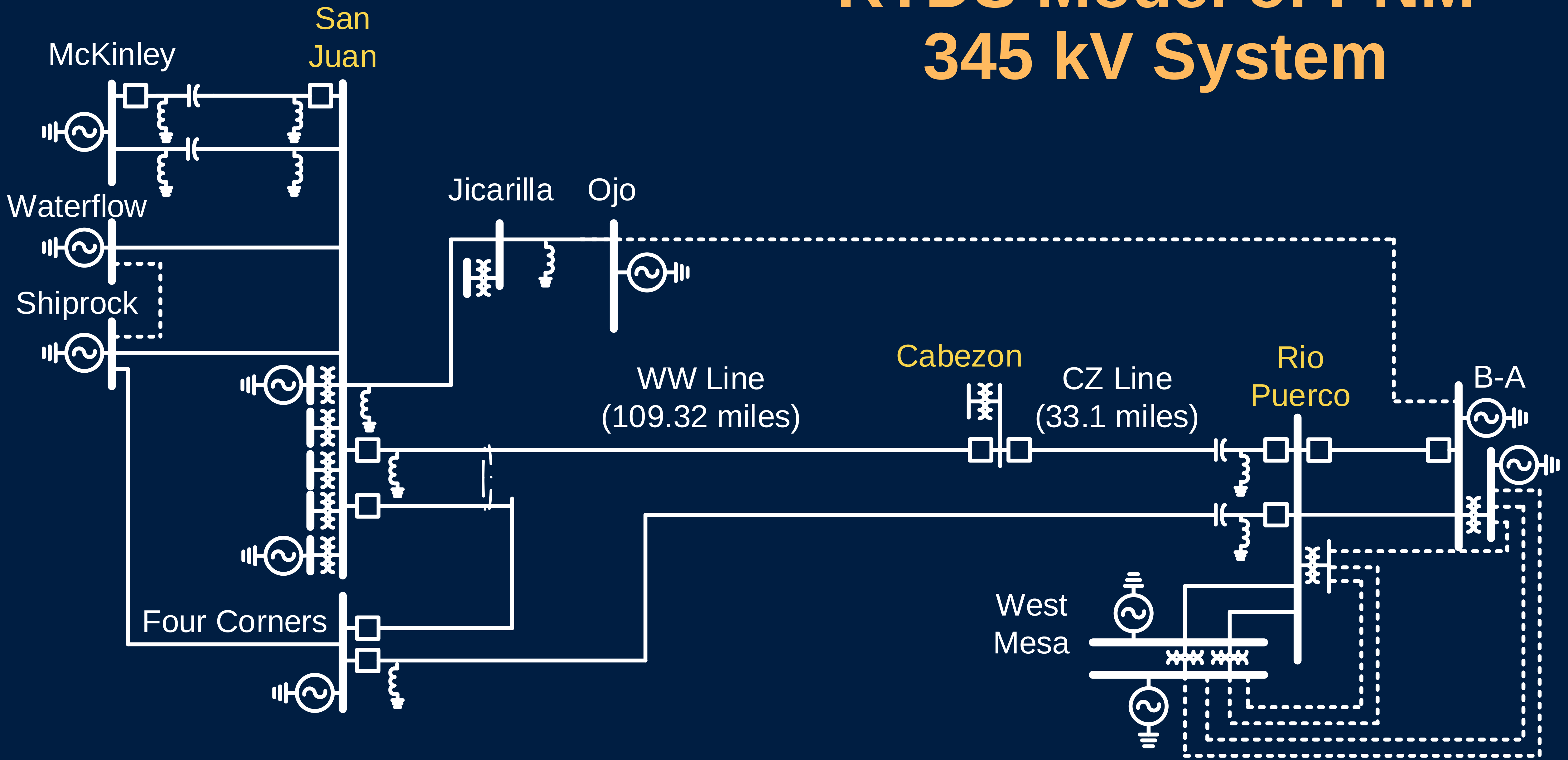
Short-Circuit Model



Reduced Short-Circuit Model



RTDS Model of PNM 345 kV System



Model Validation

Positive-Sequence: $Z1\_source := Z_{525} \cdot (0.00037 + j \cdot 0.01186)$

$Z1\_ohms := |Z1\_source|$ $\quad Z1\_ohms = 32.71\,\Omega$

$Z1\_ang := \arg(Z1\_source)$ $\quad Z1\_ang = 88.21 \cdot deg$

Zero-Sequence: $Z0\_source := Z_{525} \cdot (0.00035 + j \cdot 0.01120)$

$Z0\_ohms := |Z0\_source|$ $\quad Z0\_ohms = 30.89\,\Omega$

$Z0\_ang := \arg(Z0\_source)$ $\quad Z0\_ang = 88.21 \cdot deg$

$$Zps := \frac{7.93}{100}\left(\frac{100MVA}{600MVA}\right) = 0.01322$$

$$Zpt := \frac{13.07}{100}\left(\frac{100MVA}{100MVA}\right) = 0.1307$$

$$Zst := \frac{8.55}{100}\left(\frac{100MVA}{100MVA}\right) = 0.0855$$

CAPE:

$Z1 := Z_{525} \cdot (0.00097 + j \cdot 0.02434)$

$Z0 := Z_{525} \cdot (0.01264 + j \cdot 0.08735)$

$Z0M := Z_{525} \cdot (0.0112 + j \cdot 0.0436)$

$Z1 = (2.67 + 67.09i)\,\Omega$ $\quad Z1\_cape := |Z1| = 67.14\,\Omega$ $\quad Z1A\_cape := \arg(Z1) = 87.72 \cdot deg$

$Z0 = (34.84 + 240.76i)\,\Omega$ $\quad Z0\_cape := |Z0| = 243.27\,\Omega$ $\quad Z0A\_cape := \arg(Z0) = 81.77 \cdot deg$

$Z0M = (30.87 + 120.17i)\,\Omega$ $\quad Z0M\_cape := |Z0M| = 124.074\,\Omega$ $\quad Z0MA\_cape := \arg(Z0M) = 75.59 \cdot deg$

RTDS:

$Z1 := Z_1 \cdot (2.88 + j \cdot 67.33)$ $\quad Z\_shunt\_pos\_rtds := Z_1 \cdot |0 + j \cdot 1246.16|$

$Z0 := Z_1 \cdot (33.93 + j \cdot 246.93)$ $\quad Z\_shunt\_zero\_rtds := Z_1 \cdot |0 + j \cdot 2162.94|$

$Z0M := Z_1 \cdot (31.00 + j \cdot 127.05)$

$Z1 = (2.88 + 67.33i)\,\Omega$ $\quad Z1\_rtds := |Z1| = 67.39\,\Omega$ $\quad Z1A\_rtds := \arg(Z1) = 87.55 \cdot deg$

$Z0 = (33.93 + 246.93i)\,\Omega$ $\quad Z0\_rtds := |Z0| = 249.25\,\Omega$ $\quad Z0A\_rtds := \arg(Z0) = 82.18 \cdot deg$

$Z0M = (31 + 127.05i)\,\Omega$ $\quad Z0M\_rtds := |Z0M| = 130.78\,\Omega$ $\quad Z0MA\_rtds := \arg(Z0M) = 76.29 \cdot deg$

$$RTDS\_Error\_pos := \frac{Z1\_rtds - Z1\_cape}{Z1\_cape} \qquad RTDS\_Error\_pos = 0.374 \cdot \%$$

$$RTDS\_Error\_zero := \frac{Z0\_rtds - Z0\_cape}{Z0\_cape} \qquad RTDS\_Error\_zero = 2.46 \cdot \%$$

$$RTDS\_Error\_mut := \frac{Z0M\_rtds - Z0M\_cape}{Z0M\_cape} \qquad RTDS\_Error\_mut = 5.403 \cdot \%$$

Test Procedure and Results

Test Procedure

- Internal faults – test dependability
- External faults – test security
- Fix any issues identified
- Run batch tests
  - All 10 fault types
  - Fault inception angles of 0, 30, 60, 90 degrees
  - All load flow cases (contingencies)

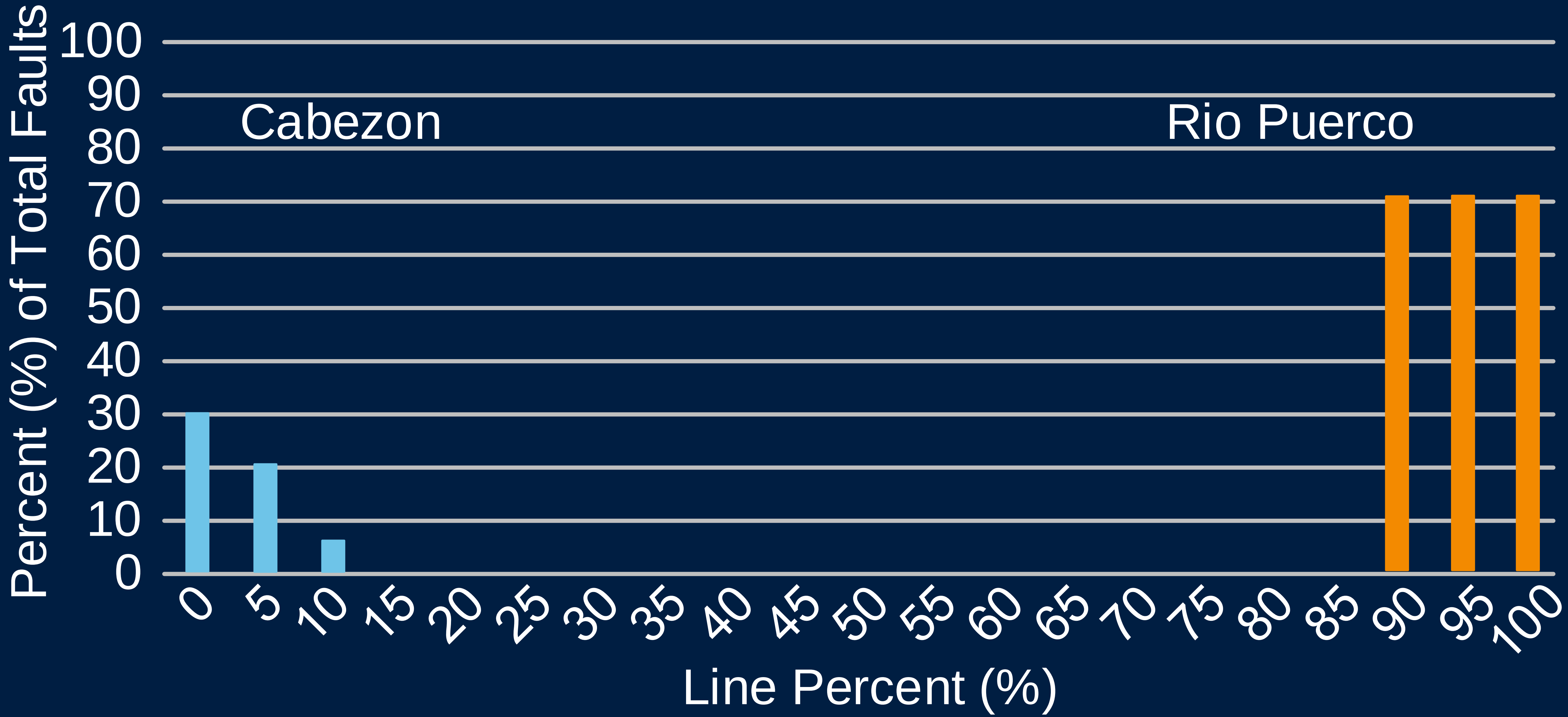
What Did We Get?

- 22 internal and 26 external locations
- 10,000+ faults applied
- Text files of relay operation times
- COMTRADE and JPEG files of every simulation

CASE	POS	TYPE	POW	LS_TPAT	LS_TPBT	LS_TPCT
LFA	Floc1	_AG	0	0.018479999	0	0
LFA	Floc1	_AG	45	0.018409999	0	0

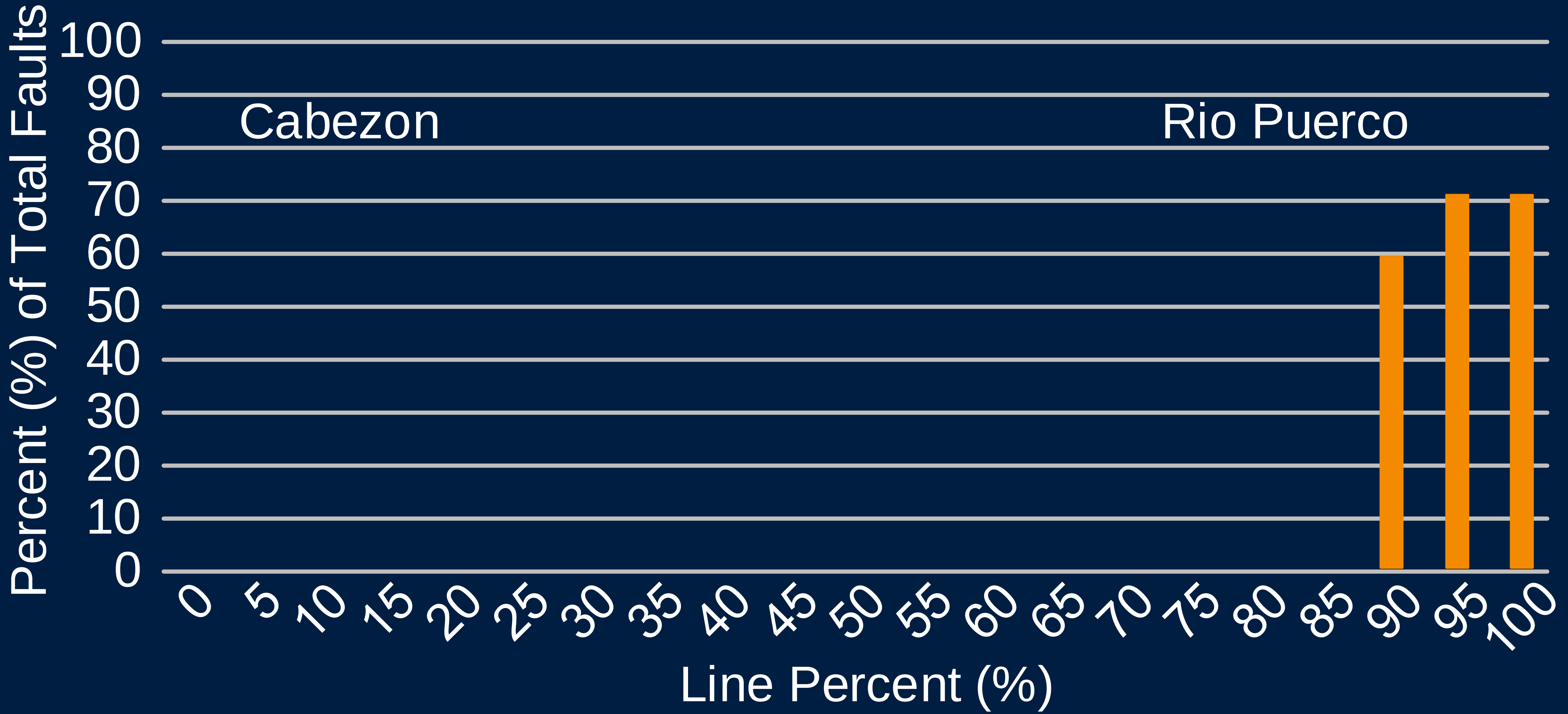
Ground Overcurrent

Phasor-Based Protection



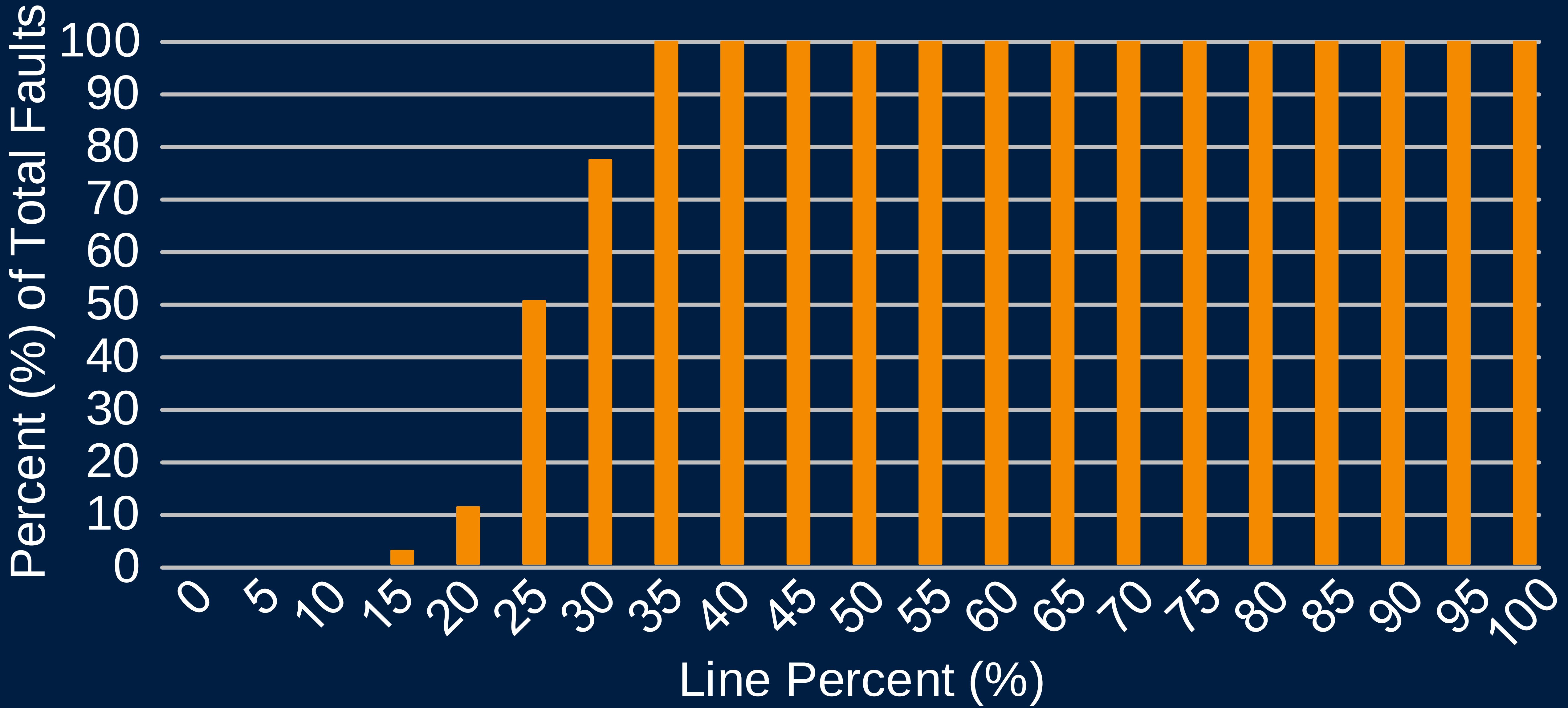
Phase Overcurrent

Phasor-Based Protection



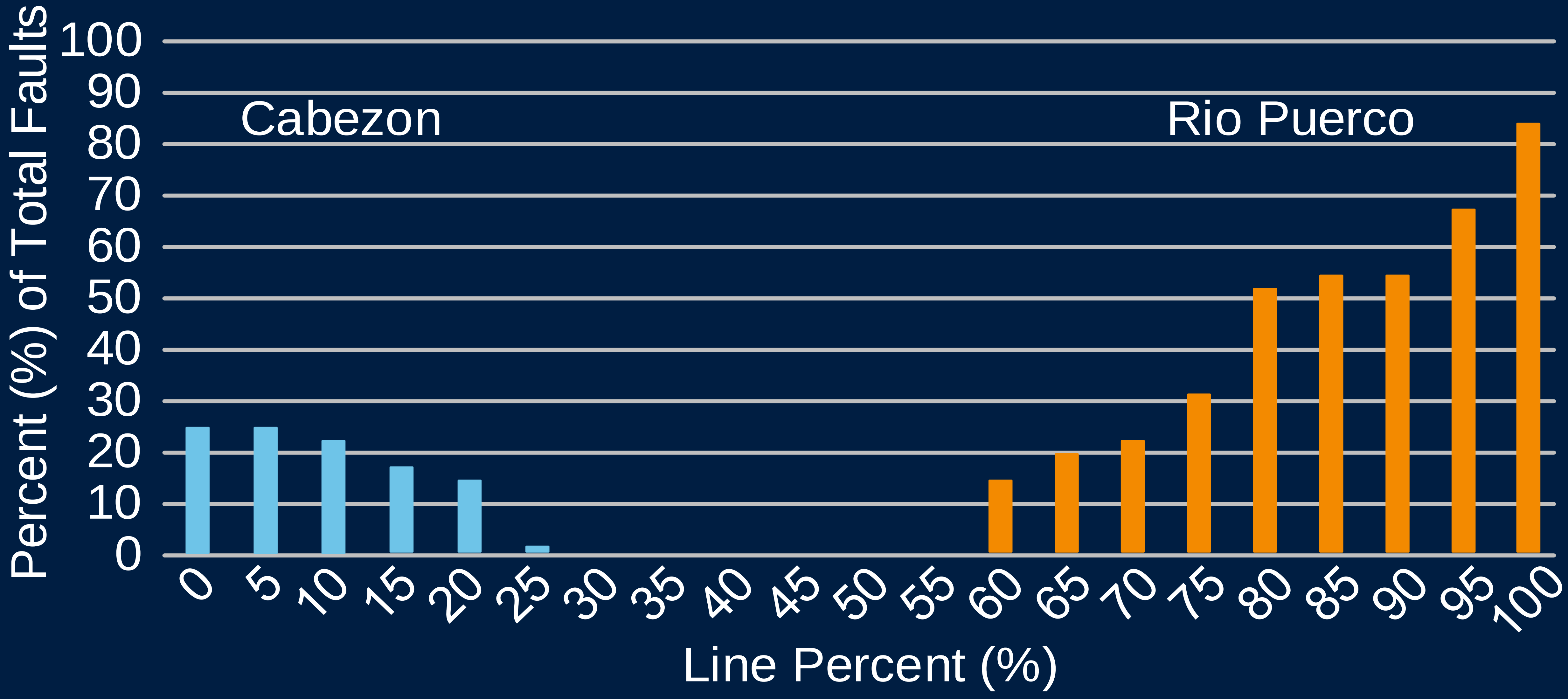
Zone 1 Performance

Phasor-Based Protection

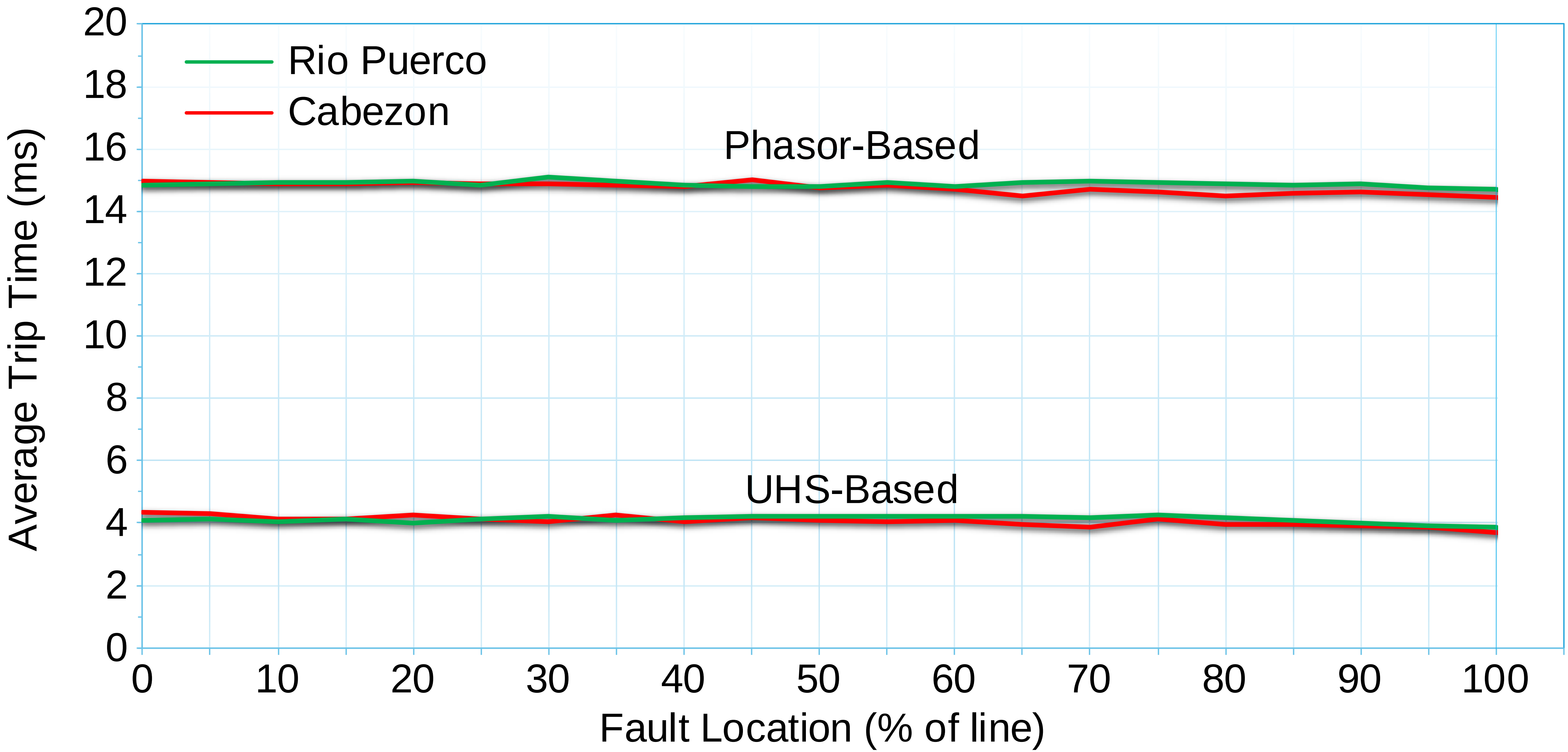


Zone 1 Performance

Time-Domain Protection



Operating Time Results



How Did We Test Traveling-Wave Functions?

TWRT

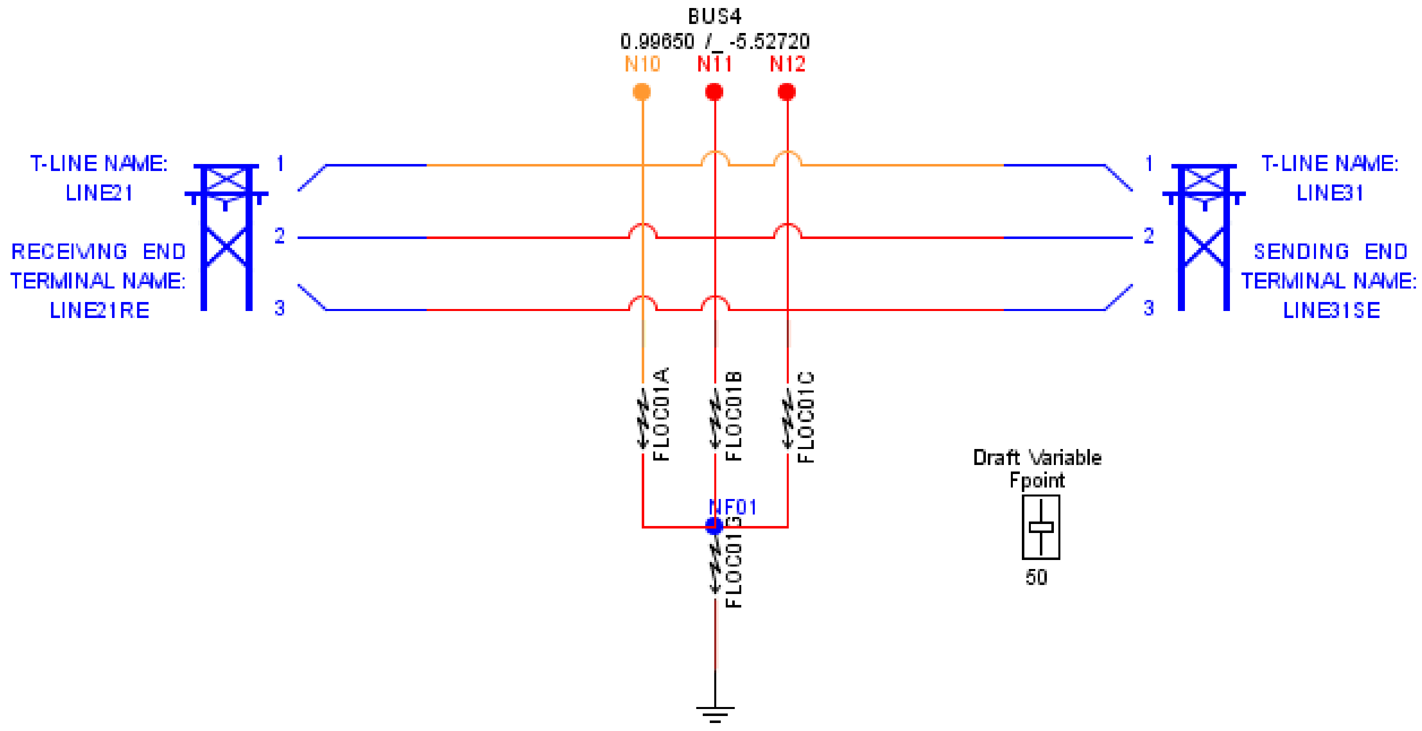
Traveling Wave Relay Testing
with the RTDS® Simulator

Background

- March 2017: SEL-T400L released
- June 2017: SEL hosts Time-Domain Summit
- February 2018: RTDS demonstrates TWRT solution
- March 2018: NovaCor with TWRT arrives for evaluation
- March 2018: Customer demonstration with SEL-T400L

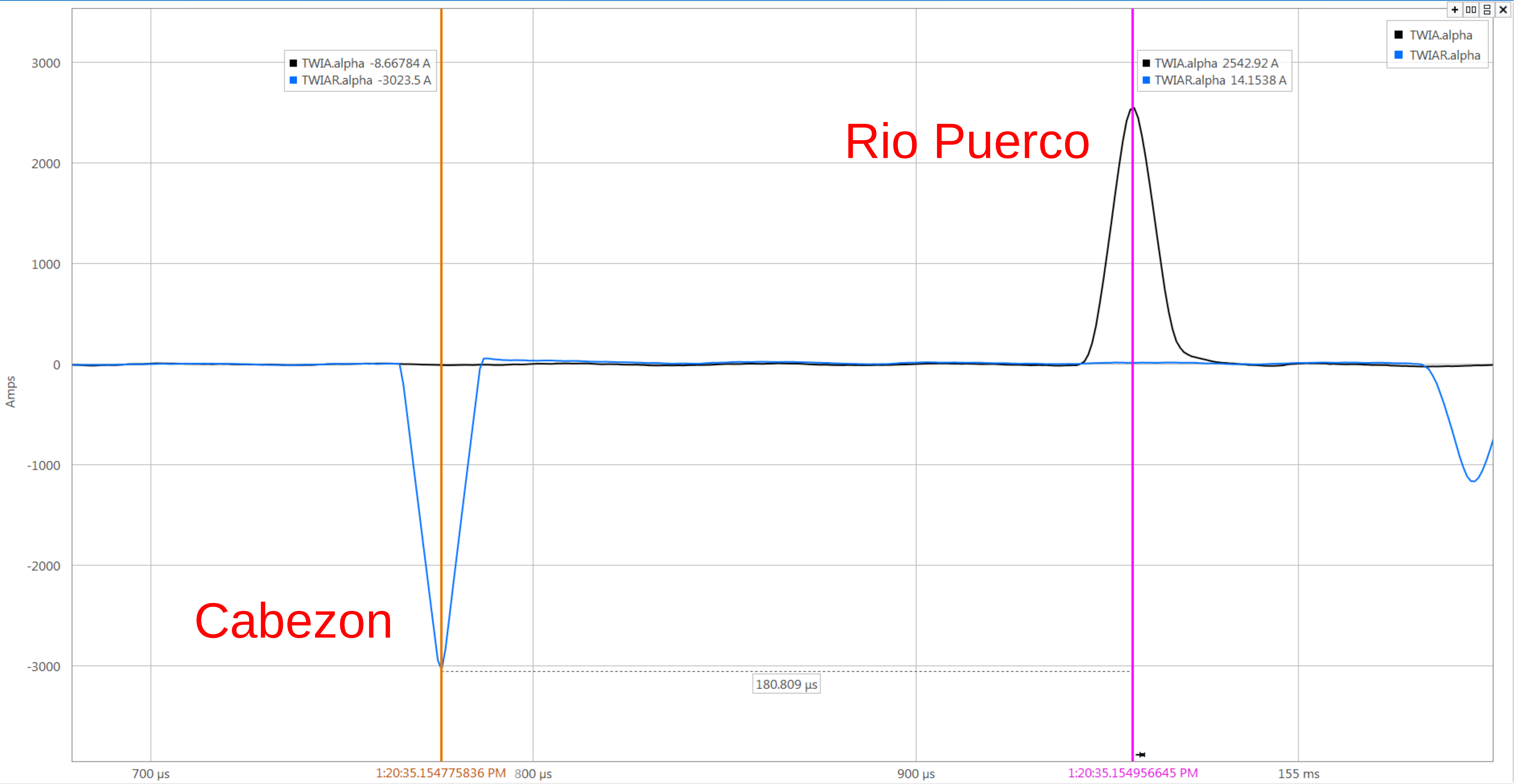
TWRT Test Setup

- Beta version TWRT for testing
- New GTAO firmware
- 2 microsecond time-step
- Specialized T-line models for traveling waves (TWs)
- Simple model: line under test, then a single line out from each terminal, then a source

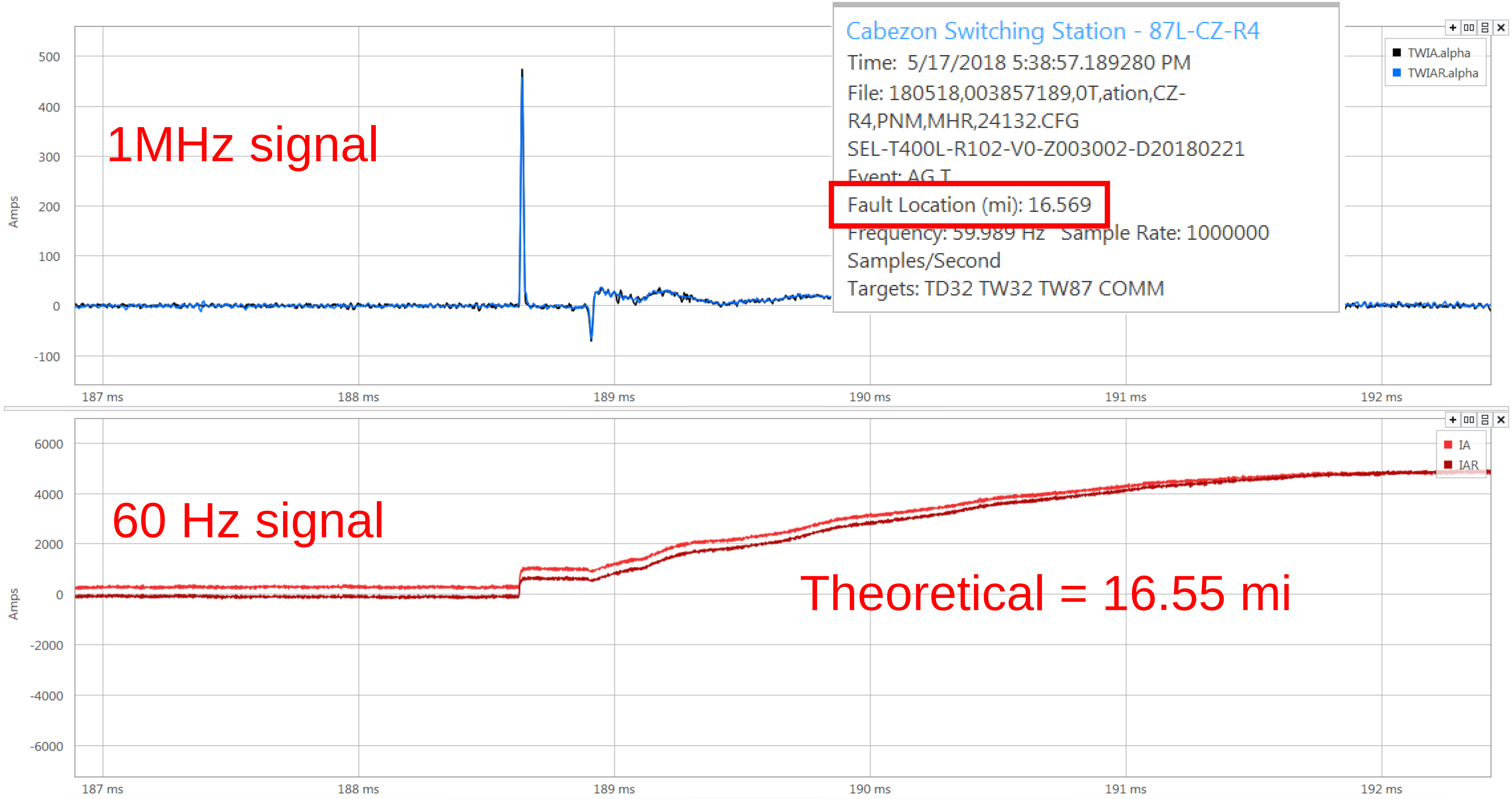

BUS4
0.99650 /_ -5.52720
N10
N11
N12
T-LINE NAME:
LINE21
RECEIVING END
TERMINAL NAME:
LINE21RE
T-LINE NAME:
LINE31
SENDING END
TERMINAL NAME:
LINE31SE
1
2
3
1
2
3
FLOC01A
FLOC01B
FLOC01C
NF01
FLOC01G
Draft Variable
Fpoint
50

Fault Behind Cabezon

Referenced From Rio Puerco

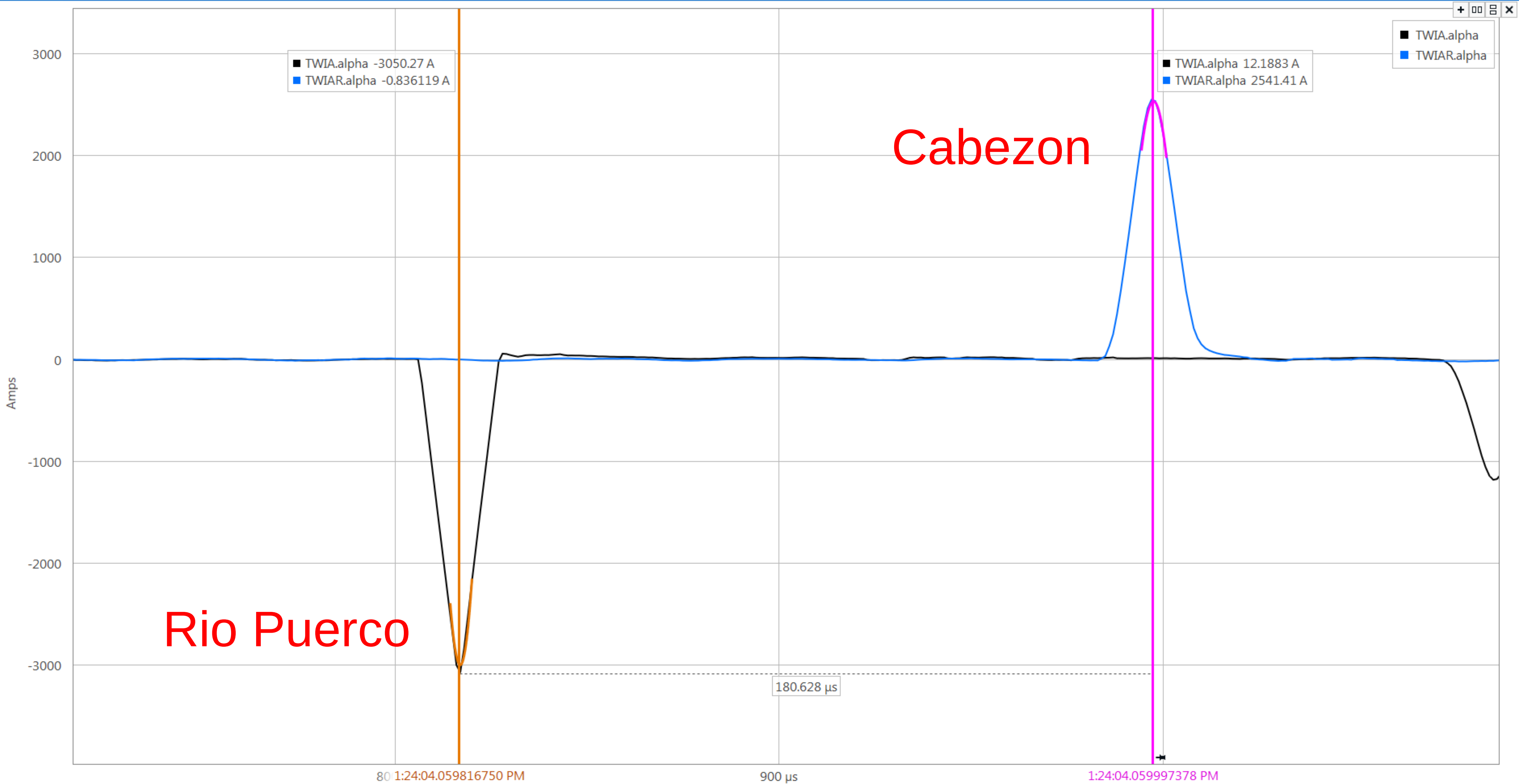


Midline Fault



Fault Behind Rio Puerco

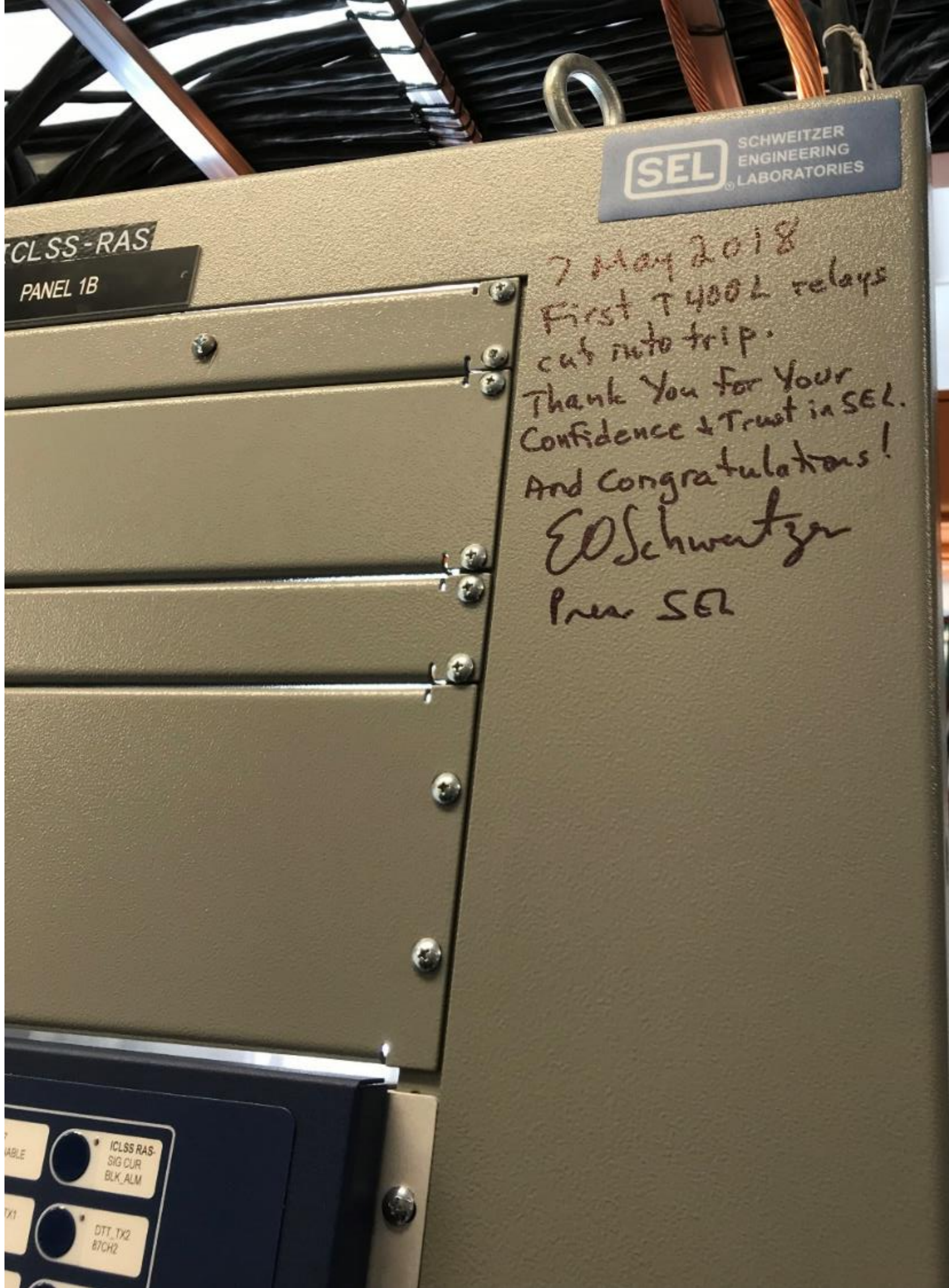
Referenced From Rio Puerco



PNM®

First Utility to Use SEL-T400L Relays for Line Protection!

May 7, 2018
Trip Outputs Connected to Breakers



RTDS NEWS

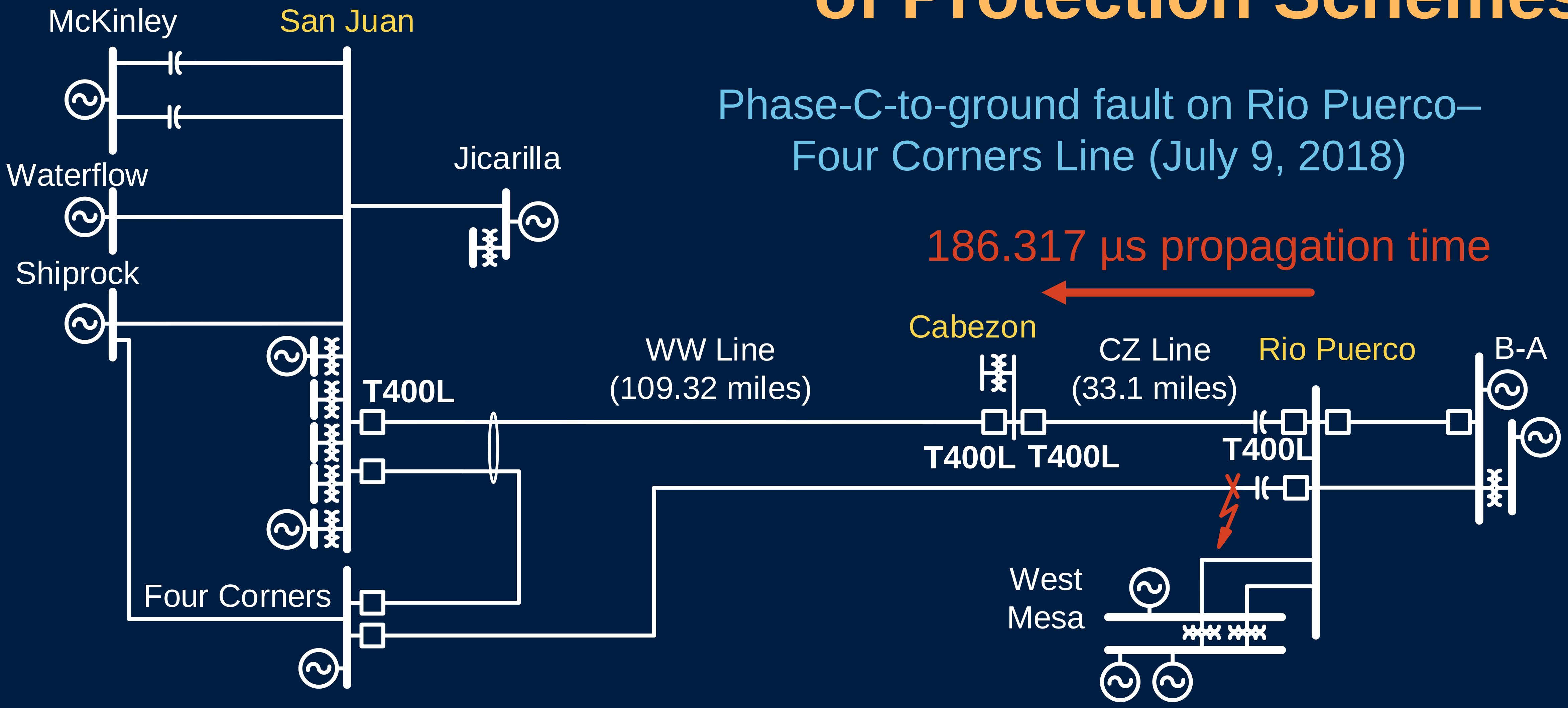
WHAT'S NEW: JUNE 2018

BREAKING: First ever HV transmission line protected with traveling wave relay tested by SEL on the RTDS Simulator

New Superstep tool allows users to simulate larger networks with less hardware

External Fault Validates Security of Protection Schemes

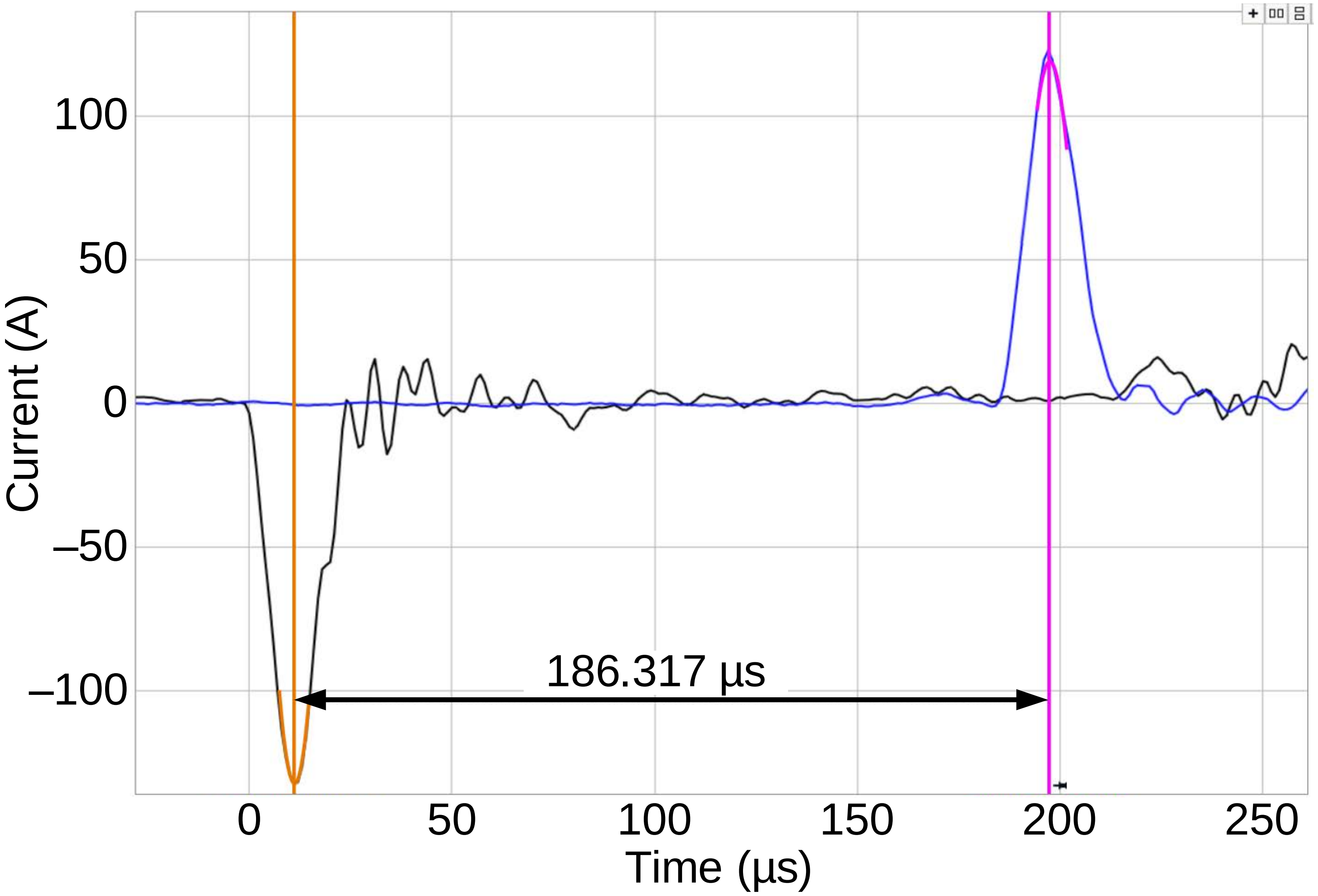
External Fault Validates Security of Protection Schemes



SEL-T400L Relays installed on San Juan–Cabezon and Cabezon–Rio Puerco lines

TW87 Restrains for External Fault

Local and Remote TWs



PNM Has Confidence to Trip With SEL-T400L

Questions?