Series-Compensated Line Protection Challenges in the CREZ Region

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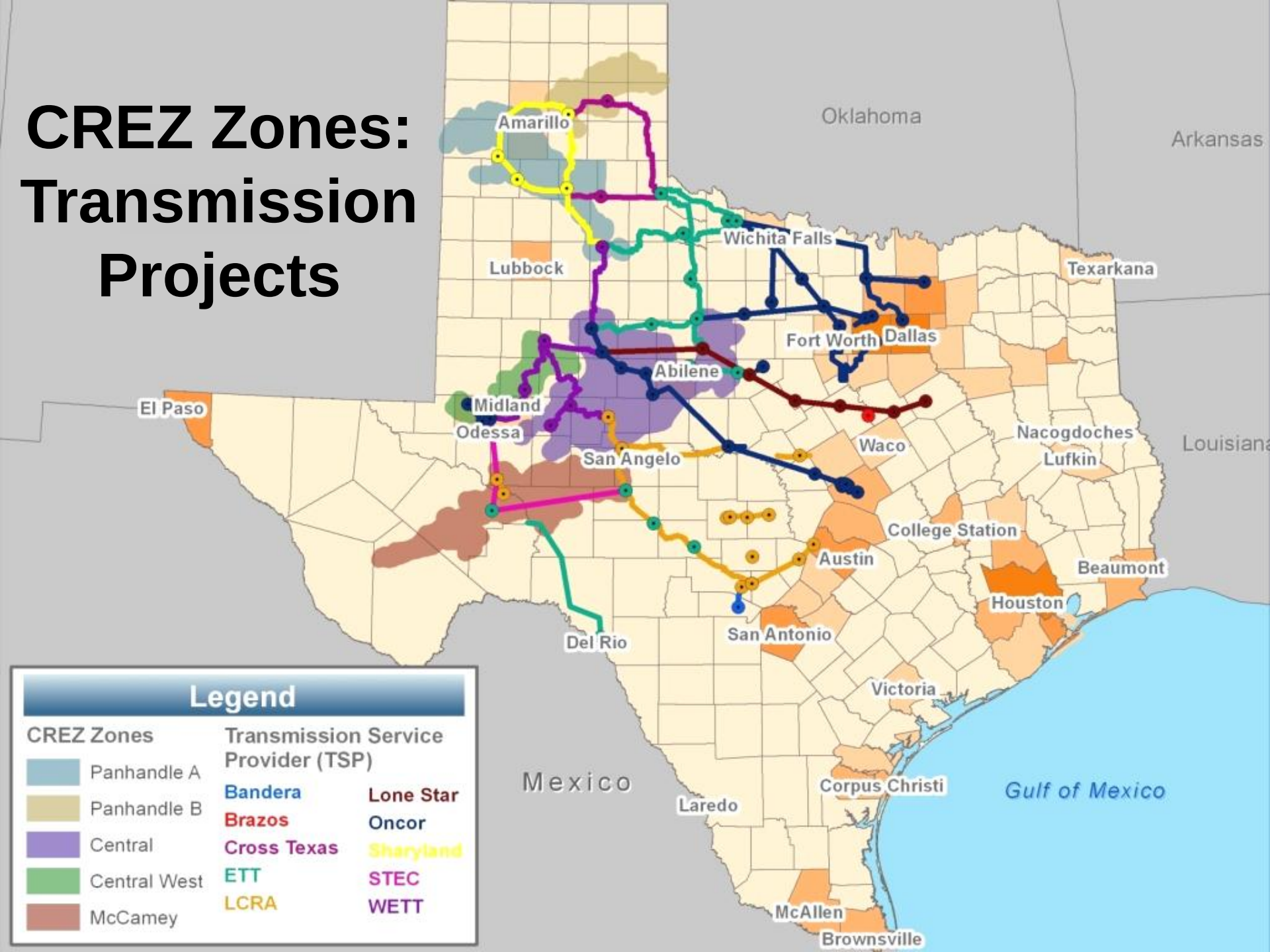
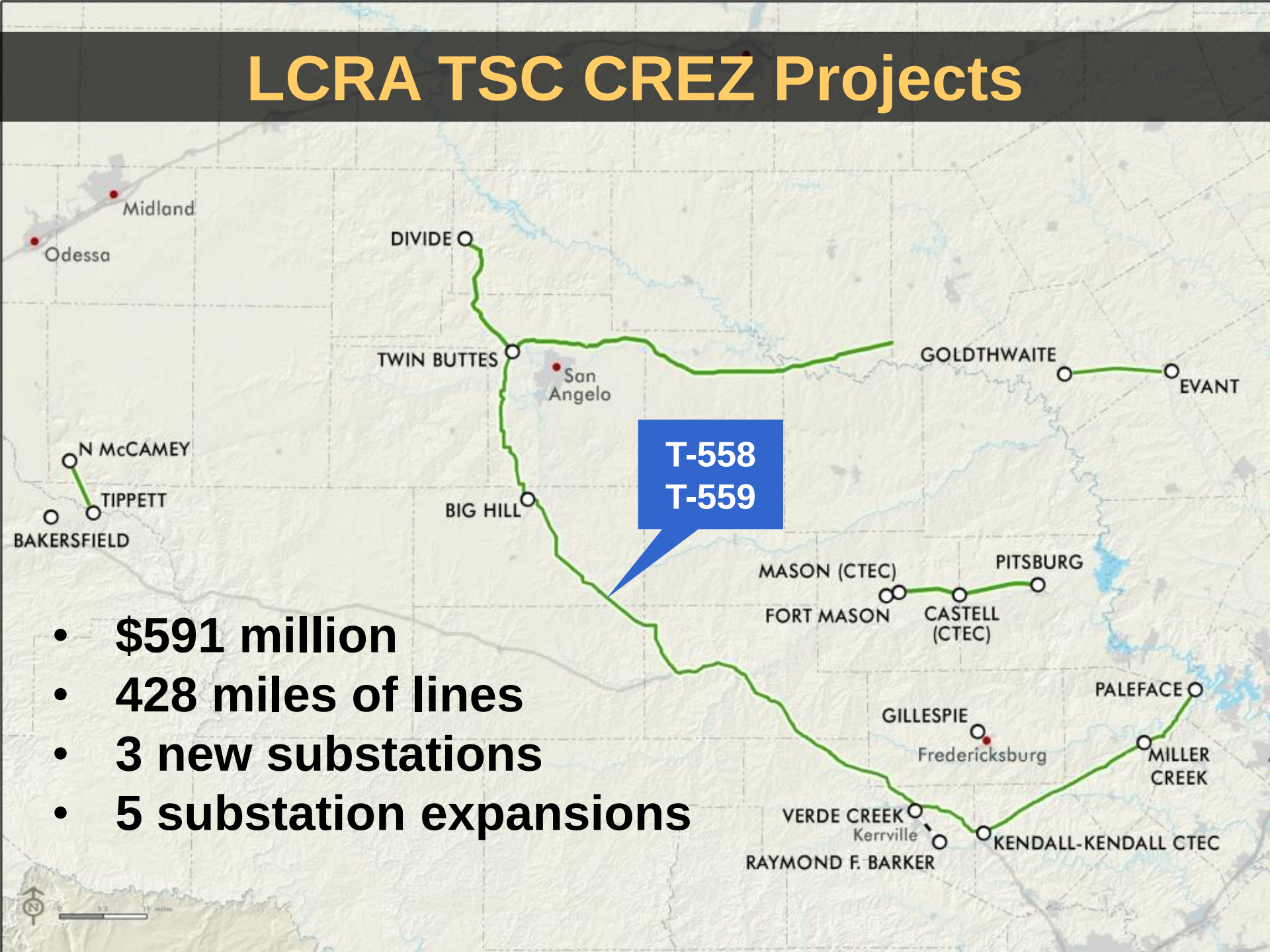
Topics

- CREZ background
- Design requirements
- Power system modeling
- Field commissioning
- Relaying performance

CREZ Zones: Transmission Projects



LCRA TSC CREZ Projects



- **$591 million**
- **428 miles of lines**
- **3 new substations**
- **5 substation expansions**

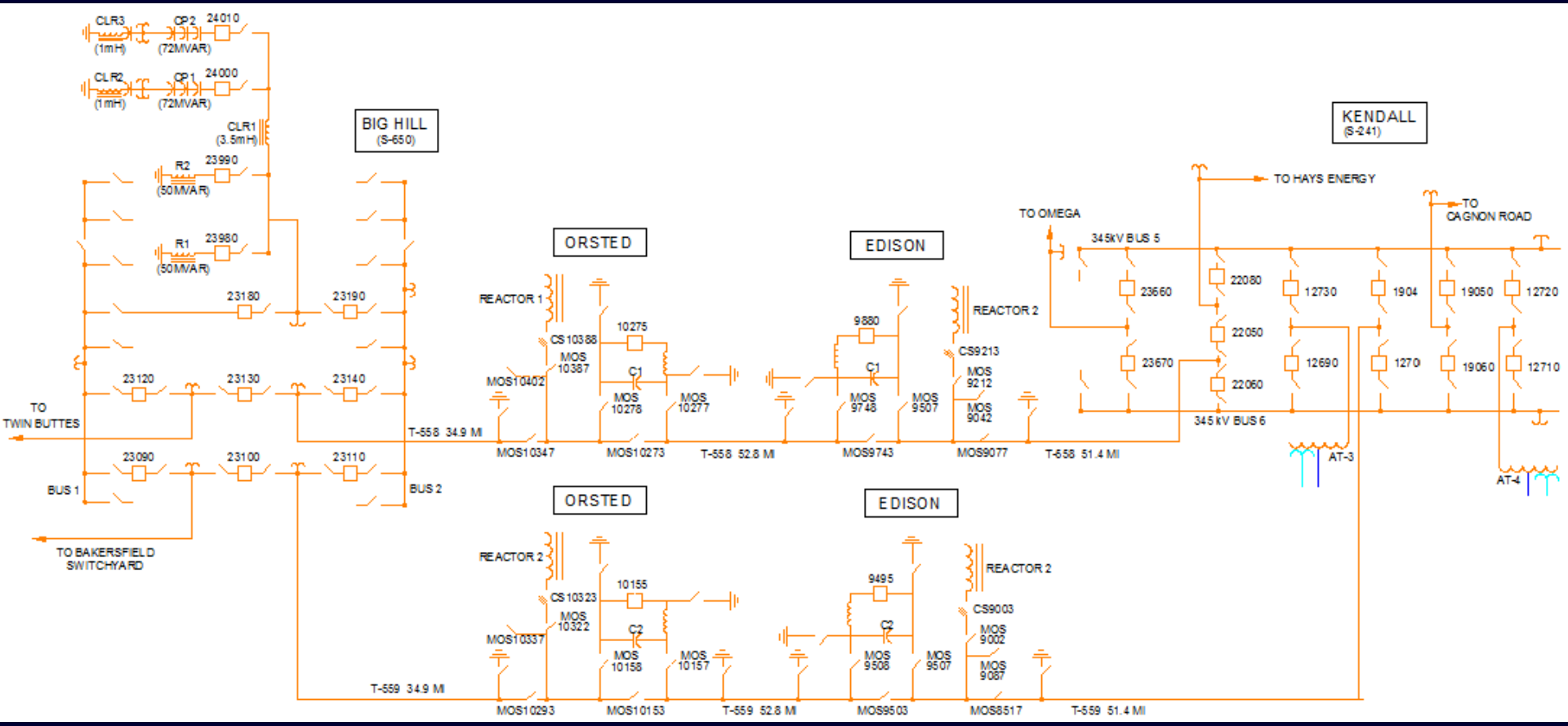
Big Hill Substation

- Completed May 2013
- Cost $28.5 million
- New substation

Big Hill to Kendall

- Completed August 2013
- Cost $335 million
- New 345 kV double-circuit lines (T-558, T-559)

System One-Line Diagram



ERCOT Nodal Operating Guide Revision Request #048

- Provides more stringent protection and control requirements for new CREZ 345 kV facilities
- Impacts Section 6 and Section 7
- Approved November 4, 2010
- Went into effect December 1, 2010

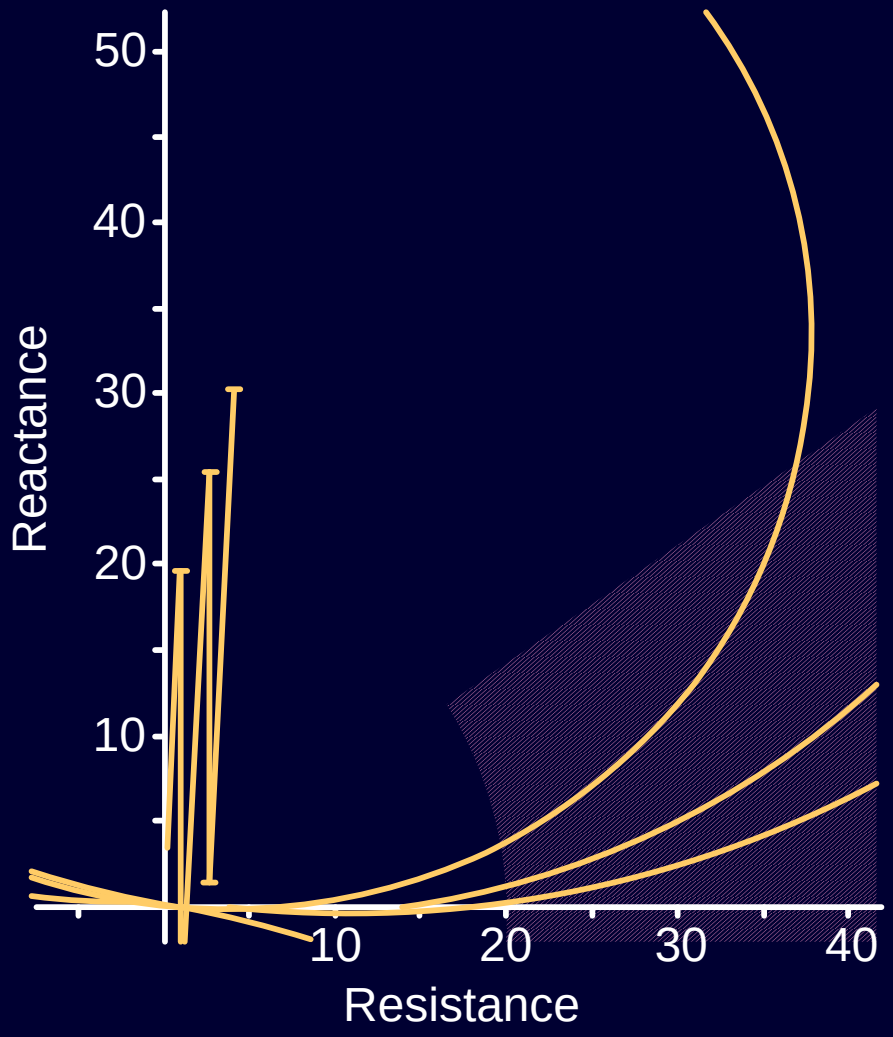
Applicable CREZ Lines

- Big Hill to Kendall (double circuit)
- Big Hill to Twin Buttes
- Bakersfield to Big Hill
- Bakersfield to North McCamey*
- North McCamey to Odessa*

* LCRA TSC terminal equipment

Unique Challenges

- Series compensation
- Shunt reactors
- Mutual coupling
- Large geographic area
- Multiple asset owners



Benefits of Differential Relaying

- Not impacted by mutual coupling, current reversal during adjacent line faults, or series capacitor voltage inversion effect
- Not concerned by weak infeed from nonconventional sources
- Not impacted by varying line loading levels

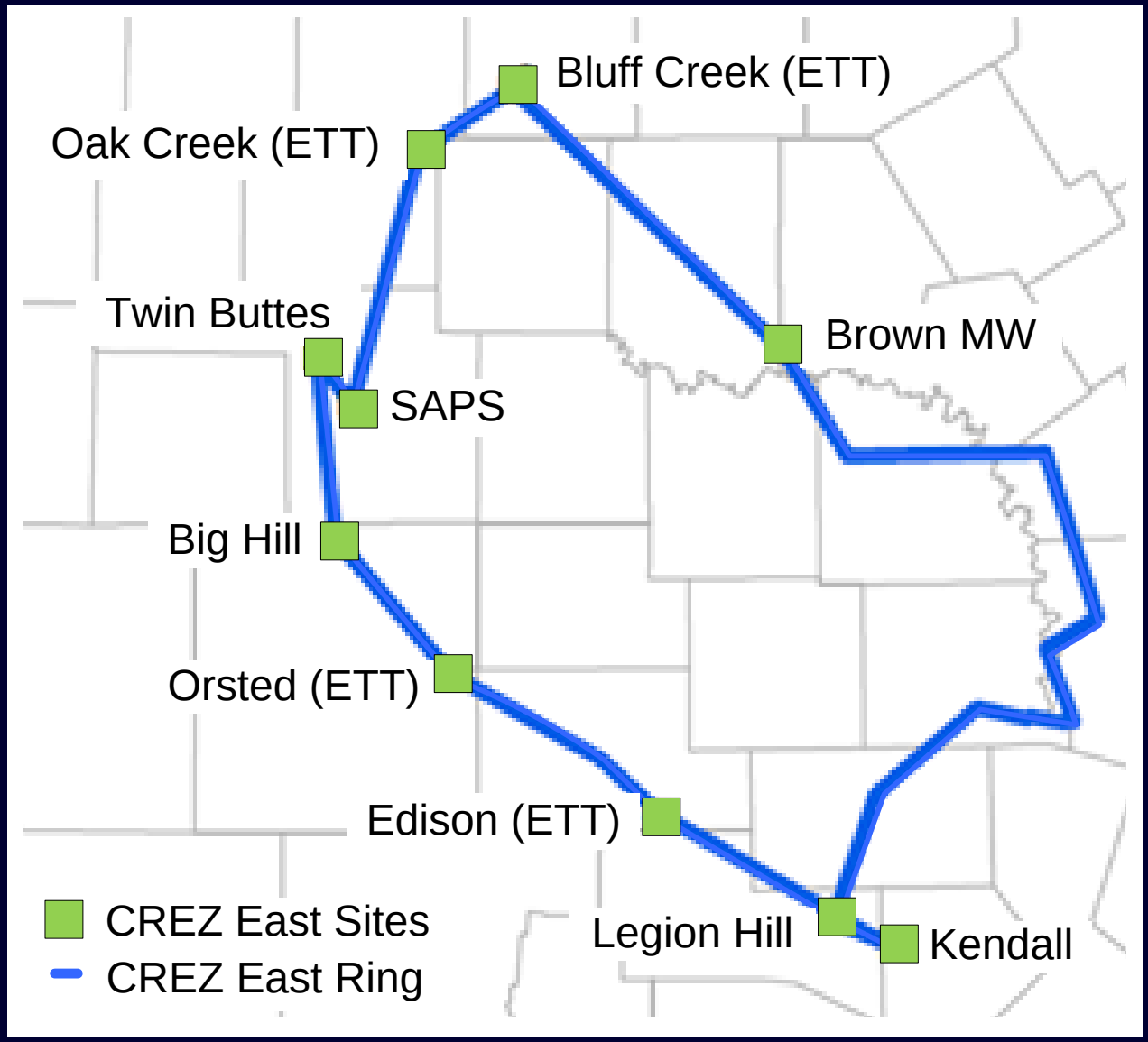
Benefits of Differential Relaying

- Has good sensitivity for high-impedance faults
- Offers good performance for evolving or cross-country faults
- Does not depend on power line carrier equipment or fault directionality determination

SONET Ring Configuration

CREZ Transmission Line	Relay A		Relay B	
	Channel 1	Channel 2	Channel 1	Channel 2
Bakersfield to Big Hill	21-A PT2 SONET west ring	21-A PT3 SONET west ring	87-B CH1 SONET west ring	87-B CH2 SONET west ring
Big Hill to Kendall (T-558)	87-A CH1 SONET east ring	87-A CH2 SONET east ring	87-B CH1 SONET east ring	87-B CH2 SONET east ring
Big Hill to Kendall (T-559)	87-A CH1 SONET east ring	87-A CH2 SONET east ring	87-B CH1 SONET east ring	87-B CH2 SONET east ring
Big Hill to Twin Buttes	21-A PT2 SONET east ring	21-A PT3 SONET west ring	87-B CH1 SONET east ring	87-B CH2 SONET west ring

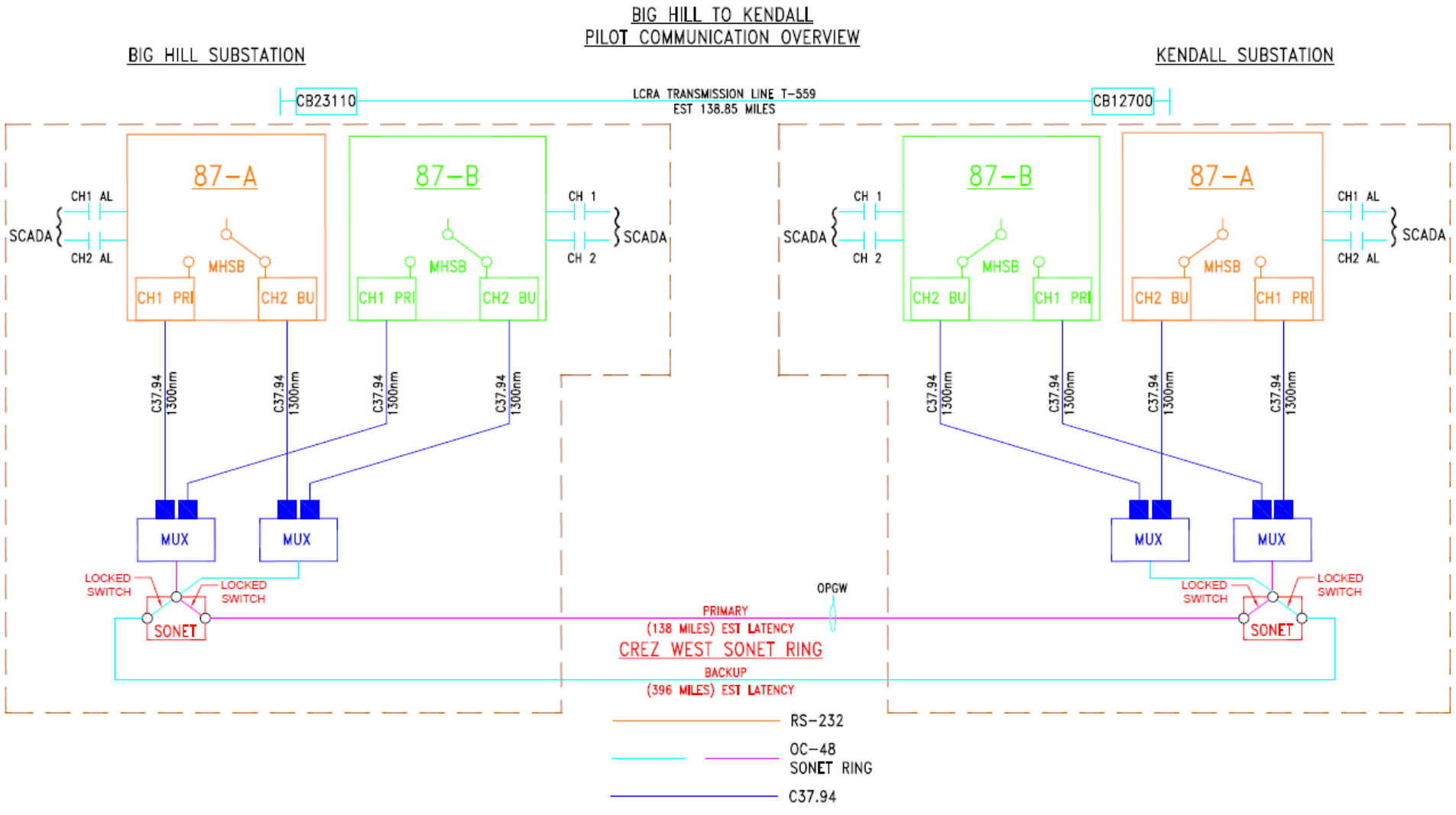
CREZ East Ring



CREZ East Ring

Channel Timing	Primary Channel 1 (ms)	Standby Channel 2 (ms)
Roundtrip delay	5.5	11.4
Transmit delay	2.6	5.7
Receive delay	2.5	5.7
Asymmetry	0.32	0.04

Pilot Communications Overview



Need for Redundancy

Optical ground wire conductor damage near Edison substation February 23, 2014

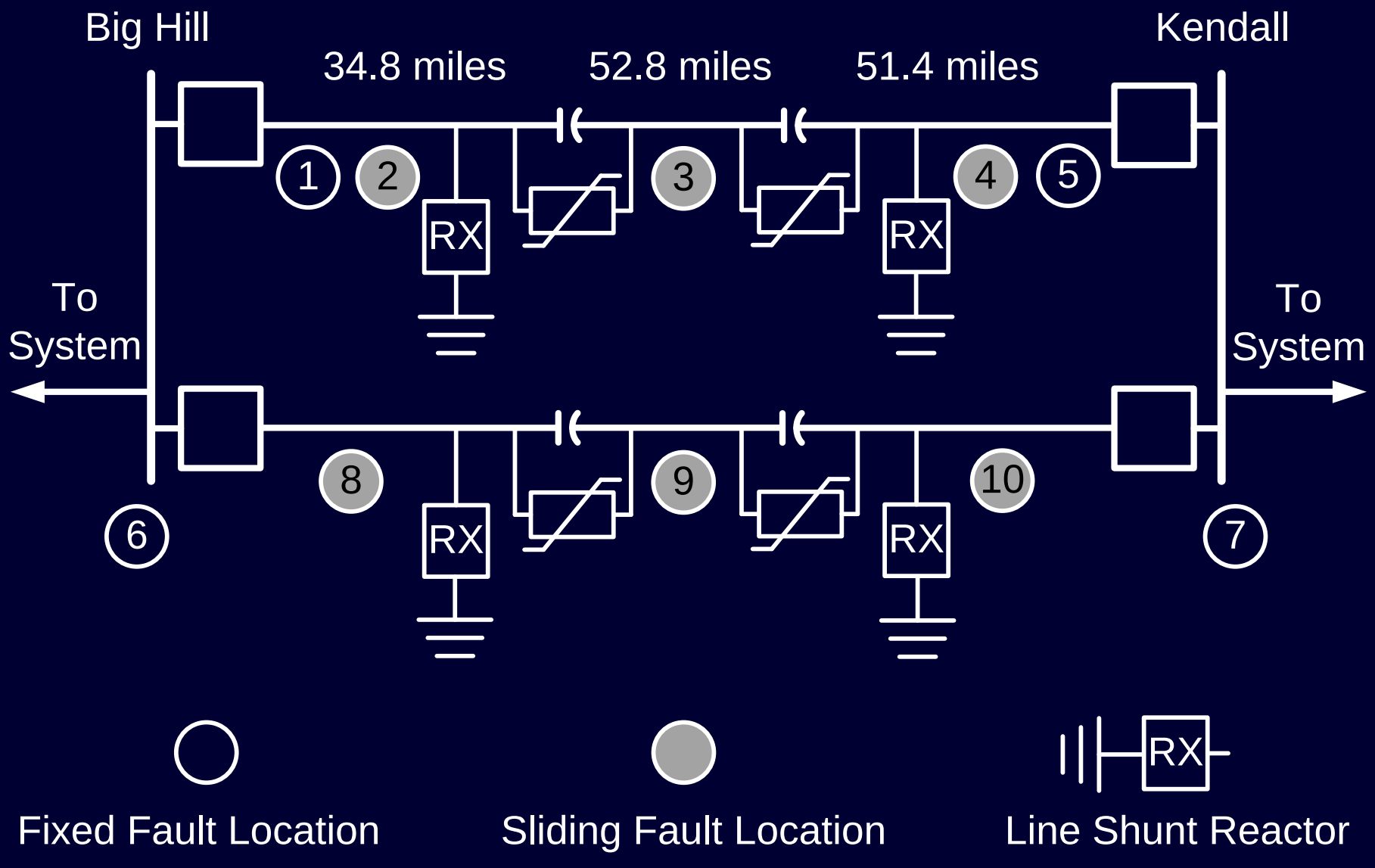
Additional Related Studies

- Transposition study
  - Structure installation not cost-effective
  - Used series capacitor site structures
  - Reduced inherent phase current unbalance
- End-to-end system angle analysis
  - Investigated wind dispatch scenarios
  - Impacted synchronism-check settings
  - Is monitored via phasor measurement

Real-Time Digital Simulation

- Fulfills need for model power system testing
- Provides study of series-compensated lines
- Reproduces transient behavior of lines under fault conditions
- Performs closed-loop testing, interfacing with physical protection and control devices
- Studies response under changing system conditions

Reduced System Model



Model Power System Testing

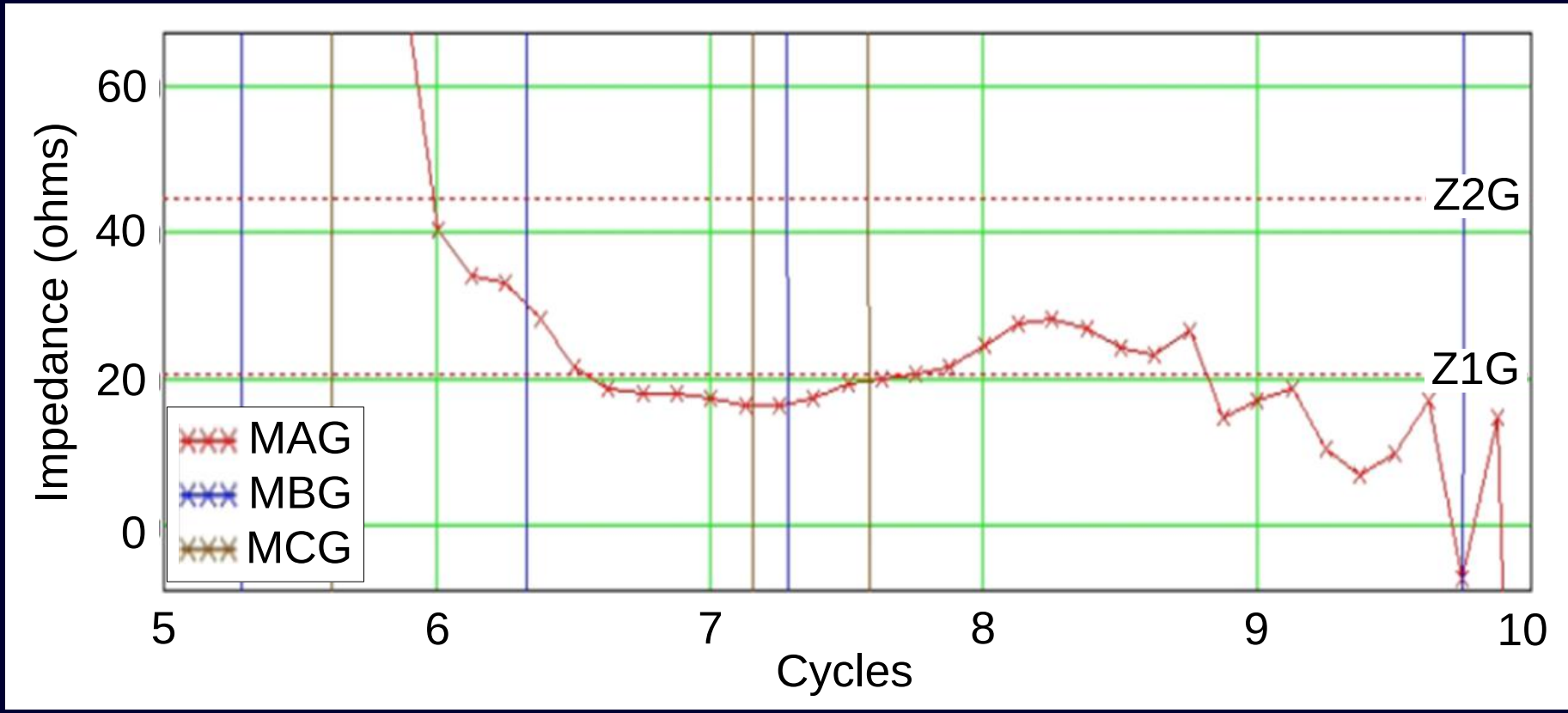
- Interface protective relays to simulation with analog voltages and currents
- Wire up relay inputs and outputs
- Test relays live with thousands of faults
- Simulate all 10 possible fault types
- Analyze results

Tests Performed

- Zone 1 margin
- Switch on to fault
- High-impedance faults
- Recloser tests
- Cross-country faults
- Batch tests

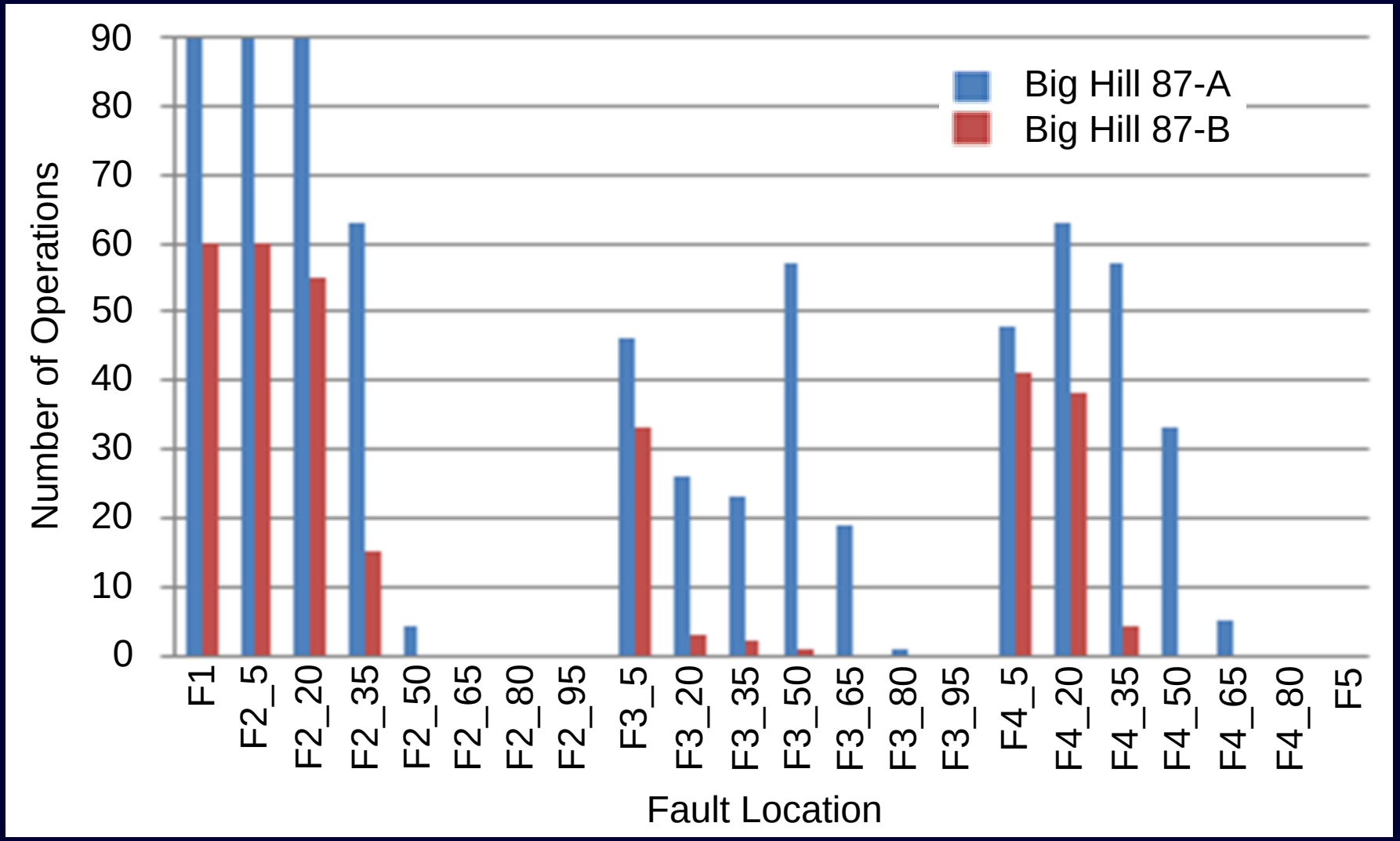
Zone 1 Margin Analysis

Study of Oscillation of Impedance Due to Subharmonic Frequency Transients



Zone 1 Dependability Analysis

Study to Evaluate Zone 1 Coverage



Batch Tests

- Performed for internal and external faults, with every fault type at varying points on wave
- Conducted for all fault locations in strong and weak source conditions

Phase Differential Operating Times

Terminal	Relay	Minimum (ms)	Average (ms)
Big Hill	87-A	20	29
	87-B	28	36
Kendall	87-A	21	29
	87-B	27	35

Sequence Differential Operating Times

Terminal	Relay	Minimum (ms)	Average (ms)
Big Hill	87-A	20	28
	87-B	23	37
Kendall	87-A	20	28
	87-B	23	37

Field Commissioning

- Completed required end-to-end testing
- Used GPS-synchronized test sets and COMTRADE waveforms from model power system testing
- Selected 20 faults for field testing
- Tested primary and standby communications channels
- Tested direct transfer trip and reclosing

West Texas Winter Storm
November 25, 2013

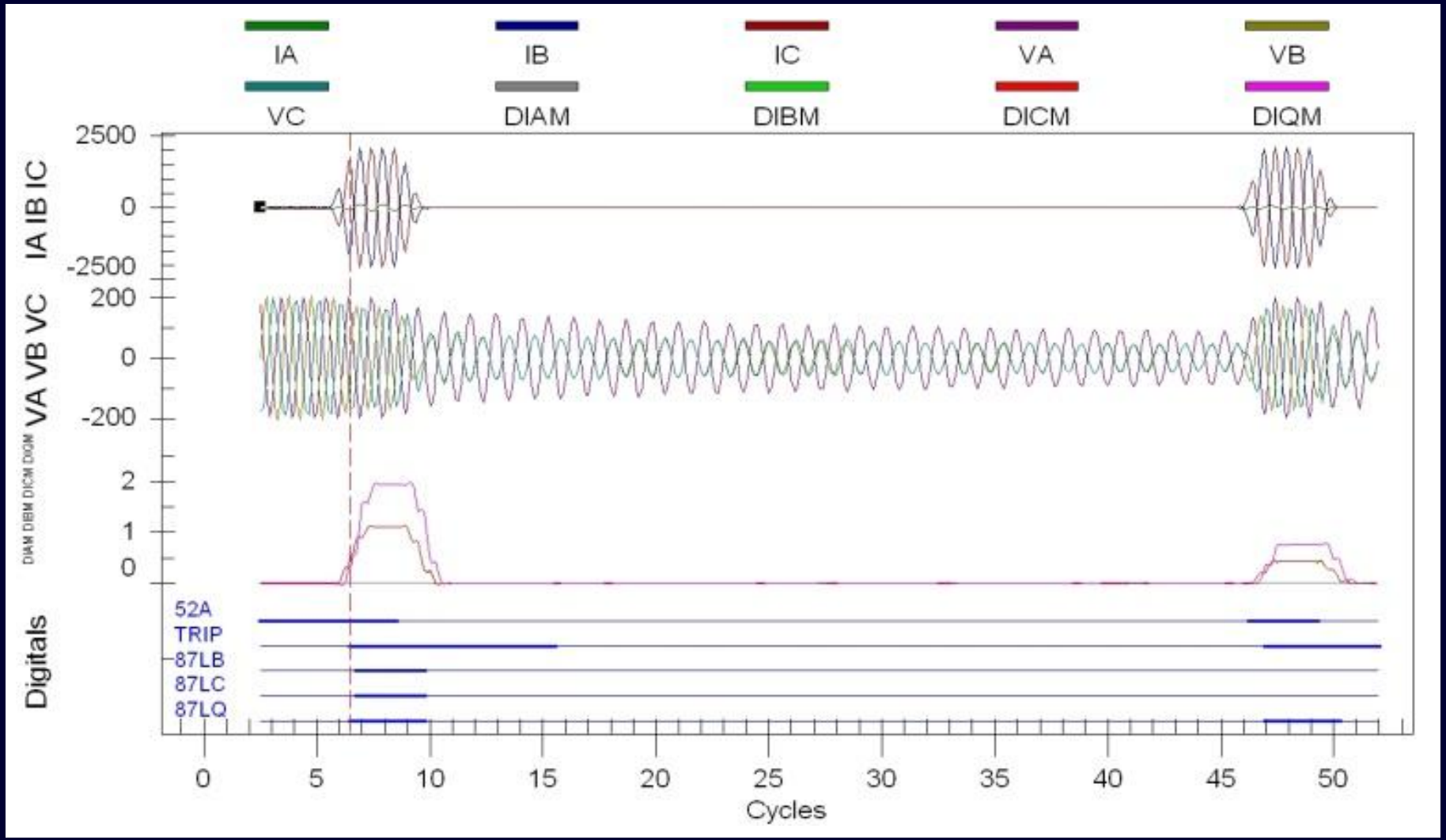
Relaying Performance on Line T-559

No.	Time (CST)	87-A Big Hill Targets	87-A Kendall Targets	Restoration
1a	10:23 a.m.	87LB/C/Q, Z2P 3.25 cycles	87LB/C/Q, Z2P, Z4P 3.0 cycles	Reclose attempted from Kendall, tripped back open
1b	*t* + 40 cycles	NA	87LQ, Z2P, Z4P 3.0 cycles	Restored by SCADA at 15:53 CST

Relaying Performance on Line T-558

No.	Time (CST)	87-A Big Hill Targets	87-A Kendall Targets	Restoration
2	10:31 a.m.	87LB/C/Q, Z2P, Z4P 3.25 cycles	87LB/C/Q, Z2P, Z4P 2.75 cycles	Reclose attempted from Kendall, held closed; measured line angle at closing 1°
3a	10:35 a.m.	87LB/C/Q, Z2P, Z4P 3.25 cycles	87LB/C/Q, Z2P, Z4P 2.75 cycles	Reclose attempted from Kendall, tripped back open
3b	*t* + 30 cycles	NA	87LQ, Z2P, Z4P 3.0 cycles	Restored by SCADA at 15:50 CST

Relaying Performance: T-558 87-A



Traveling Wave Performance

Line	No.	87-A Big Hill (miles)	SA TW Big Hill (miles)	87-A Kendall (miles)	SA TW Kendall (miles)
T-559	1a	26.24	25.71	112.86	113.34
T-558	2	21.81	21.25	117.29	117.80
	3a	26.26	25.73	112.84	113.32

Summary

- First LCRA TSC series-compensated lines
- Many unique line protection challenges
- ERCOT Nodal Operating Guide requirements established design criteria
- Selection of dual line current differential

Summary

- Wide-area SONET ring implemented to support relaying application
- Value of model power system testing demonstrated
- Initial performance results are promising


Questions?