Protective Relays and Cascading Failures

Dr. Greg Zweigle

Schweitzer Engineering Laboratories, Inc.

IEEE General Meeting, August 8, 2018

Purpose of Protective Relaying

"The purpose of protective relays and relaying systems is to operate the correct circuit breakers so as to disconnect only the faulty equipment from the system as quickly as possible, thus minimizing the trouble and damage caused by faults when they do occur"

A.R. van C. Warrington, 1962

Purpose of Protective Relaying

"The purpose of protective relays and relaying systems is to operate the correct circuit breakers so as to disconnect only the faulty equipment from the system as quickly as possible, thus minimizing the trouble and damage caused by faults when they do occur"

A.R. van C. Warrington, 1962

Purpose of Protective Relaying

"Relays are compact analog networks that are connected throughout the power system to detect intolerable or unwanted conditions within an assigned area. They are, in effect, a form of active insurance designed to maintain a high degree of service continuity, and limit equipment damage."

J. Lewis Blackburn, 1982

Purpose of Protective Relaying

"Relays are compact analog networks that are connected throughout the power system to detect intolerable or unwanted conditions within an assigned area. They are, in effect, a form of active insurance designed to maintain a high degree of service continuity, and limit equipment damage."

J. Lewis Blackburn, 1982

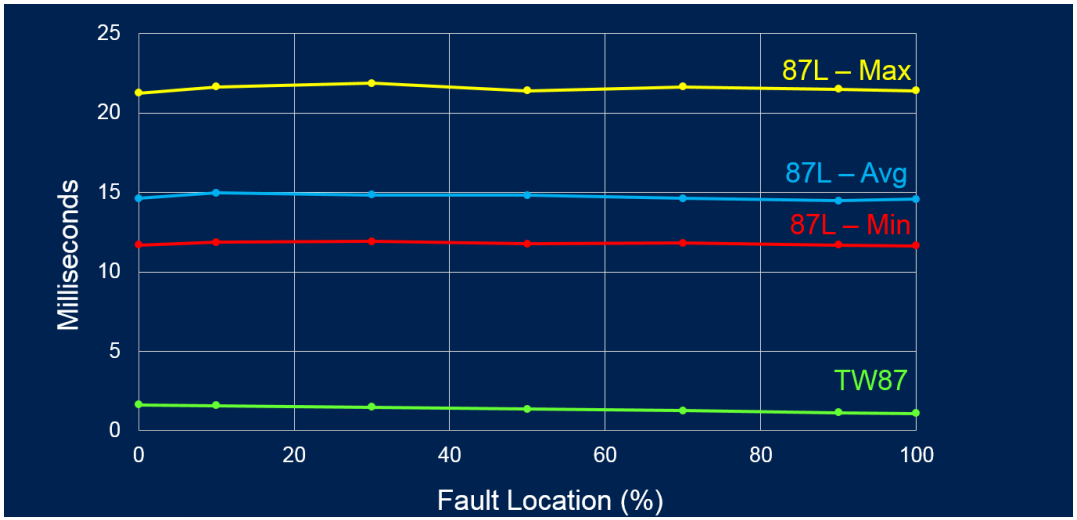
Purpose Summary

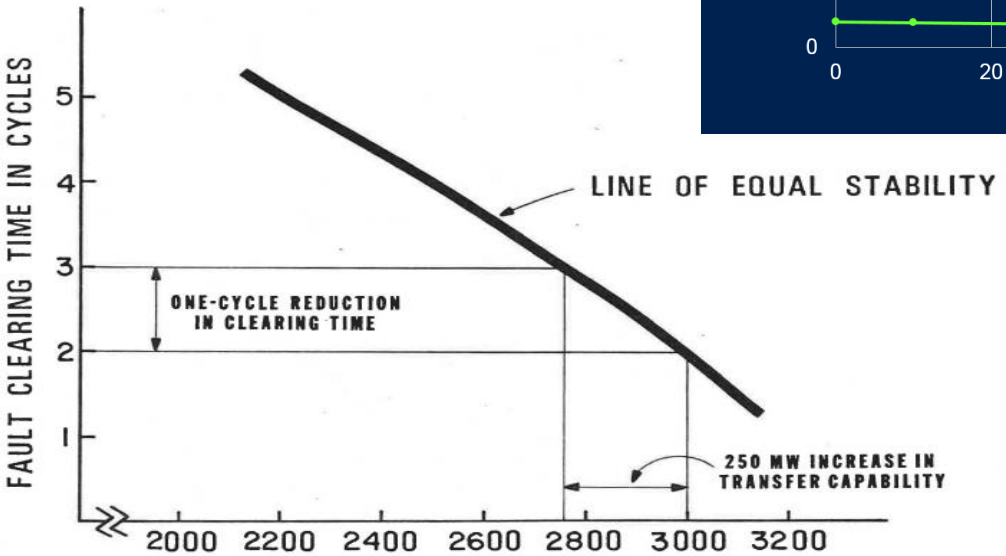
- Watch:
  - Observe a subset of the power system
  - Detect bad conditions within that subset
- Act:
  - Disconnect only the faulted equipment
  - Do so as quickly as possible
- So that:
  - Limit equipment damage (and keep people safe)
  - Keep remainder of system in service

Trip Fast!

Faster tripping =>

- stays closer to equilibrium
- fewer contingencies
- less state variation





Purpose Summary

- Watch:
  - Observe a subset of the power system
  - Detect bad conditions within that subset
- Act:
  - Disconnect only the faulted equipment
  - Do so as quickly as possible
- So that:
  - Limit equipment damage (and keep people safe)
  - Keep remainder of system in service

Protection Design Criteria (Blackburn)

- Reliability

  Dependability: Perform correctly when needed

  Security: Do not operate incorrectly

- Speed

  A faster response reduces damage and increases stability

- Selectivity

  Disconnect the minimum amount of equipment

- Economics
- Simplicity

Relays During Major Disturbances*

…low voltage, high power flows, power swings, abnormal frequency changes, rapid topology changes, …

Element	Challenges During Major Disturbance
Zone 1 distance	Power swing sensitivity Polarizing voltage memory
Overreaching distances – zones 2, 3, 4	Load encroachment
Instantaneous overcurrent	Power swing
Undervoltage	Transient low voltage conditions
Generator protection	Protecting the asset
Differentials & phase comparison	Immune to swings

** D. Tziouvaras, "Relay Performance During Major System Disturbances", WPRC, 2006 – Available at www.selinc.com*

Protection Design Criteria (Blackburn)

- Reliability

  Dependability: Perform correctly when needed

  Security: Do not operate incorrectly ←

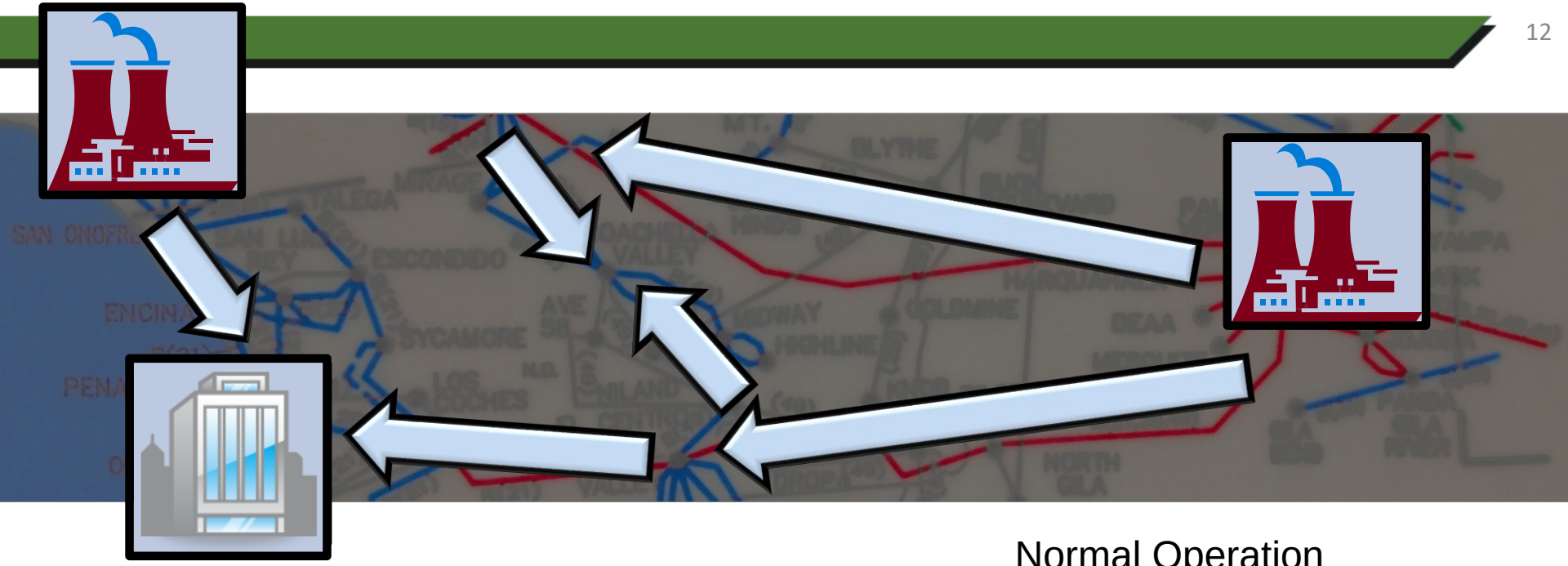
- Speed

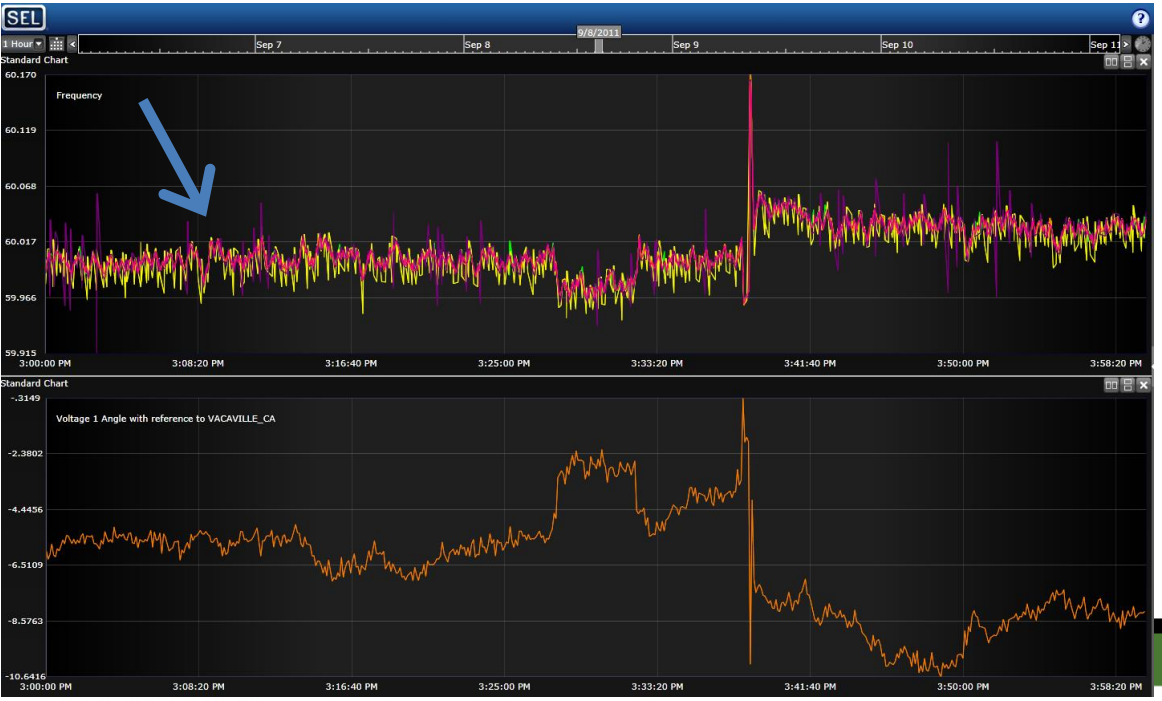
  A faster response reduces damage and increases stability

- Selectivity

  Disconnect the minimum amount of equipment

- Economics
- Simplicity

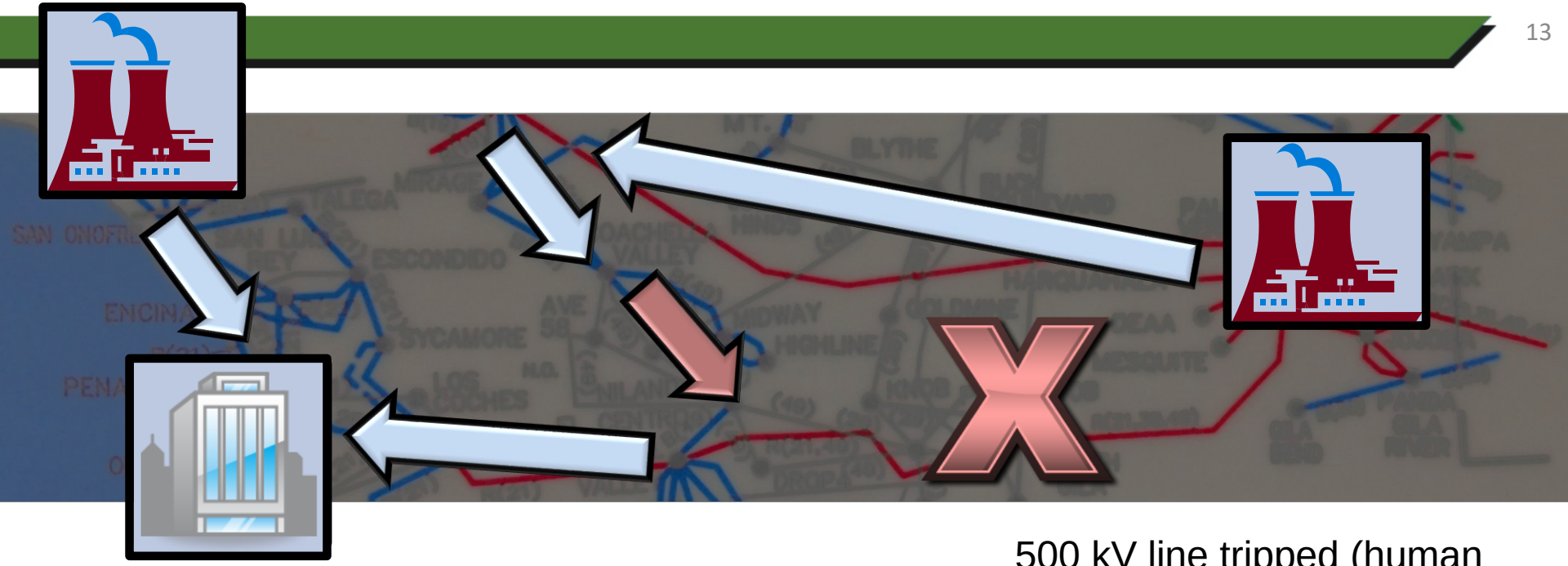




Normal Operation

Power flows from East and North

Loads are in the Western region



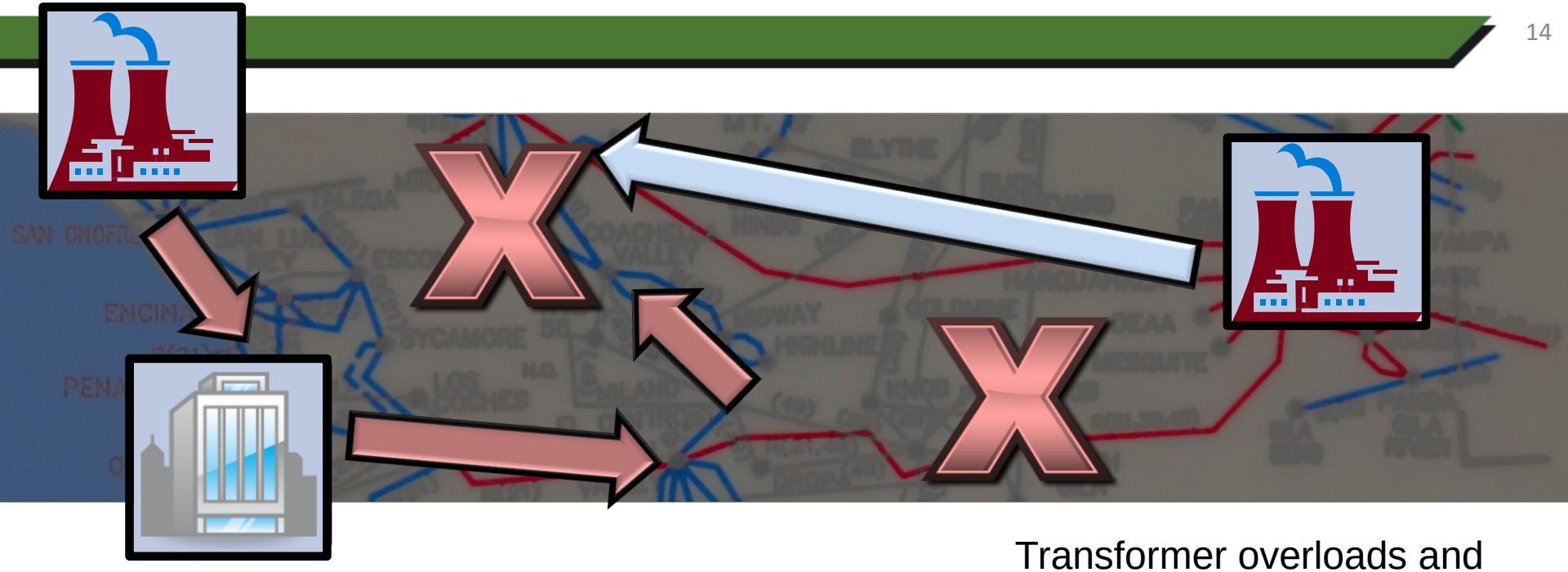
500 kV line tripped (human error)

Not normally a problem

But, could not reclose because of large standing angle

And, could not see angle

Heavy loads cause power flow directional change

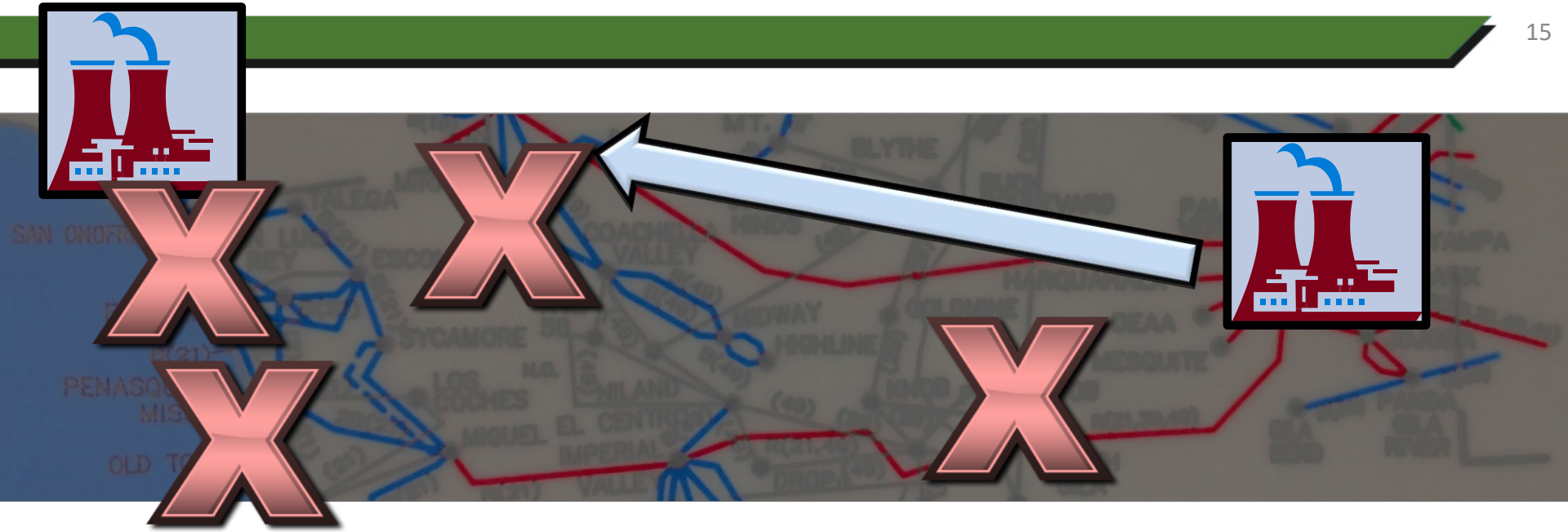


Transformer overloads and trips

Multiple power flow changes

Lines become highly overloaded

San Diego fed primarily through single line to San Onofre Nuclear and it also is highly overloaded



San Onofre line overload duration leads to line trip

Large frequency swings

Final cascading blackout

Relay Actions

Time	Action
15:27:39	Trip H-NG transmission line to clear A-C fault (500kV)
15:28:16	Trip CV transformer No.2 on inverse time overload (230/92kV)
15:28:17	Trip CV transformer No.1 on inverse time overload (230/92kV)
15:32:10	Trip Ramon transformer on inverse time overload (230/92kV)
15:32:11 – 15:33:46	Trip distribution on undervoltage (92kV) Loss of multiple small generation sites
15:32:13 – 15:32:15	Loss of multiple transmission lines on overload and zone 3 (161kV)
…	…
15:38:21	Trip Path 44, current exceeded 8000 amps (230kV)

Relay Manufacturer Responsibilities

Did the relay operate as expected?

Protection element design
Relay SW design
Relay HW design
Relay reliability

Was relaying properly engineered?

Listening / Learning
Teaching
Relay instruction manual
Technical papers (free)
Local product support
Relay settings simplicity
Relay settings software

Did we understand the system?

Relay models

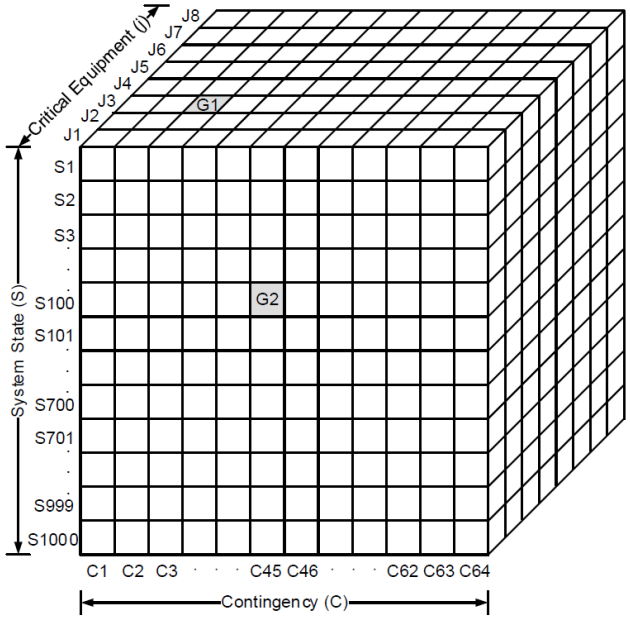
System Integrity Protection Schemes
aka
Remedial Action Schemes
aka
Special Protection Systems

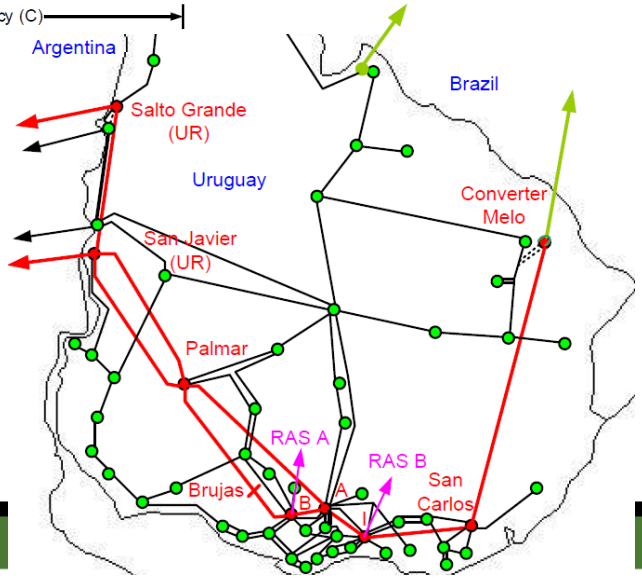
Remedial Action Scheme (FERC)

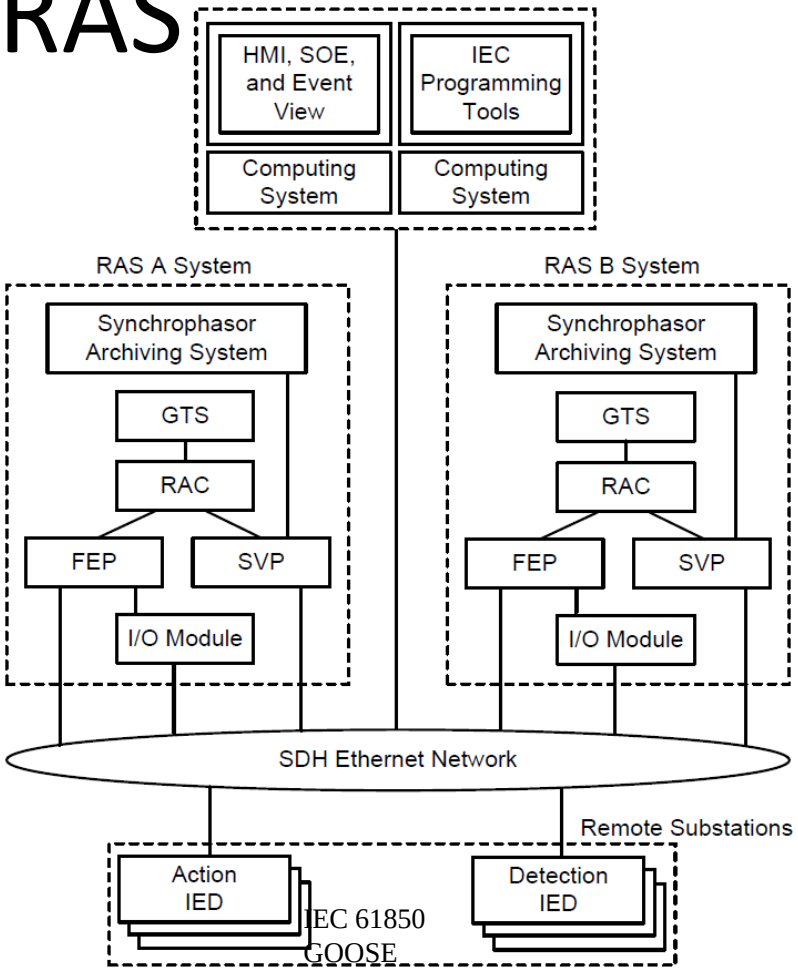
A scheme designed to detect predetermined System conditions and automatically take corrective actions that may include, but are not limited to, adjusting or tripping generation, tripping load, or reconfiguring the System.

- Meet requirements identified in the NERC Reliability Standards;
- Maintain Bulk Electric System (BES) stability;
- Maintain acceptable BES voltages;
- Maintain acceptable BES power flows;
- Limit the impact of Cascading or extreme events.

Uruguay RAS



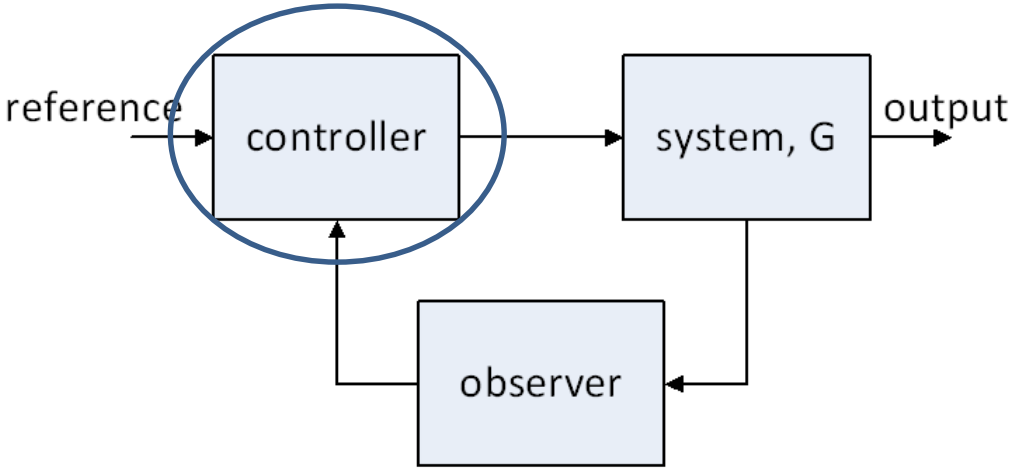




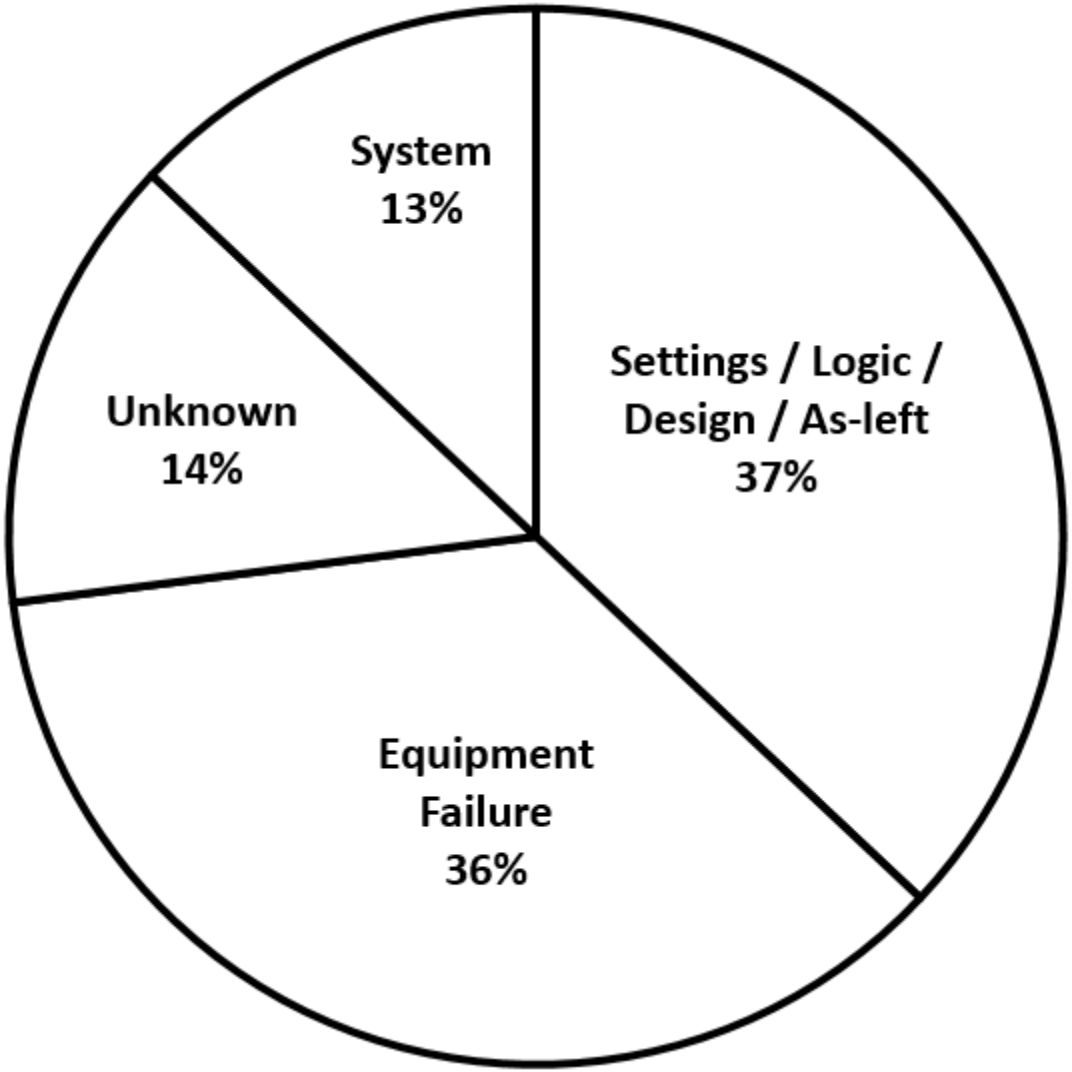
"Implementing a Country-Wide Modular Remedial Action Scheme in Uruguay",2015, www.selinc.com

Future: Control System Design That:

- Is designed for nonlinear systems
- Is structural, not signal based
- Stabilizes a wide range of contingencies
- Keeps states within acceptable bounds
- Minimizes the cost of controls
- Is robust and resilient

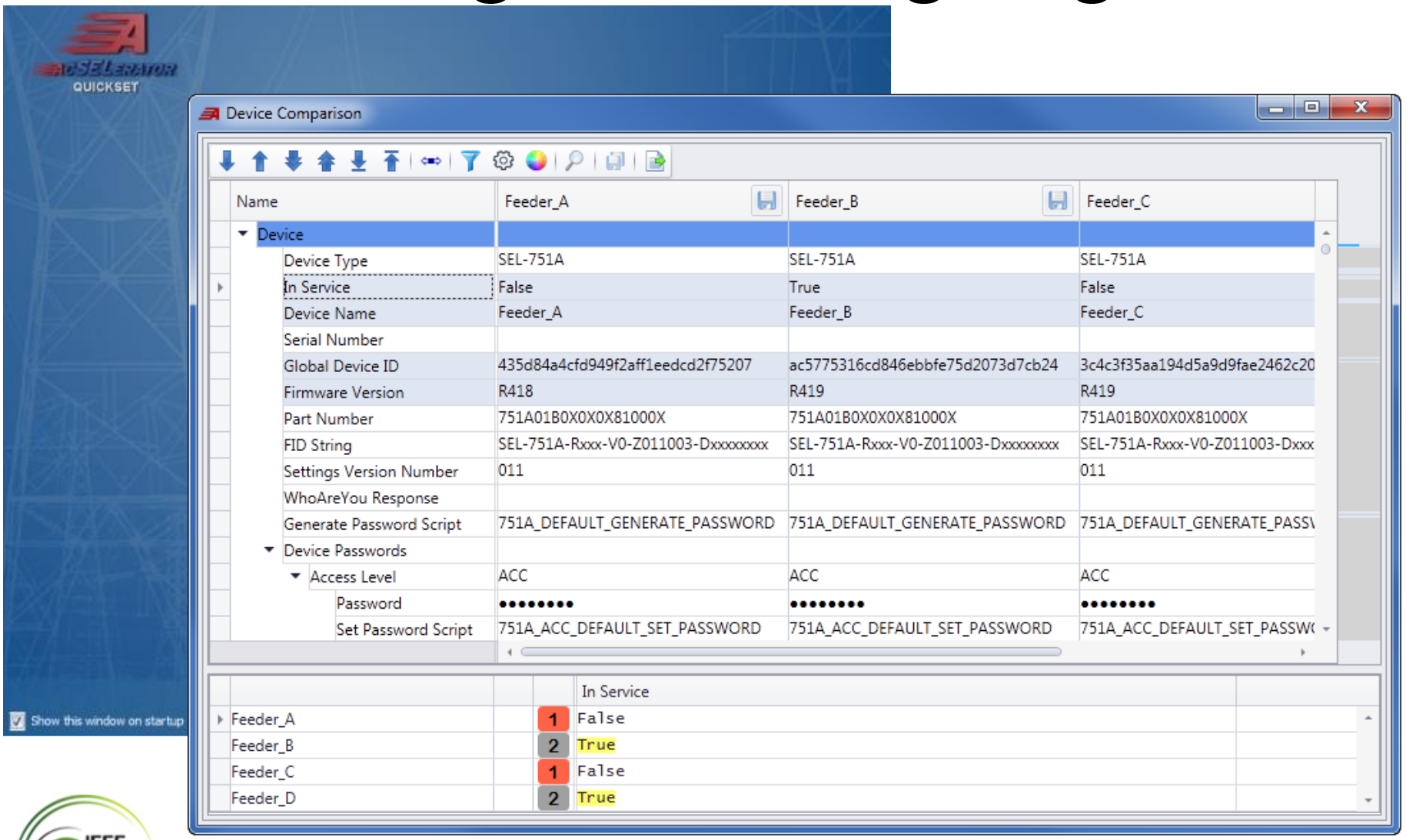


Settings!



NERC Staff Analysis of System Protection Misoperations, December 2014

Getting The Settings Right



Name	Feeder_A	Feeder_B	Feeder_C
Device			
Device Type	SEL-751A	SEL-751A	SEL-751A
In Service	False	True	False
Device Name	Feeder_A	Feeder_B	Feeder_C
Serial Number			
Global Device ID	435d84a4cfd949f2aff1eedcd2f75207	ac5775316cd846ebbfe75d2073d7cb24	3c4c3f35aa194d5a9d9fae2462c20
Firmware Version	R418	R419	R419
Part Number	751A01B0X0X0X81000X	751A01B0X0X0X81000X	751A01B0X0X0X81000X
FID String	SEL-751A-Rxxx-V0-Z011003-Dxxxxxxxx	SEL-751A-Rxxx-V0-Z011003-Dxxxxxxxx	SEL-751A-Rxxx-V0-Z011003-Dxxx
Settings Version Number	011	011	011
WhoAreYou Response			
Generate Password Script	751A_DEFAULT_GENERATE_PASSWORD	751A_DEFAULT_GENERATE_PASSWORD	751A_DEFAULT_GENERATE_PASS\
Device Passwords			
Access Level	ACC	ACC	ACC
Password	••••••••	••••••••	••••••••
Set Password Script	751A_ACC_DEFAULT_SET_PASSWORD	751A_ACC_DEFAULT_SET_PASSWORD	751A_ACC_DEFAULT_SET_PASSW(

		In Service
Feeder_A	1	False
Feeder_B	2	True
Feeder_C	1	False
Feeder_D	2	True

Conclusions

- Relays take quick action to isolate only faulted elements - but during a cascade asset removal can further weaken the system
- Need better modeling of relays in planning and control systems
- Simplifying settings and providing better settings tools
- System level control solutions of the future adapt to large order contingencies
- The “need for speed” – time domain protection