NASPI North American SynchroPhasor Initiative

Cascading Outage Prevention in the Western Interconnection

Hongming Zhang, Brett Wangen

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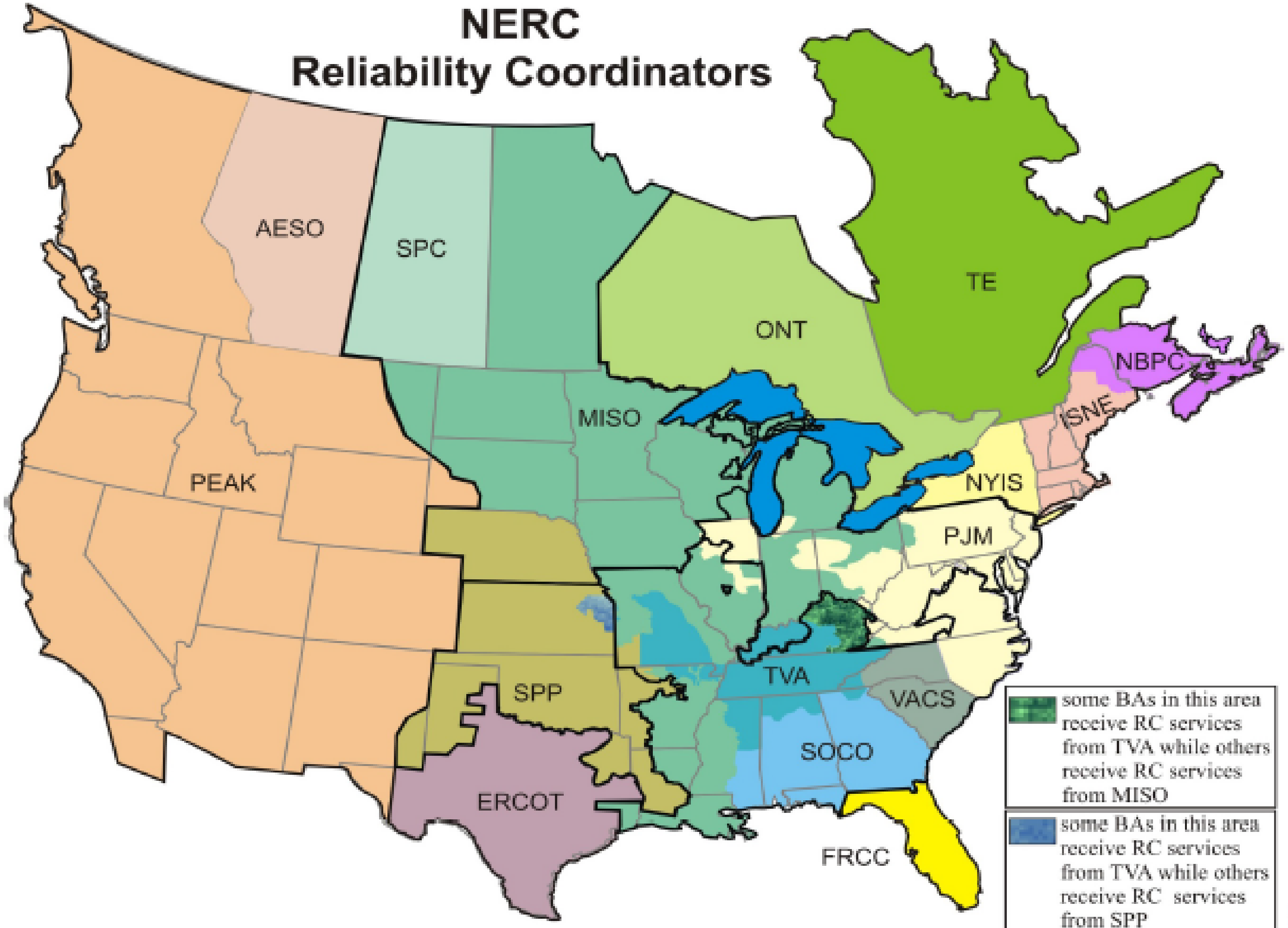
PEAK RELIABILITY
assuring the wide area view

Agenda

- Pacific SW cascading outage analysis
- Peak's actions taken to prevent new cascading events
- Peak's Response to FERC & NERC Report Finding & Recommendation 27
  - Monitor phasor angle difference (PAD) in RTCA
  - A preliminary study for angle separation monitor
- Future work

Peak Reliability: We provide situational awareness & real-time monitoring of the Reliability Coordinator (RC) Area within the Western Interconnection.



Reliability Area: 1.6 million square miles; 110,129 miles of transmission, and a population of 74 million.

 *AESO is currently providing their own Reliability Coordinator services consistent with Alberta legislation

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Pacific SW Cascading Outage on 9/8/2011

- **Summary of the Event Impacts**
  - Arizona, Southern California, Baja California, Mexico
  - Over 2.7 million people
  - 7,835 MW load lost
  - 12 hours to restore
  - Businesses disrupted
- **Statistics of Cascading Outages**
  - **3:27 pm**: HY-NG 500kV line tripped during a switching operation
  - **3:36 pm**. Two APS 161kV lines to Yuma, AZ tripped
  - **3:38 pm**. the P44 safety net triggered to separate Path 44. Following tripping of 2 Songs units, the blackout occurred

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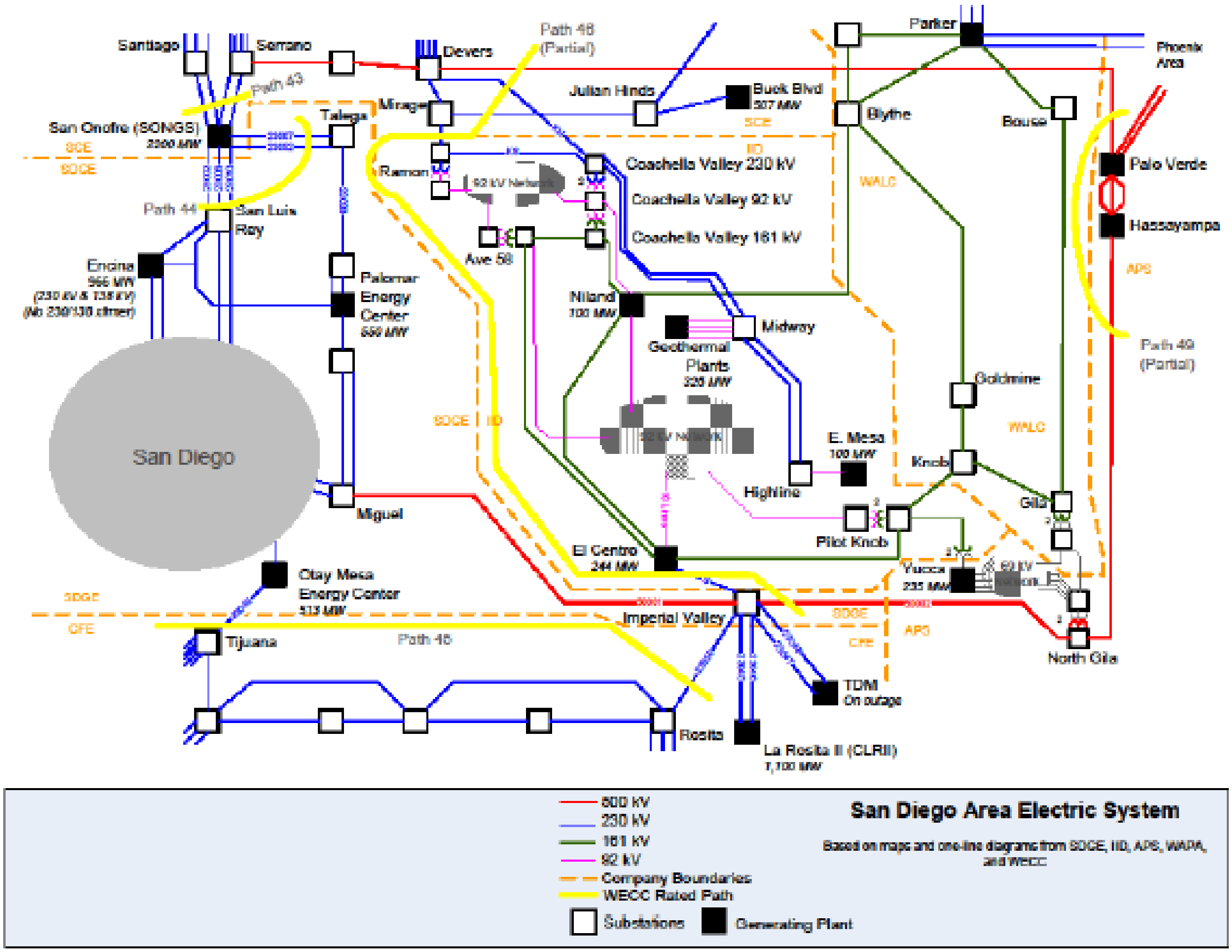
Case Study



Santiago
Serrano
Devers
Path 46 (Partial)
Parker
Phoenix Area
Path 43
Julian Hinds
Buck Blvd
507 MW
Mirage
Talega
Blythe
Bouse
San Onofre (SONGS)
2300 MW
SCE
SDGE
IID
Ramon
Coachella Valley 230 kV
Palo Verde
92 kV Network
WALC
Coachella Valley 92 kV
Path 44
San Luis Rey
Coachella Valley 161 kV
Hassayampa
Ave 58
Encina
966 MW
(230 kV & 138 kV)
(No 230/138 xfmer)
APS
Palomar Energy Center
559 MW
Niland
100 MW
Midway
Geothermal Plants
328 MW
Path 49 (Partial)
Goldmine
San Diego
92 kV Network
E. Mesa
100 MW
Knob
Highline
Miguel
Gila
Pilot Knob
El Centro
244 MW
Yucca
235 MW
69 kV Network
Otay Mesa Energy Center
513 MW
Imperial Valley
CFE
Tijuana
Path 45
North Gila
TDM
On outage
Rosita
La Rosita II (CLRII)
1,100 MW
500 kV
230 kV
161 kV
92 kV
Company Boundaries
WECC Rated Path
Substations
Generating Plant
San Diego Area Electric System
Based on maps and one-line diagrams from SDGE, IID, APS, WAPA, and WECC

Drivers to Pacific SW Event

- How did this cascading event happen?
  - Lack of understanding of BES impacts of sub-100-kV transmission systems
  - Remedial Action Schemes (RAS) missing in RTCA and unexpected impact of RAS in reality
  - Lack of understanding of transmission facility relay settings
  - Lack of adequate tools for IROL monitoring
- Could RTCA predict the risk in advance?

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Challenges to Predict Cascading Outage

- Modeling requirements
  - Clear understanding of equipment that impact the BES, including sub-100-kV networks
  - Inclusive and accurate RAS model available in RTCA
  - Awareness of protective relay trip settings, or a potential IROL threshold e.g. 125% Emergency Limits
- Intelligent alarming & visualization for effective real-time operation situational awareness
- RTCA capability for cascading outage screening
- Availability of real-time IROLs assessment tools

Peak's Actions Taken

- Make RTCA-RAS model accurate & inclusive in the West-wide System Model (WSM) as much as we can
- Initiate West-wide System Model and Basecase Reconciliation Task Force (WBRTF)
- Identify sub-100kV network elements that impact BES
- Ensure cascading risk assessment e.g. RC IROL test against severe RTCA post-contingency exceedances
- Roll out RT Voltage Security Assessment Tool (VSA) and continuously improve the VSA tool solution creditability
- Improve the quality of day ahead (DA) study by validating it against actual SE solutions. Implement look ahead RTCA monitoring

Having Inclusive RAS Model in RTCA

- Since the time of the event, Peak has
  - Included **over 250 additional RAS**, and greater specificity about the existing RASs, in Peak-RTCA
  - Added **212 additional RASs** to its SCADA overview displays, and **5000 additional RAS ICCP** points in SCADA
  - Identified and will continue to identify additional RASs through Peak regular review of all of the systems in its footprint and update RTCA-RAS model periodically
- Ensure correctness of RTCA reported violations

WBRTF Current Status & Facts

- >**95**% gen capacity mapped between WSM and WECC planning basecase *.dyd.
  - Majority of units (capacity >10 MW) were mapped up.
- **35+** BA/TOP have reviewed the WSM on their footprints, mostly focusing on units & GSUs in 2015
- BPA wind farms were re-modeled and Northwest regional model review made good progress
- Now focus on model comparison review on California footprint and the rest areas
- Create WSM-WECC BC equipment master mapping files to expedite model comparison and review process

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Monitoring the IROLs by RT VSA Tools

- Per the new SOL Methodology, the ultimate task of TOPs and the RC is to *continually assess and evaluate* projected system conditions as Real-time approaches with the objective of ensuring acceptable system performance in Real-time against SOL/IROL exceedance
- A few IROLs were identified by the Western Interconnection: ***NW Washington Net Load, SDGE Summer and Non-Summer Import et al*** (subject to voltage stability concern)
- Peak has implemented V&R Peak ROSE-online Voltage Security Analysis (VSA) tool to calculate/monitor theses IROLs in near real-time operations (5min cycle)

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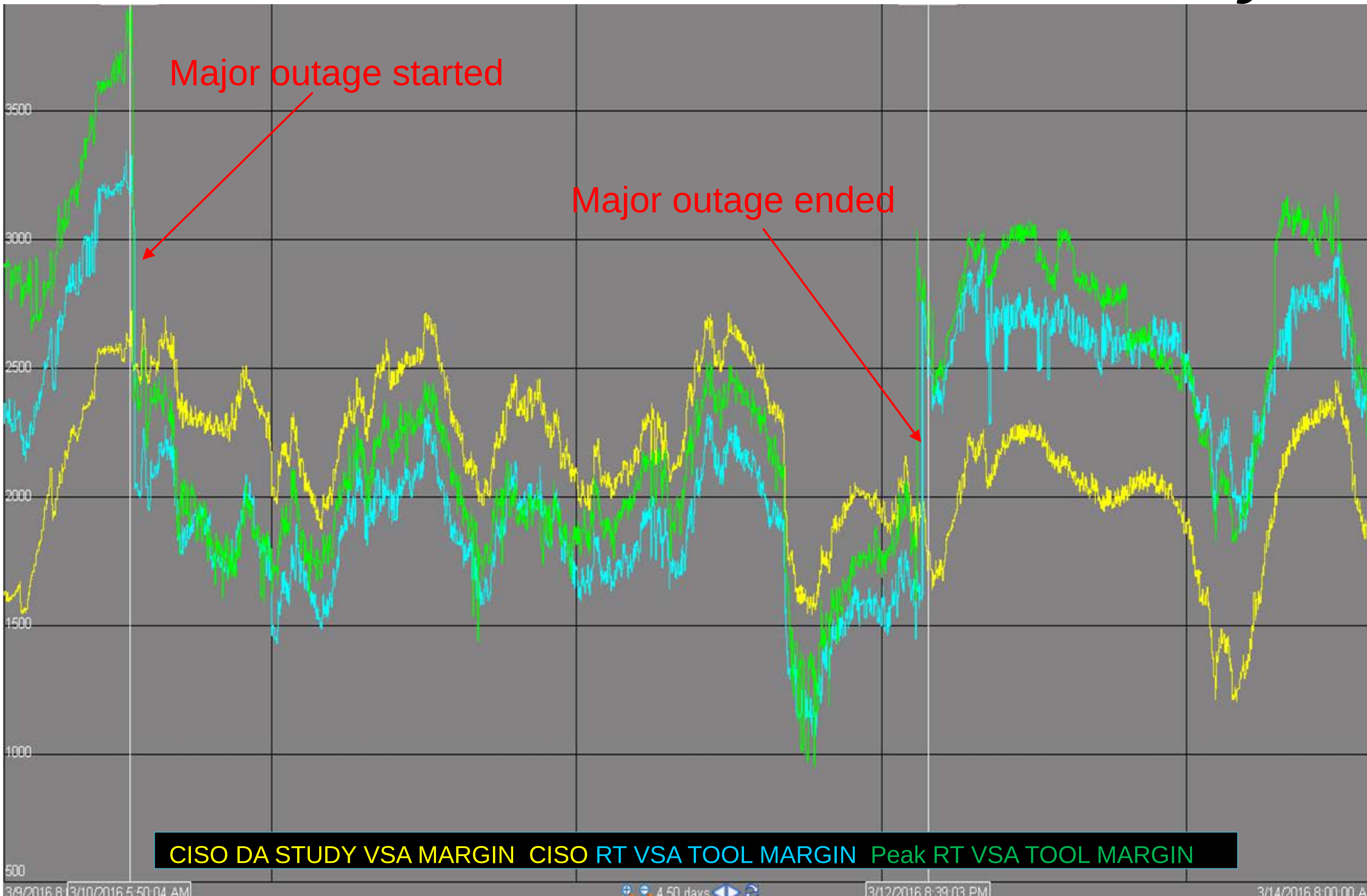
VSA Results: RT Tools vs DA Study



Peak's Response to FERC & NERC Report Finding & Recommendation 27

Finding 27*:"...TOPs have no tools in place to determine Phase Angle Difference (PAD) following loss of transmission Line…"*

Recommendation 27*: "TOPs should have: (1) the tools necessary to determine phase angle differences following the loss of lines; and (2) mitigation and operating plans for reclosing lines with large phase angle differences. TOPs should also train operators to effectively respond to phase angle differences…"*

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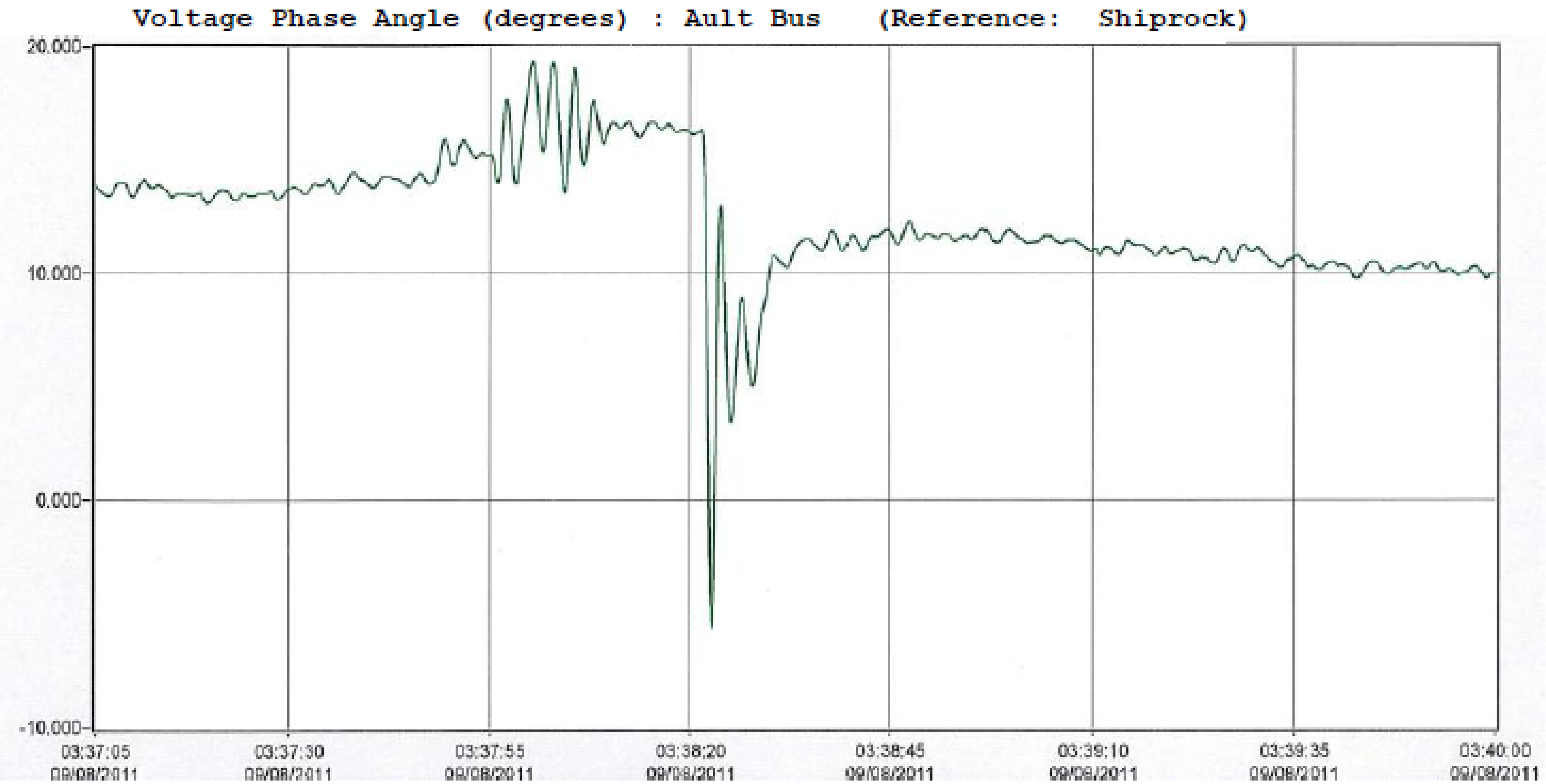
Southern Calif Outage

Sept 2011, Blackout Event
PMU Phase Angle Diff



- **Angle Separation Awareness on the outage event**

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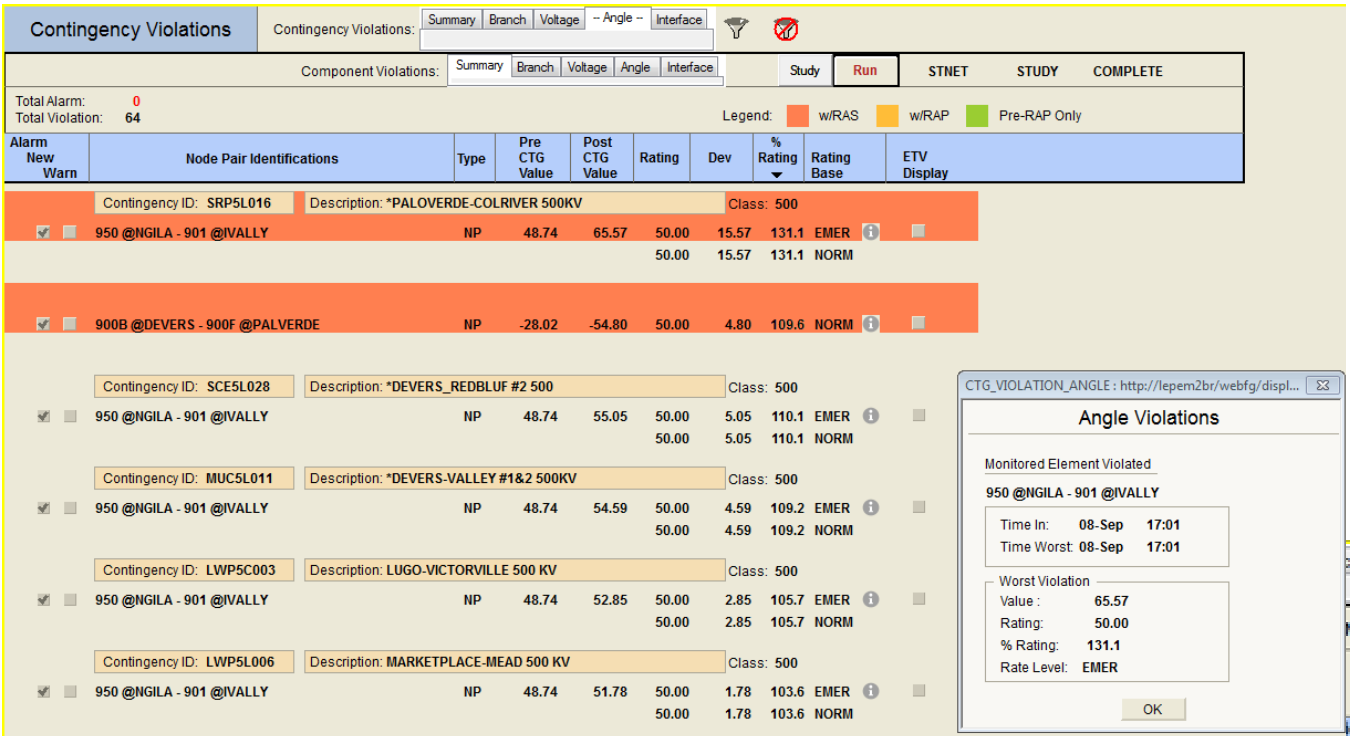
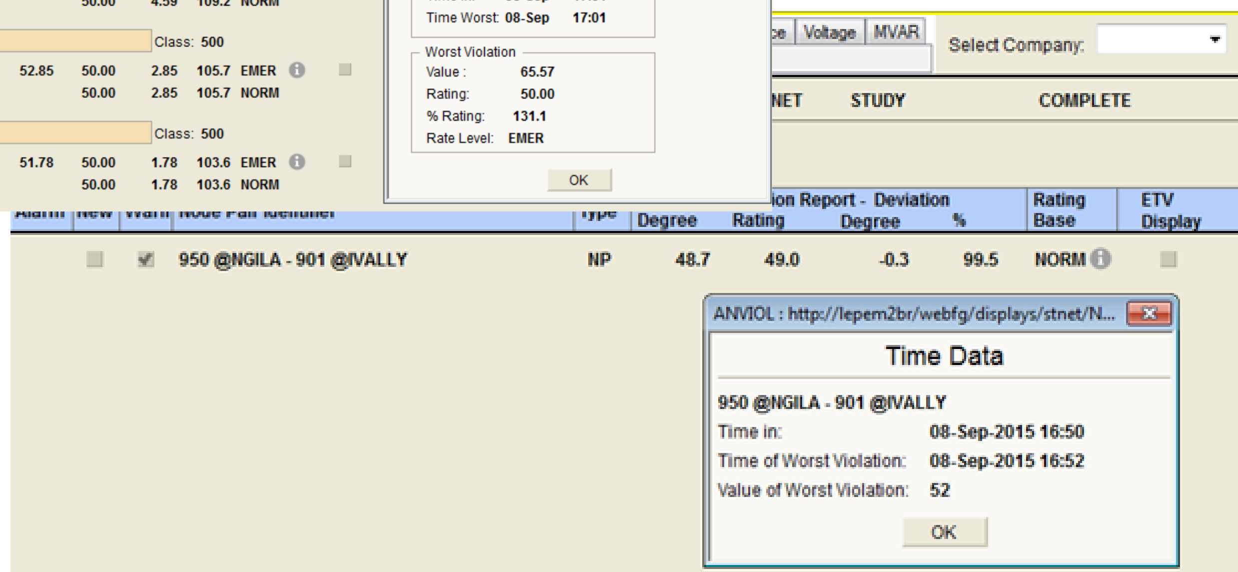
Modeling Line Reclose Relay Setting in RTCA – Synchro-Check Awareness



- Dozens of PAD limits have been modeled in RTCA for monitoring bus angle diff across a line and alarming under post-contingency



- PAD limits exceedance was implemented in SCADA and SE for alarming in real-time

Next Steps*: Can We Monitor Bus Angle Separation for Major Paths and IROLs?*

- The goal is using synchrophasor technology to gain real-time situational awareness of stressed conditions of major intertie or paths:
  - Qualified WECC Paths e.g. COI
  - Other important Paths e.g. TOT2
  - Identified IROLs:
    - SDGE Summer Import IROL
    - SDGE Non-Summer Import IROL
    - NW Washington Net Load

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Introducing Concept of Virtual Angle Pair

Single Line

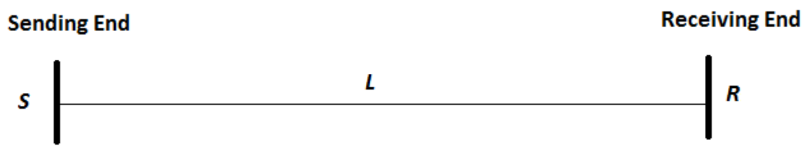

Figure 2: Single Line Topology

DC power flow:

$$P \approx \frac{1}{X}\left(\theta_S - \theta_R\right) \quad (1)$$

Multiple Lines

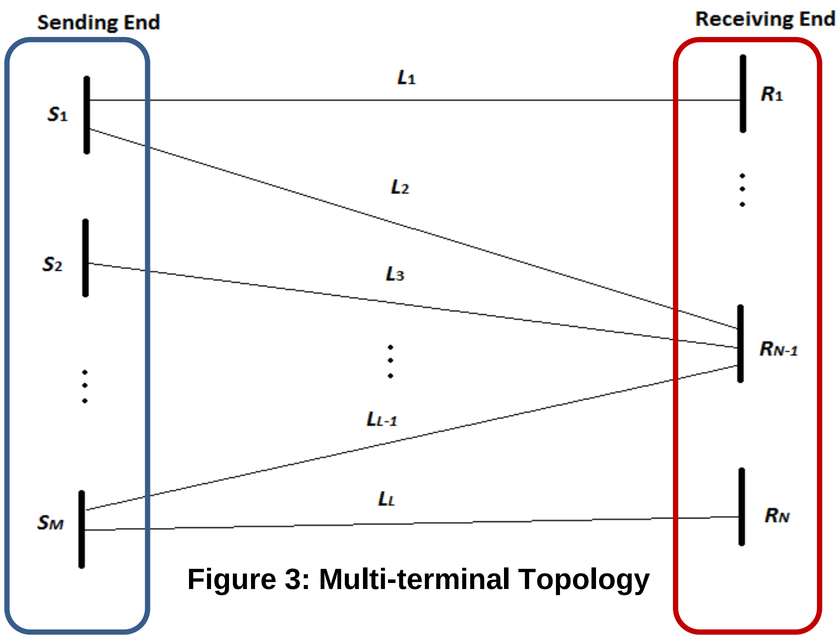

Figure 3: Multi-terminal Topology

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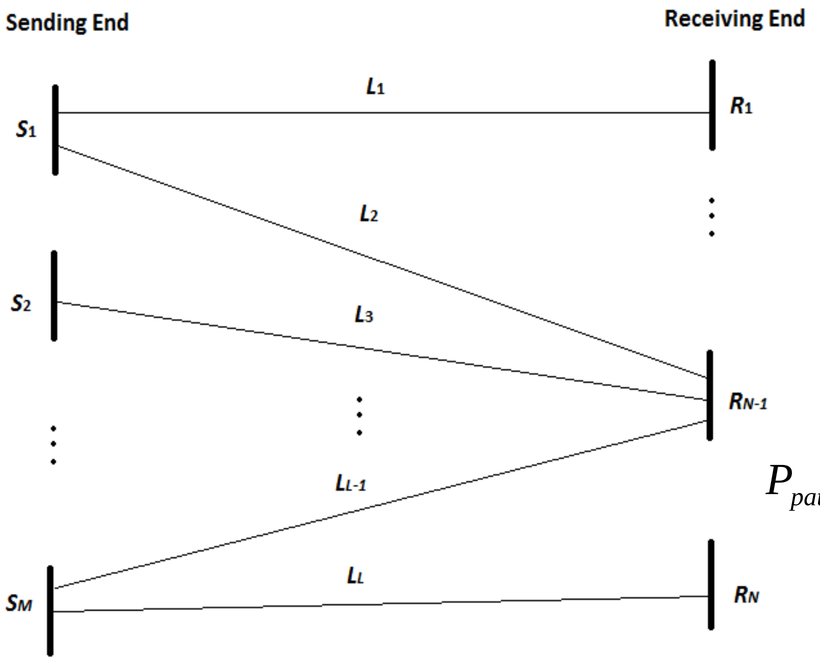
Formulation and Derivation



M sending ST (S_1, S_2 ... and S_M)
N receiving ST (R_1, R_2 ... and R_N)
L parallel lines (L_1, L_2 ... and L_L)

$$P_{path} = \sum_{i=1}^{L} P_i \approx \sum_{i=1}^{L} \frac{1}{X_i}\left(\theta_{Smi} - \theta_{Rni}\right) = \sum_{i=1}^{L} \frac{1}{X_i}\theta_{Smi} - \sum_{i=1}^{L} \frac{1}{X_i}\theta_{Rni} \qquad (2)$$

Define X_{eq} as:

$$\frac{1}{X_{eq}} = \sum_{i=1}^{l} \frac{1}{X_i} \qquad (3)$$

Equation (2) can be written as:

$$P_{path} \approx \frac{1}{X_{eq}} \sum_{i=1}^{L} \frac{X_{eq}}{X_i}\theta_{Smi} - \frac{1}{X_{eq}} \sum_{i=1}^{L} \frac{X_{eq}}{X_i}\theta_{Rni} = \frac{1}{X_{eq}}\left(\theta_S - \theta_R\right) \qquad (4)$$

Where:

$$\theta_S = \sum_{i=1}^{L} \frac{X_{eq}}{X_i}\theta_{Smi} \qquad (5) \qquad\qquad \theta_R = \sum_{i=1}^{L} \frac{X_{eq}}{X_i}\theta_{Rni} \qquad (6)$$

Formulation and Derivation (Cont'd)

Define the set of lines a sending ST, *Sm*, is connected with as A_m:

$$A_m = \{i : L_i \text{ connects to } S_m\}$$

Define the set of lines a receiving ST, *Rn*, is connected with as B_n:

$$B_n = \{i : L_i \text{ connects to } R_n\}$$

Equation (5) and (6) can be written as:

$$\theta_S = \sum_{m=1}^{M} \left(\sum_{j \in A_m} \left(\frac{X_{eq}}{X_j} \right) \theta_{Sm} \right) \quad (7)$$

$$\theta_R = \sum_{n=1}^{N} \left(\sum_{j \in B_n} \left(\frac{X_{eq}}{X_j} \right) \theta_{Rn} \right) \quad (8)$$

Define weighting factor as:

$$w_{Sm} = X_{eq} \cdot \sum_{j \in A_m} \left(\frac{1}{X_j} \right) \quad (9)$$

$$w_{Rn} = X_{eq} \cdot \sum_{j \in B_n} \left(\frac{1}{X_j} \right) \quad (10)$$

Path flow can be expressed as:

$$P_{path} \approx \frac{1}{X_{eq}} (\theta_S - \theta_R) = \frac{1}{X_{eq}} \left(\sum_{m=1}^{M} (w_{Sm} \cdot \theta_{Sm}) - \sum_{n=1}^{N} (w_{Rn} \cdot \theta_{Rn}) \right) \quad (11)$$

Note: Virtual PAD is considered linearly proportion to interface flow

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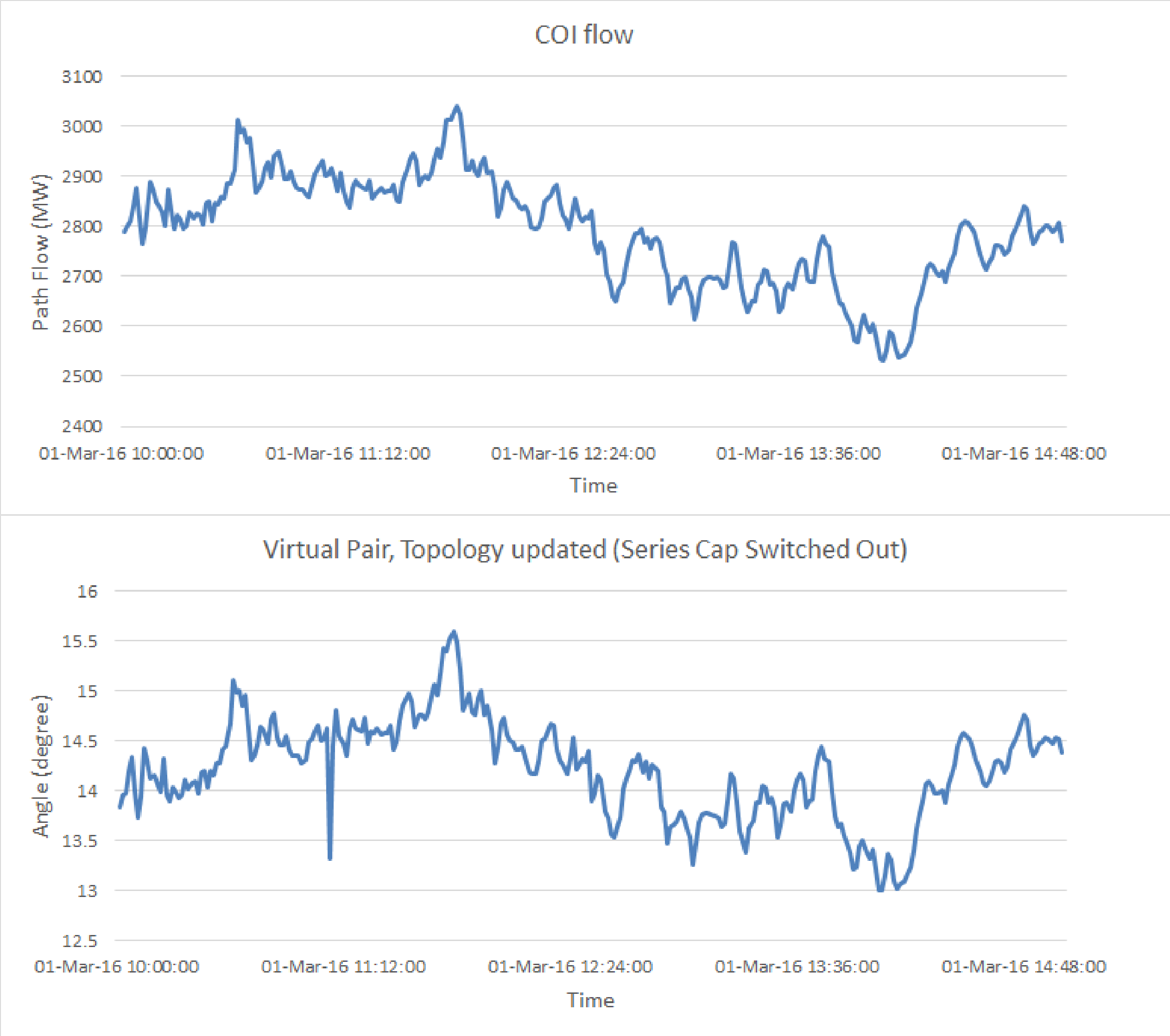
Angle Pair Separation Monitor to COI by SE Estimated Values (1-min sampling)



Remarks: PMU based wide angle separation monitor will be applicable for a major system transfer condition when PMU bus voltage angle signals are available across the substations related.

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Calculating PAD Operating Limits

- A virtual PAD limit for a WECC Path or IROL can be dynamically derived from
  - RTCA reported thermal violation that likely triggers N-x levels cascading outage
  - RT-VSA calculated online voltage stability limits
    - ❑ PADs vary w.r.t. power transfer stressing in basecase
    - ❑ PADs vary w.r.t. power transfer stressing in post-contingence
  - Online TSAT calculated RT transient stability limits

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Future Work

- Validate RAS model with the TO/BA which operators/monitors the RAS. Keep the model up to date and consistent with actual RAS operation
- Improve RAS visualization for better real-time RAS operation situational awareness to RC
- Enhance RTCA to enable cascading outage screening & risk assessment automatically
- Leverage using PMU signals and Synchrophasor technology for dynamic monitoring and indication of system operation stressfulness

Hongming Zhang
Manager, Network Applications, hzhang@peakrc.com
Brett Wangen
Director, Engineering, bwangen@peakrc.com