Application of Advanced Wide Area Early Warning Systems with Adaptive Protection

DOE Smart Grid Project DE-OE0000120

presented to:

NASPI Working Group

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California Institute for Energy and Environment

by:

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Electric Grid Research

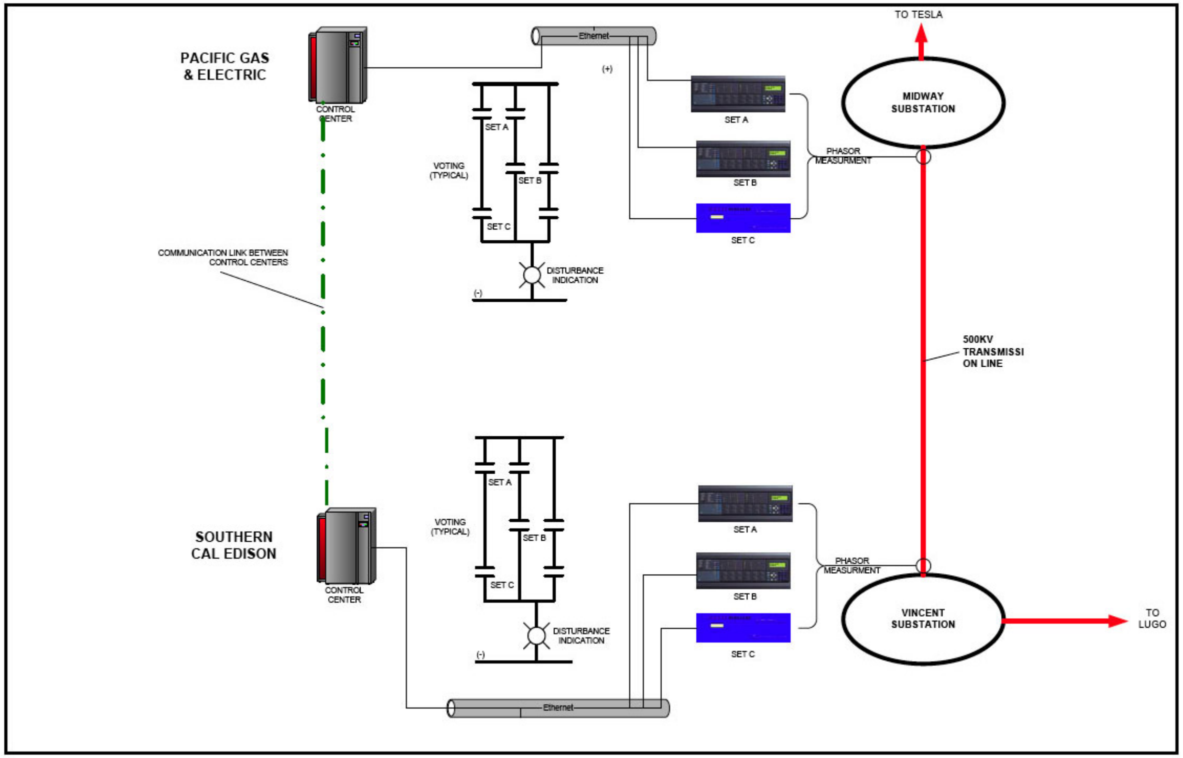
Project Objectives

- Field demonstrations of advanced protection systems using synchrophasor data:
    1. Adaptive Security/Dependability Balance
    2. Impedance Relay Zone “Encroachment” Detection & Alarm
- Develop Protection Information Tool:
    1. User-validated visualizations of protection information based on synchrophasor data
    2. Sensor web specifications enabling a uniform and standardized methodology for information exchange via extensions to OpenPDC

Research, Development & Demonstration Team

- Lloyd Cibulka – CIEE: Project management and coordination
- Jim Thorp, Virgilio Centeno – Virginia Tech: Relay algorithms development, testing and evaluation
- Roger King, Kari Babski-Reeves – Mississippi State: Protection information tool development, testing and evaluation
- Vahid Madani – PG&E: Host utility, field testing and evaluation
- Frank Ashrafi – SCE: Host utility, field testing and evaluation
- Tariq Rahman – SDG&E: Historical relay data, technical advisor
- Damir Novosel – Quanta: Technical advisor

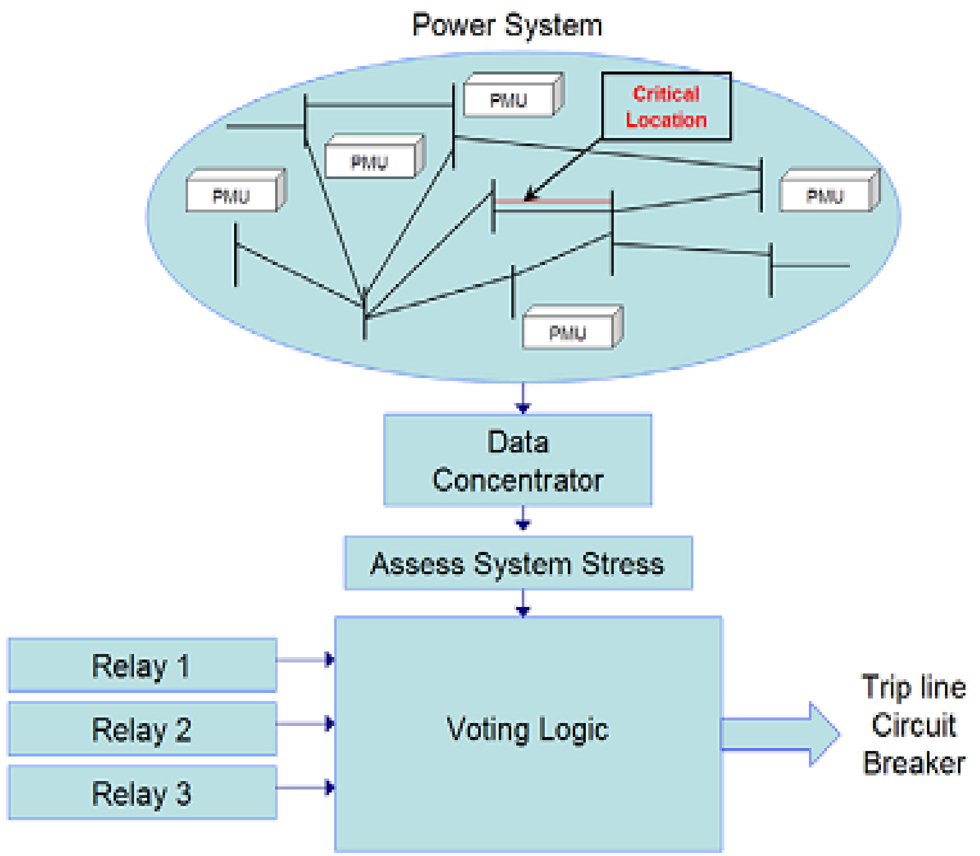
Adaptive Security/Dependability Balance



Dependability (Reliability): High probability that relays will operate for an actual fault.
Security: Low probability that relays will operate when there isn't an actual fault.

- The primary protection system consists of three redundant sets of relays, any one of which can trip the line if it detects a fault. This biases the protection system in favor of reliability for normal conditions.
- Objective of Adaptive S/D Balance is to minimize the possibility that any one set of relays will false-trip during stressed system conditions, which might contribute to a cascading outage.
- Technical Approach: Utilize an "Adaptive Voting Scheme." If stressed system conditions are detected using synchrophasor measurements, a relay supervisory signal based on a 2-out-of-3 voting scheme is generated.

Security/Dependability Adaptive Protection Conceptual Design

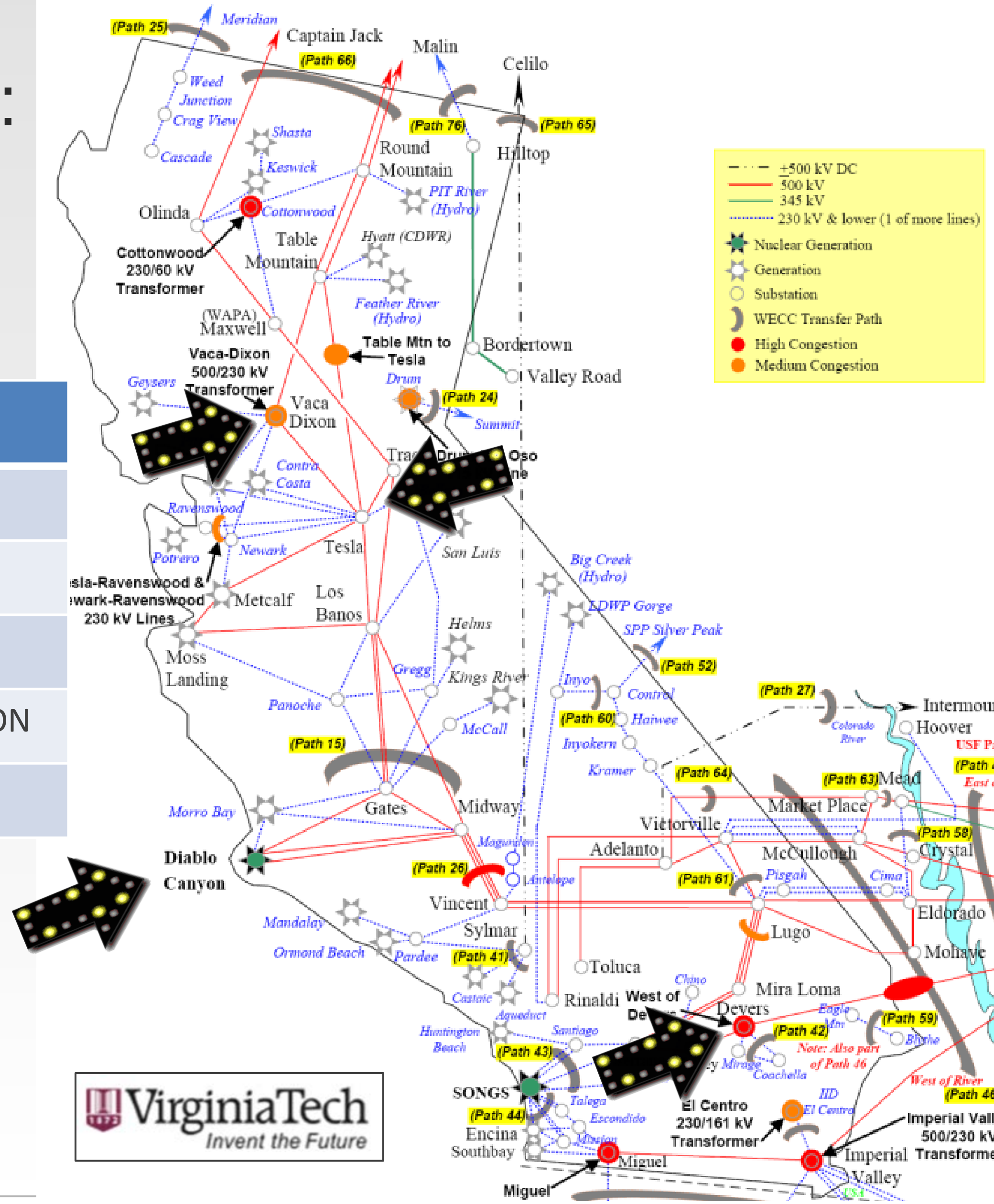


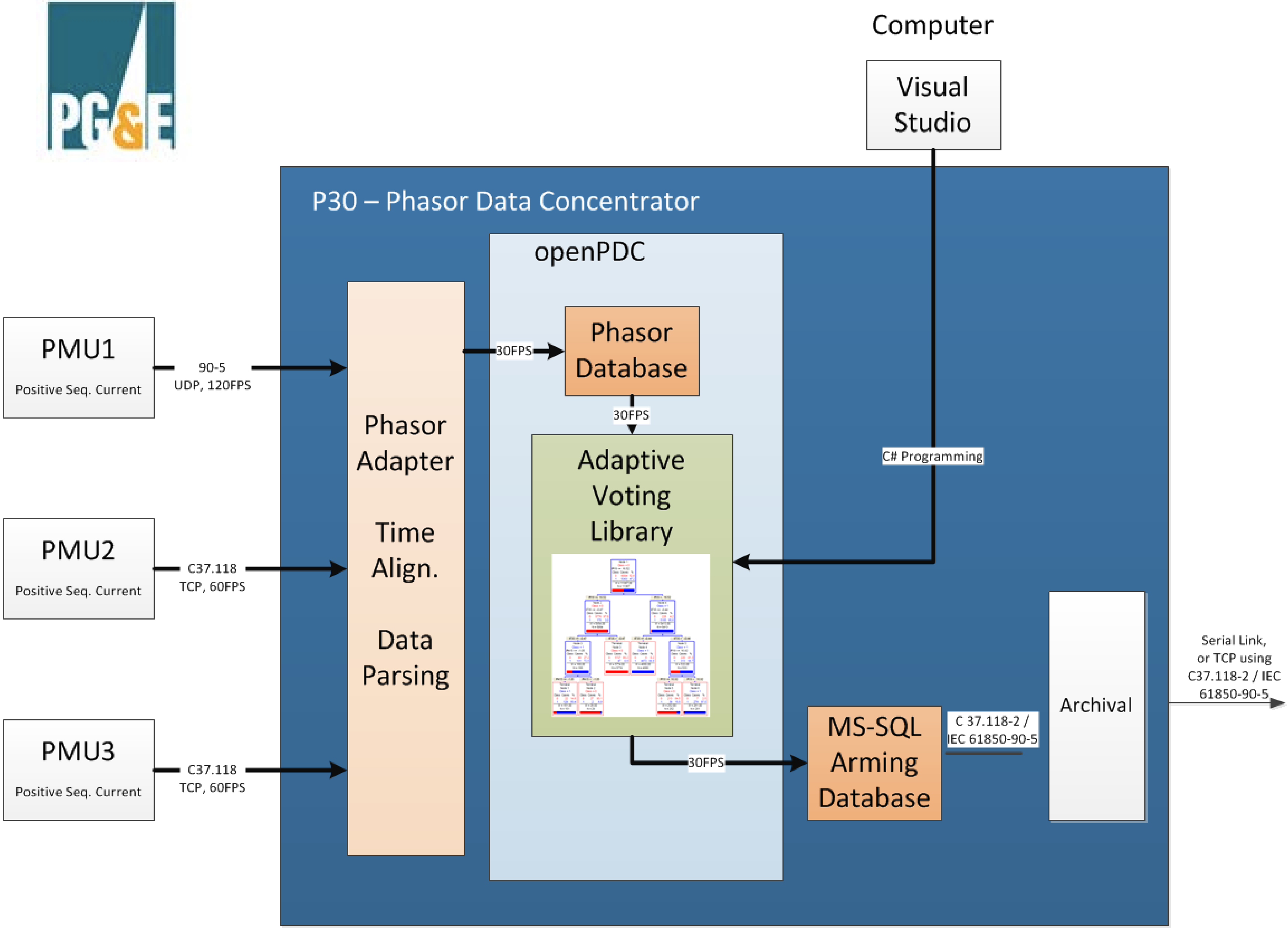
Functional diagram of the adaptive protection system.

Adaptive Voting Scheme: PMU Placement

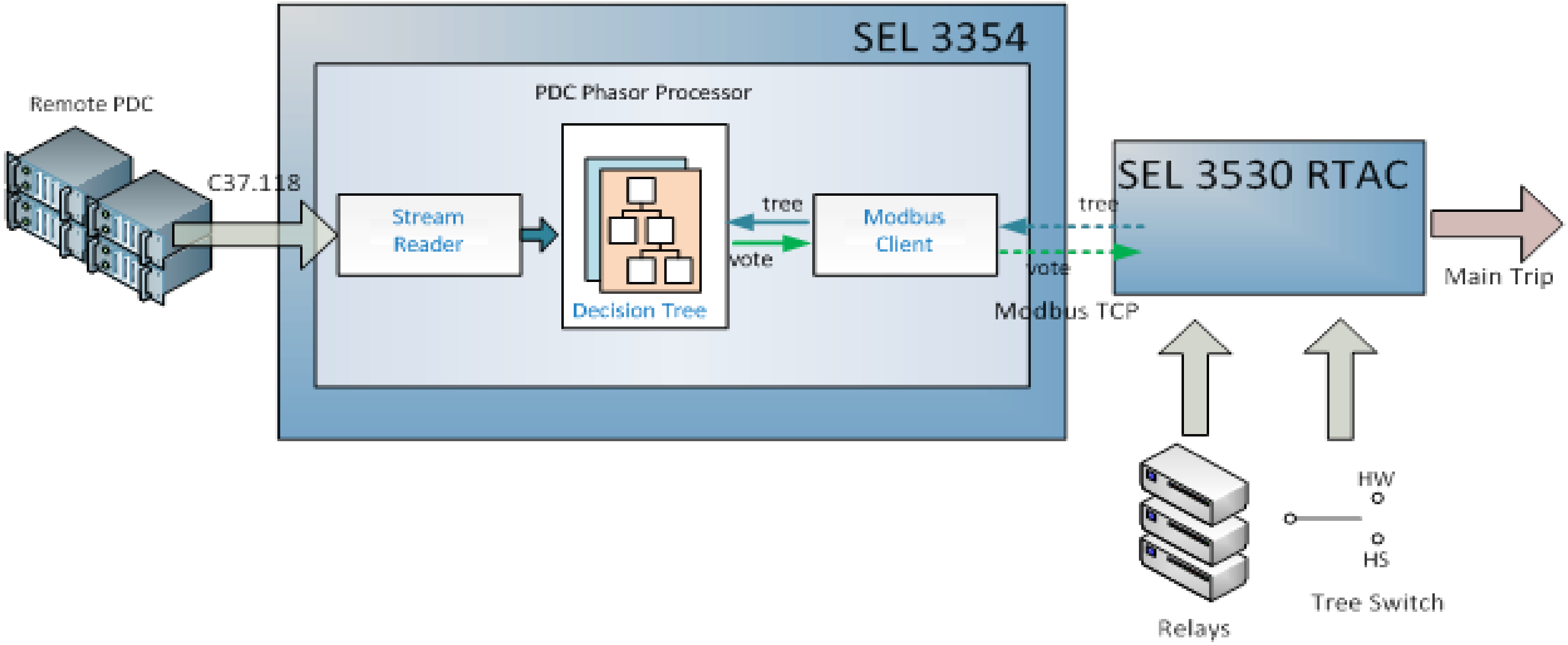
Line Current	
DEVERS	VALLEYSC
DEVERS	PALO VERDE
DIABLO	MIDWAY
TESLA	LOS BANOS
References	
Summer	VACA-DIXON
Winter	TESLA

PMU
DEVERS
TESLA
DIABLO
VACA-DIXON

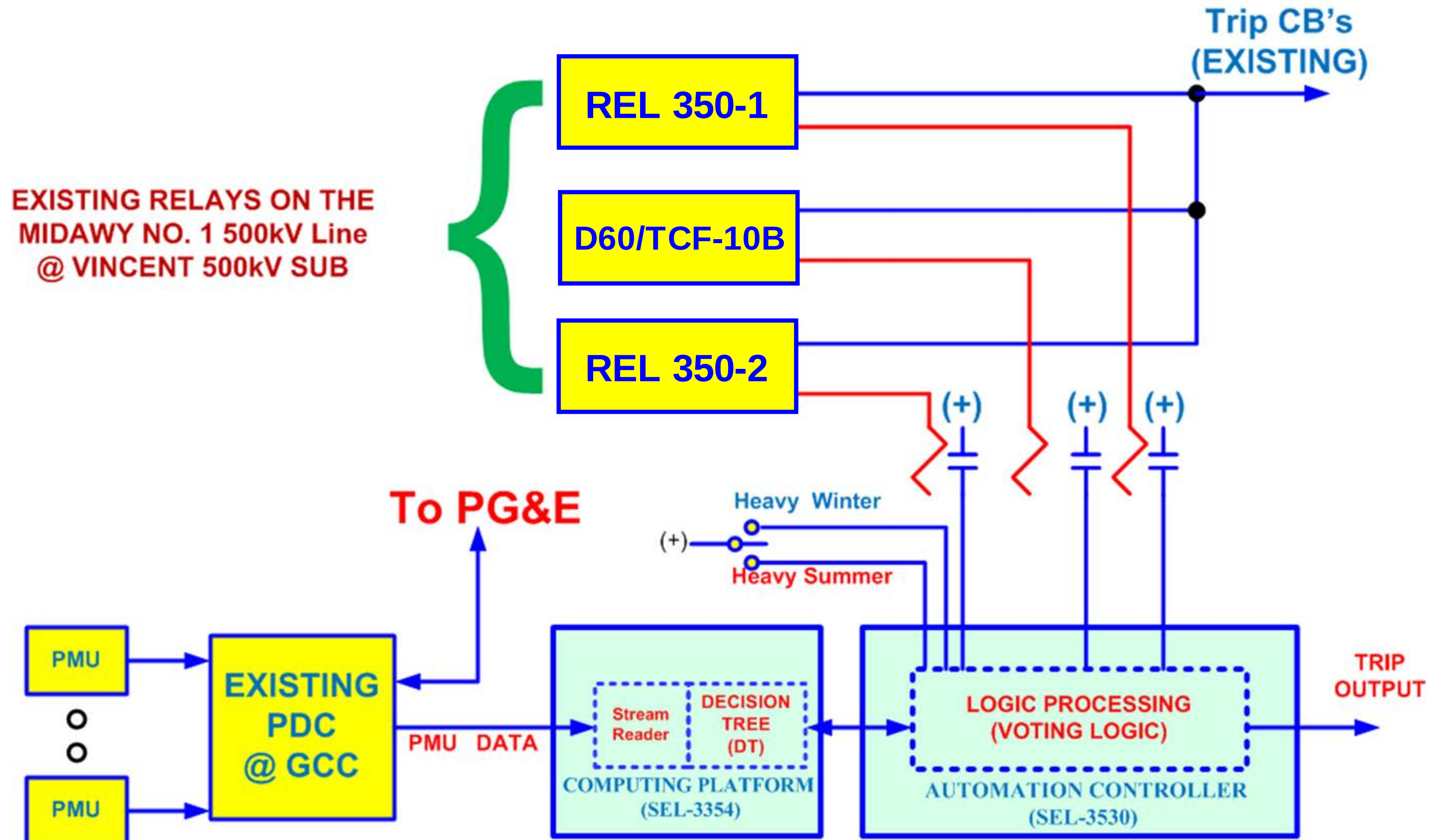



Computer
Visual Studio
P30 – Phasor Data Concentrator
openPDC
PMU1
Positive Seq. Current
90-5
UDP, 120FPS
PMU2
Positive Seq. Current
C37.118
TCP, 60FPS
PMU3
Positive Seq. Current
C37.118
TCP, 60FPS
Phasor Adapter
Time Align.
Data Parsing
30FPS
Phasor Database
30FPS
Adaptive Voting Library
C# Programming
30FPS
MS-SQL Arming Database
C 37.118-2 / IEC 61850-90-5
Archival
Serial Link, or TCP using C37.118-2 / IEC 61850-90-5

Adaptive Relay System Architecture in SCE Design



Application of Advanced Wide-Area Early Warning System with Adaptive Protection - SCE Design



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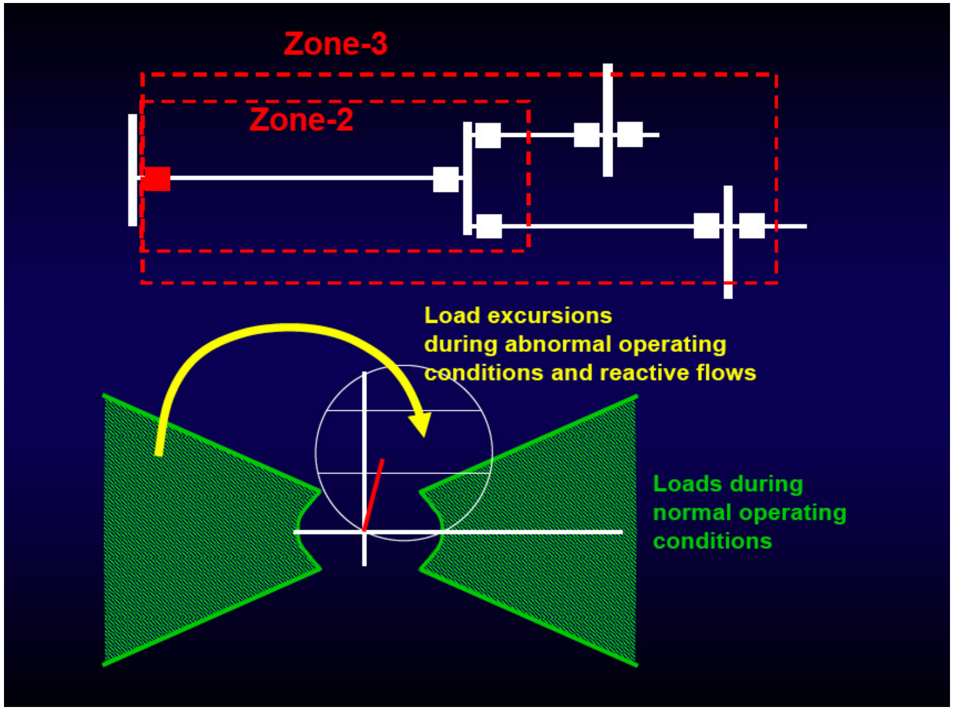
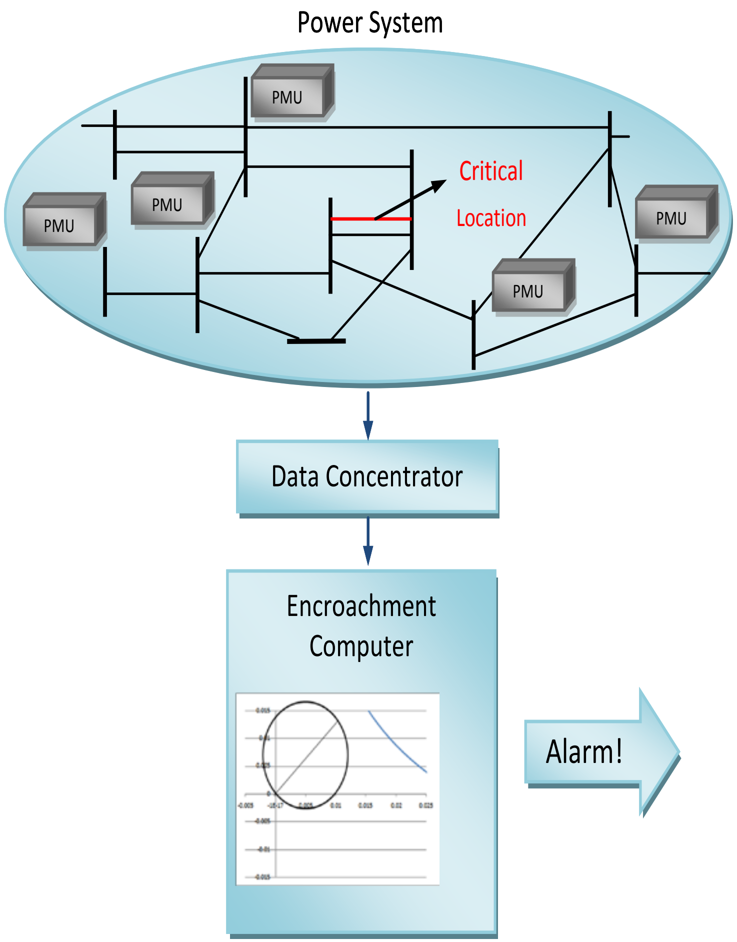
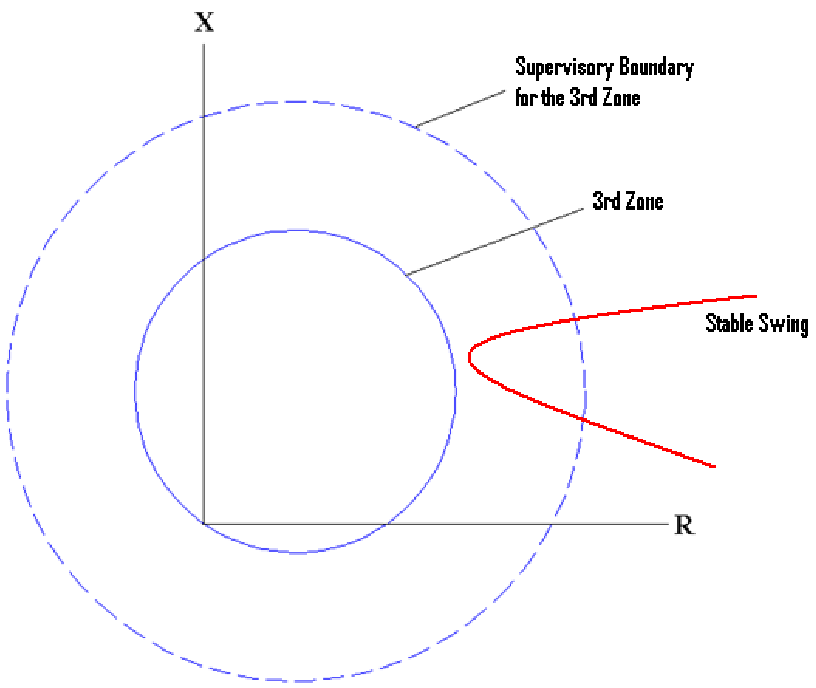
Alarms for Encroachment of Relay Trip Characteristics

- Looked at Following Relays:
  - Distance
  - Loss of Excitation
  - Out-of-Step
- Concentrated on Path 15 and Path 26
- Alarm system
  - Provides information and warning to engineers
  - Essentially a time-saving tool





The supervisory boundary is a concentric circle 50% larger than the largest zone of the relay.



Distance relays most susceptible to encroachment due to power swings or increasing power flow:

Line Name	Dist. From Z2/ Radius of Z2
Midway-Vincent ck 3 500kV	1.07
Midway-Vincent ck 2 500kV	1.12
Midway-Vincent ck 1 500kV	1.12
Los Banos-Midway ck2 500kV	3.59
Diablo-Midway ck 3 500kV	4.05
Diablo-Midway ck 2 500kV	4.36
Diablo-Gates 500kV	4.93
Vaca Dixon-Cottonwood 230kV	4.94

Phasor measurement units at:
Midway 500kV, Los Banos 500kV, Diablo 500kV, and Vaca-Dixon 230kV were initially proposed to monitor these lines.

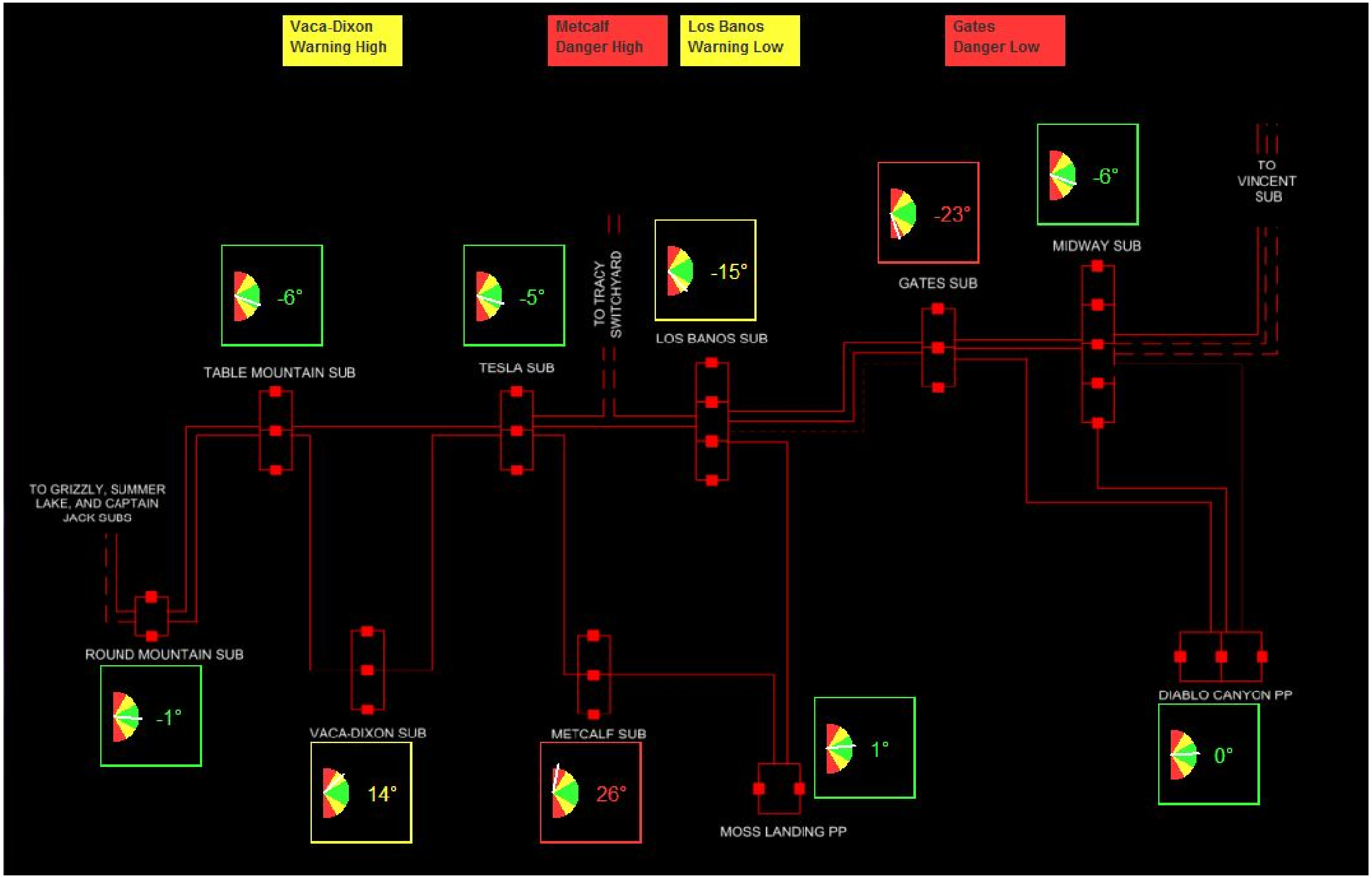
Real-Time Alarm for Relay Characteristic Encroachments – Wide-Area Measurements to Determine / Predict Trends for Relaying Parameters

- Define a help system for operators and/or system engineers
  - Alarms as system conditions approach relay characteristics
- Identify possible countermeasures
  - Warning System
    - Legacy Systems – Provide information and advance warning
    - Computer Relays – Supervisory Control Action - Alter Settings

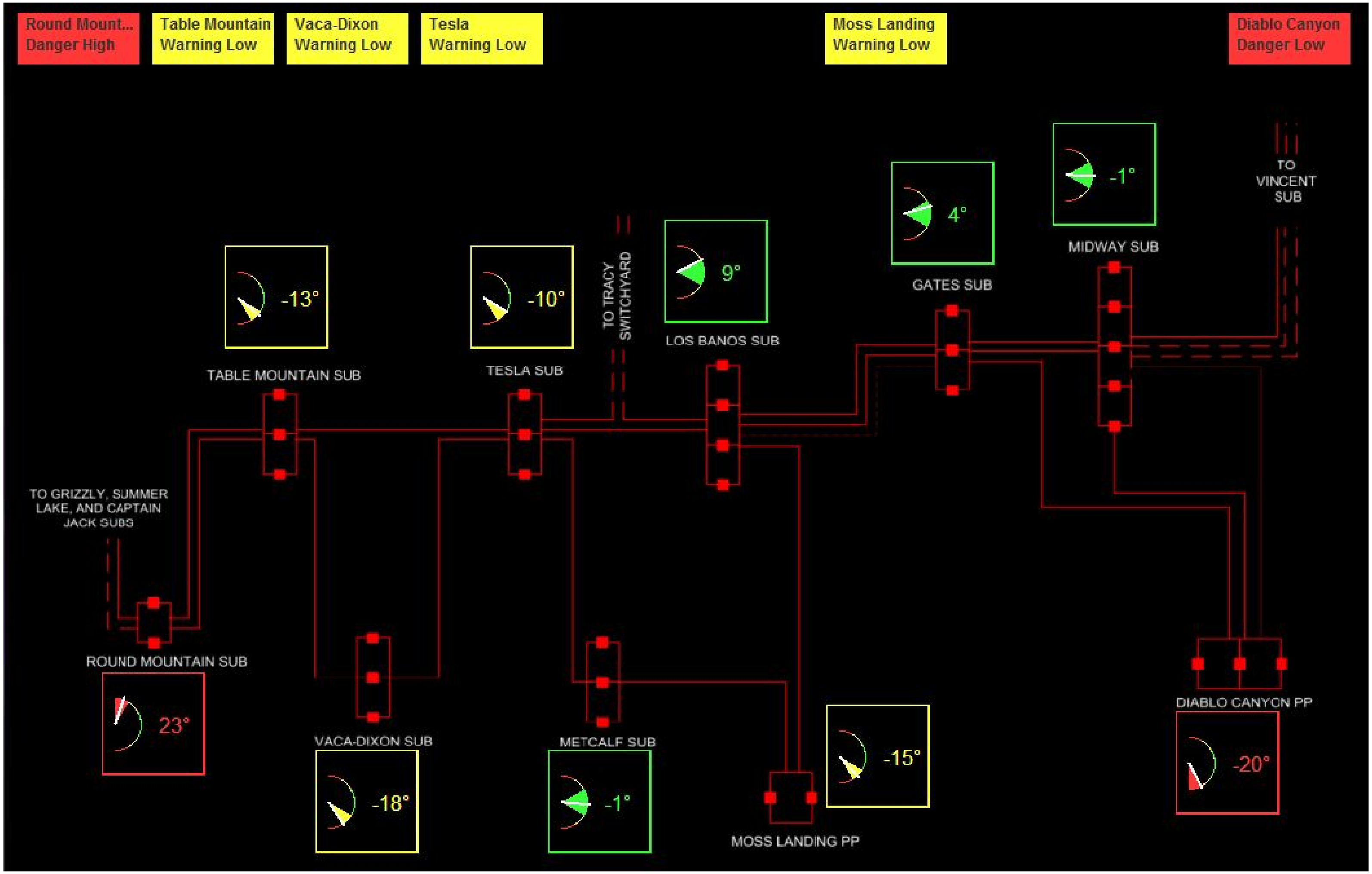
Visualization: Overview Screens

- Types:
  - Speedometer to represent phase angle
    - Full speedometer
    - Hollowed speedometer
  - Arrow to represent phase angle
  - Geographic cluster map
  - Circle Display
- Current Functionality:
  - Allows users to assess the state of the whole system quickly
  - Easy identification of trouble areas
  - Ability to view angles between non adjacent angles
- Functions to be Implemented:
  - Ability to choose which overlay is being displayed

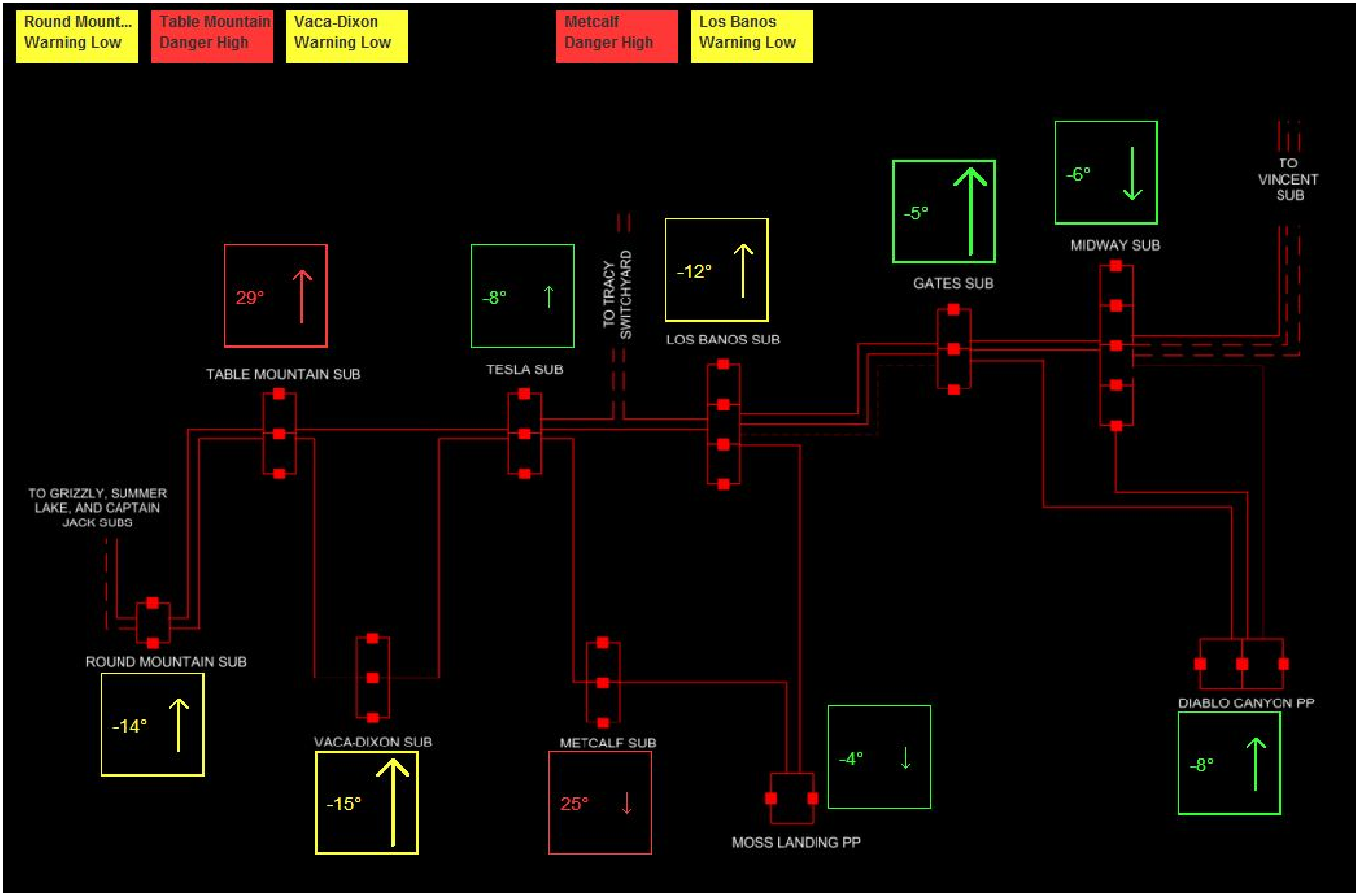
Full Speedometer



Hollowed Speedometer



Arrow



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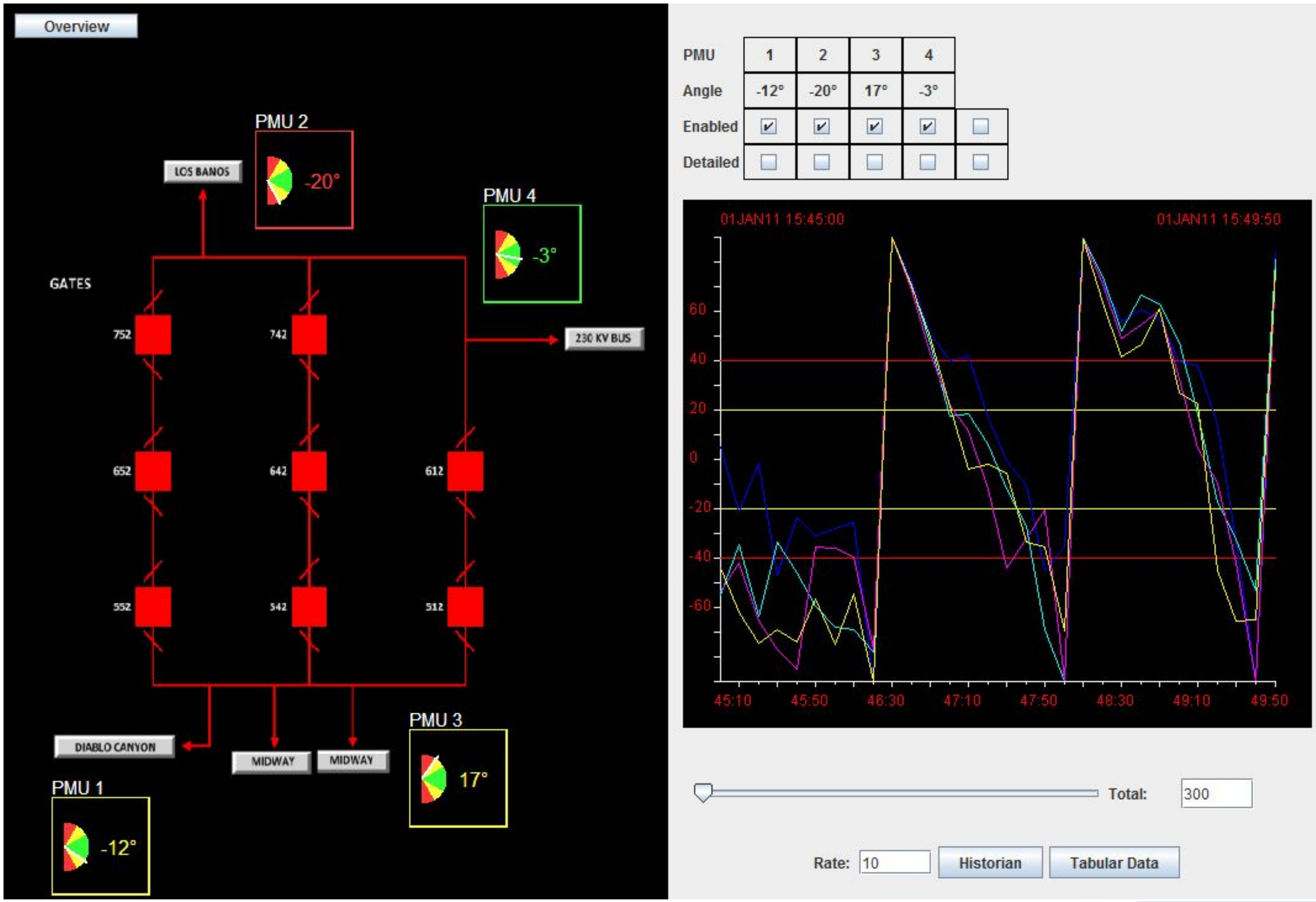
Substation View

- Substation View:
  - Based on single-line diagram
  - All overlays are linked to the same substation visualization
- Functionality:
  - Ability to select which PMU data should be displayed
  - Compare angular values for ends of the lines
  - Assess substation problems
  - Zoom in on data

Substation Views – Speedometers



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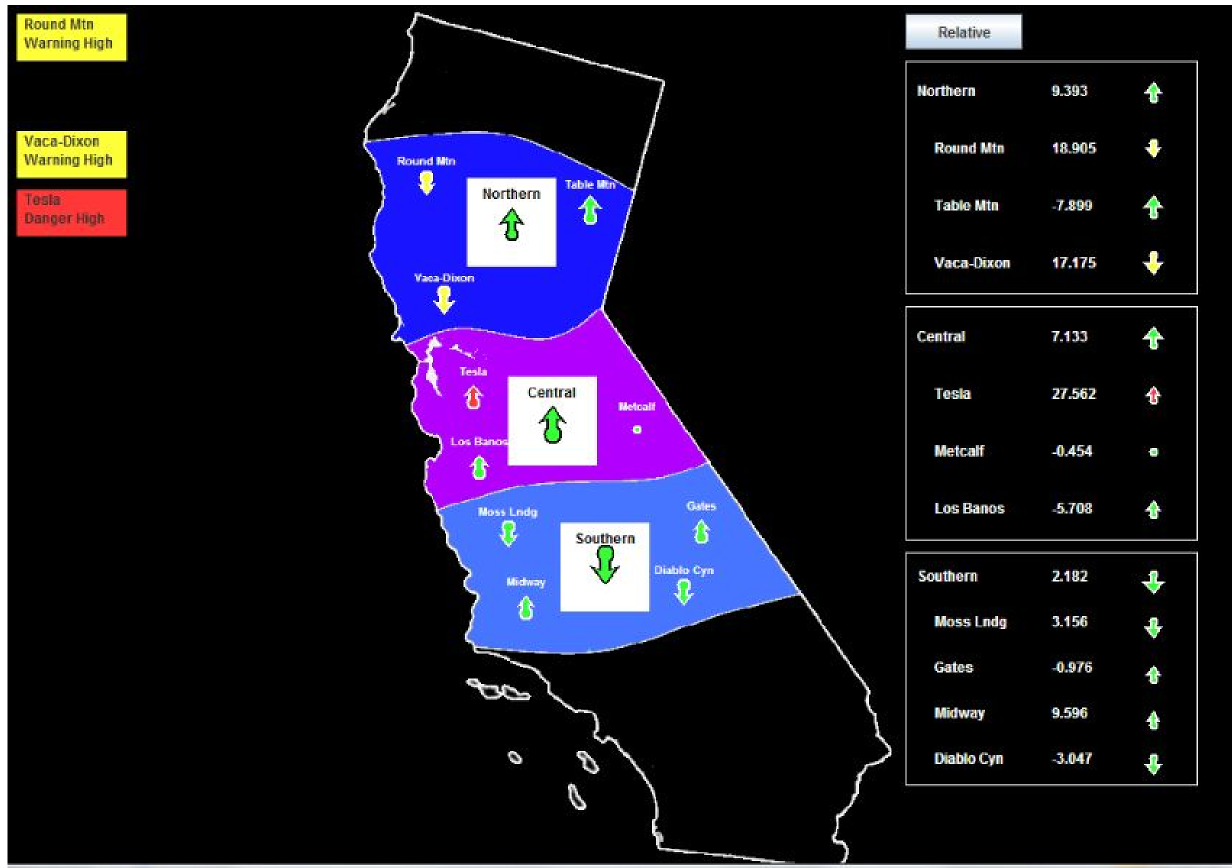
Cluster Overview

- Uses geographic map instead of single-line diagram
- Uses same substation views as single-line diagram visualizations
- Same functionality as the single-line overviews
  - Added functionality of being able to zoom in at the cluster level



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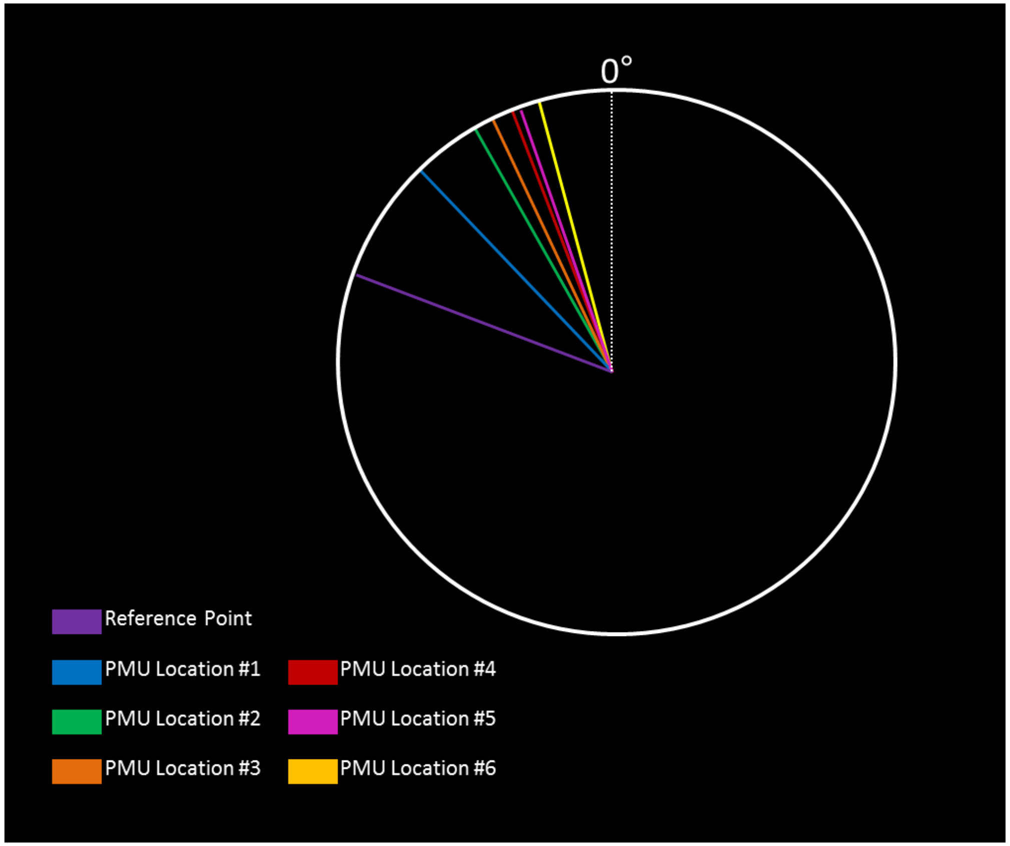
Circular Display

- Based on current display at SCE
- Shows a few selected PMUs
- Uses a single reference point
- Can change the number of PMUs displayed



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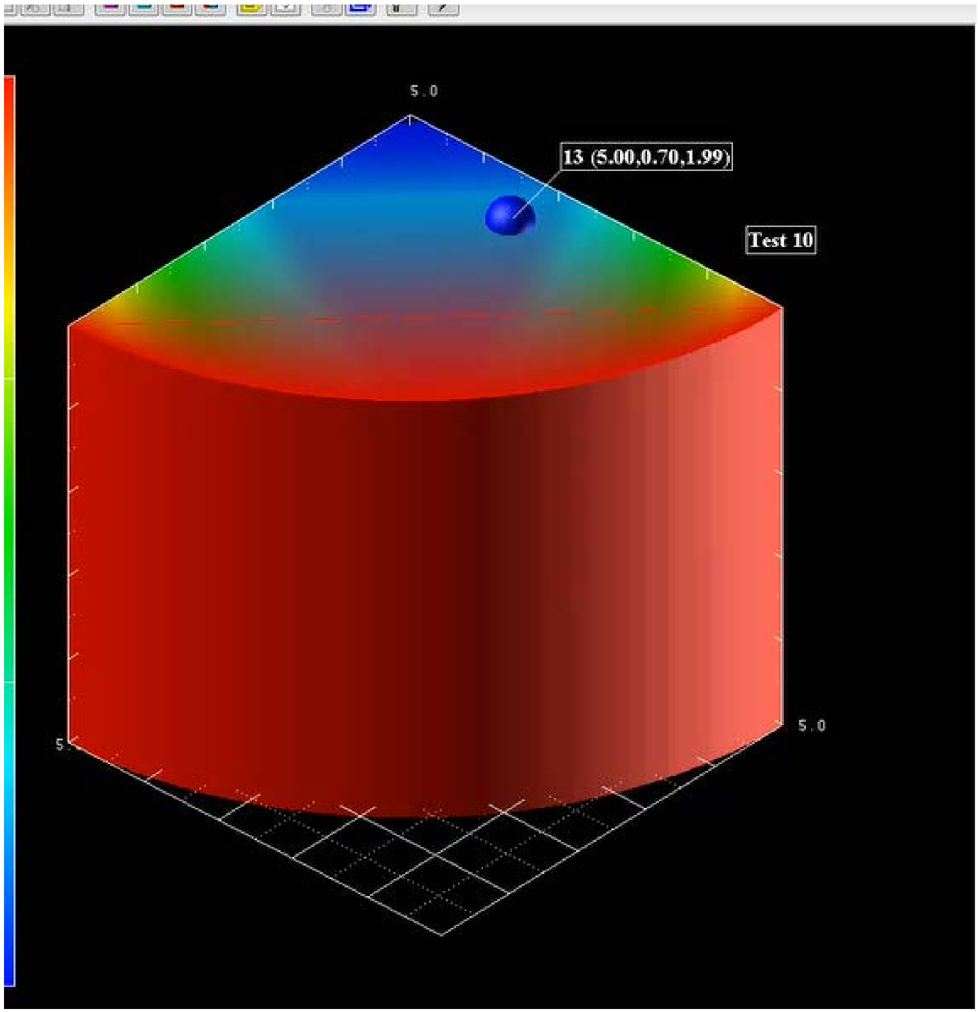
3D Nose Curve

- Changes of active power, reactive power and voltage can be seen on one single surface
- Shape and/or color can be changed in real time to indicate system status
- Can include a sphere that moves along the surface of the curves as time progresses as an indication of system state



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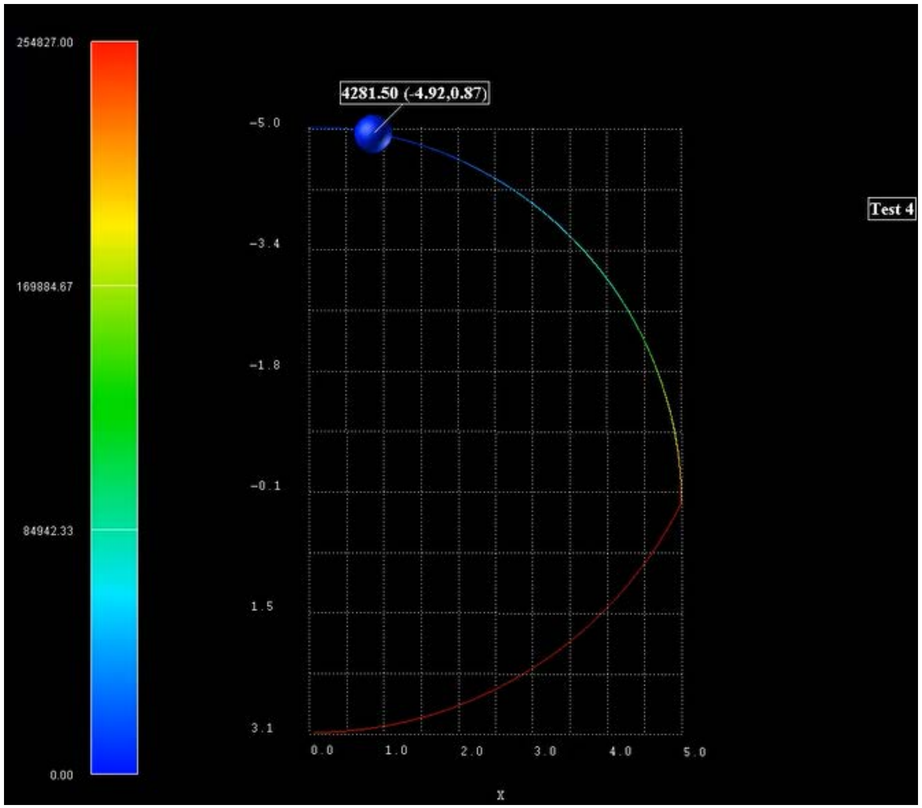
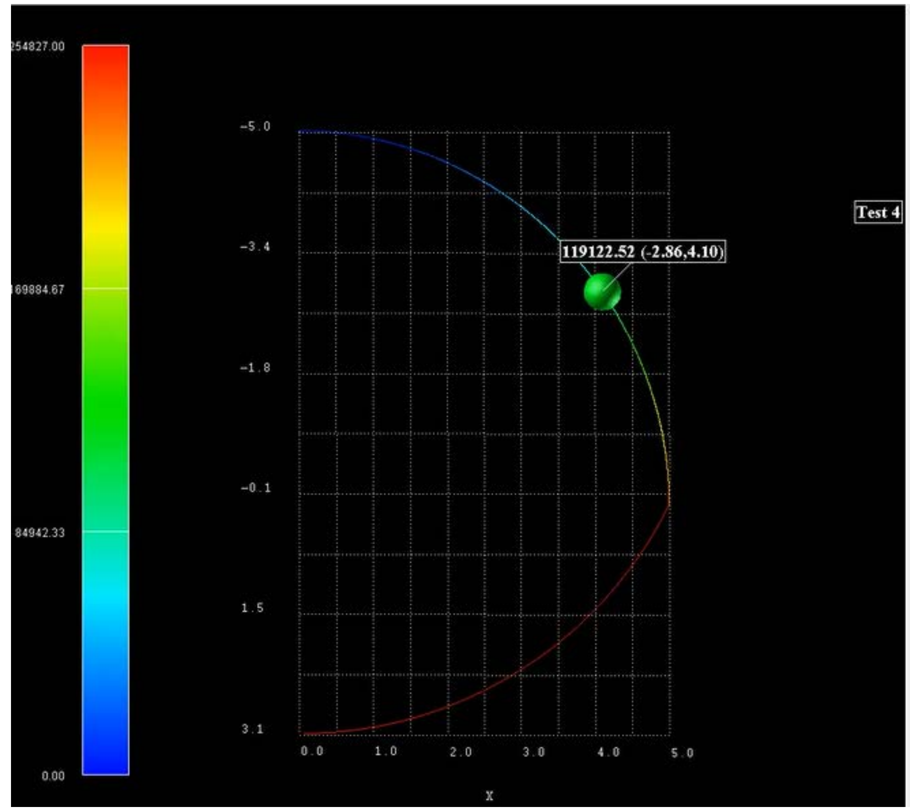
2D Nose Curve





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Project Status

- Adaptive Relaying Schemes:
  - Phase I (R&D): Development and adaptation of research algorithms to real-time utility environment. (Completed)
  - Phase II (Pilot Testing): Testing and validation (POC) of relaying schemes in University and in PG&E and SCE Protection System Laboratories. (Completed)
  - Phase III (Field Demonstration): In progress. Original project end date was September 2012, now December 2013 (pending DOE approval).
    - Field installations to be completed by ~ January 2013
    - Data collection to be completed by September 2013
    - Data evaluations, Final Report by December 2013
- Visualization Tool:
  - Phase I (R&D): OpenPDC and Sensor Web specifications; initial PIT visualizations developed (Completed)
  - Phase II (Pilot Testing): Interviews and workshops with utility engineers to refine visualizations (Completed)
  - Phase III (Field Demonstration): Second round of evaluations in users' offices (In progress).

Questions?

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Backup Slides

Decision Tree – Heavy Summer Reference PMU – Vaca Dixon (PG&E)

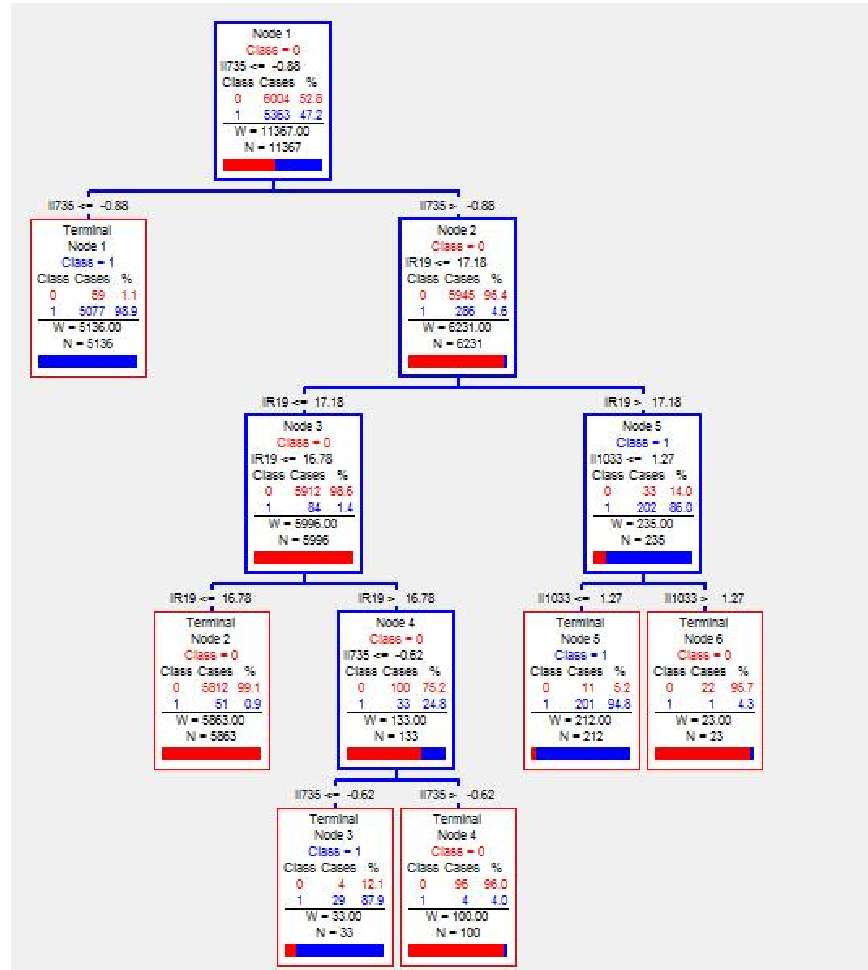
<u>PMU at DEVERS & Diablo</u>

PMU at - Ii735 (imaginary part of the current through transmission line between Devers – Valley SC) and IR19 (real part of the current through transmission line between Palo Verde – Devers) **DEVERS**

PMU at - Ii1033(imaginary part of the current through transmission line between Diablo - Midway) **DIABLO**

And

VACA DIXON



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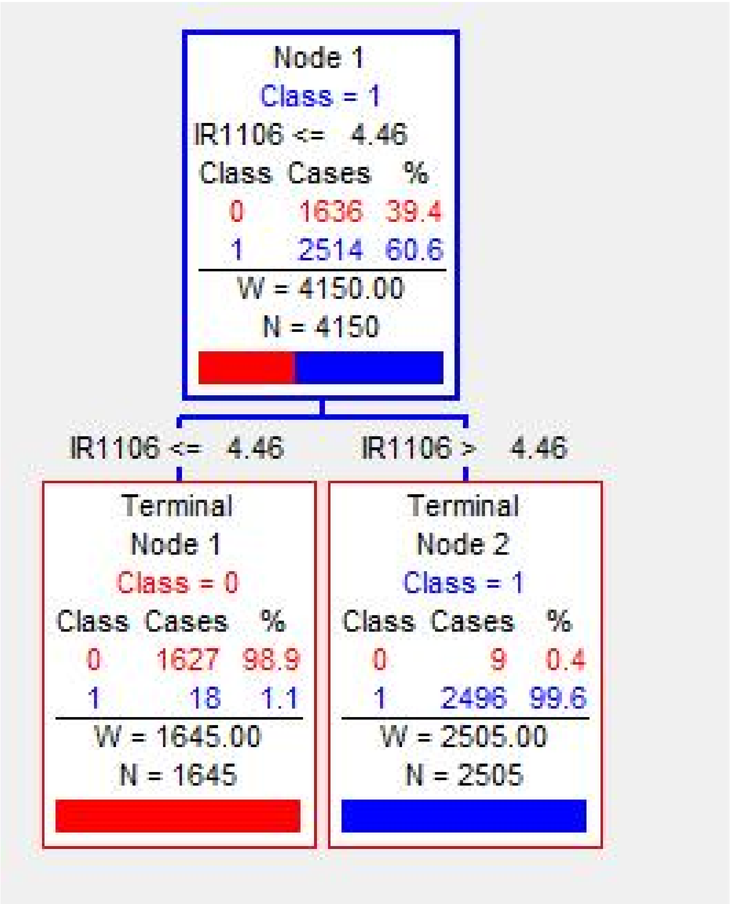
Decision Tree – Heavy Winter Reference PMU – Tesla (PG&E)

<u>PMU at TESLA</u>

PMU at – IR1106 (real part of the current through transmission line between TESLA – LOS BANOS) **TESLA**



<u>Total PMUs req. in this Project (Heavy Summer & Heavy Winter) at:</u>

VACADIXON
TESLA
DEVERS
DIABLO

PDC Phasor Processor

Stream Reader

- Reads C37.118 PDC stream
- Connection via TCP
- User selects phasor from stream for the decision tree

Decision Tree

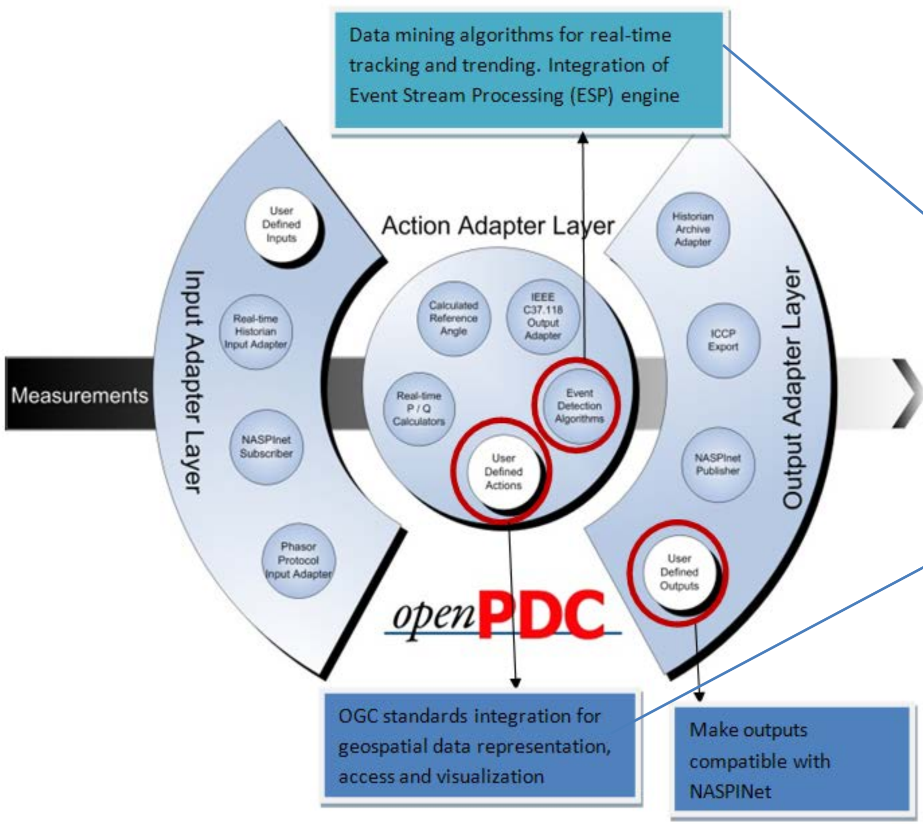
- Preprocesses data prior to tree assignment
- User selects tree type from controller

Modbus TCP

- Retrieves tree type from controller
- Sends vote value to controller from decision tree
- Tree type and vote status are both displayed in the GUI

VirginiaTech
Invent the Future

Architecture Extending OpenPDC



Highlighted components being implemented uses openPDC data streams:

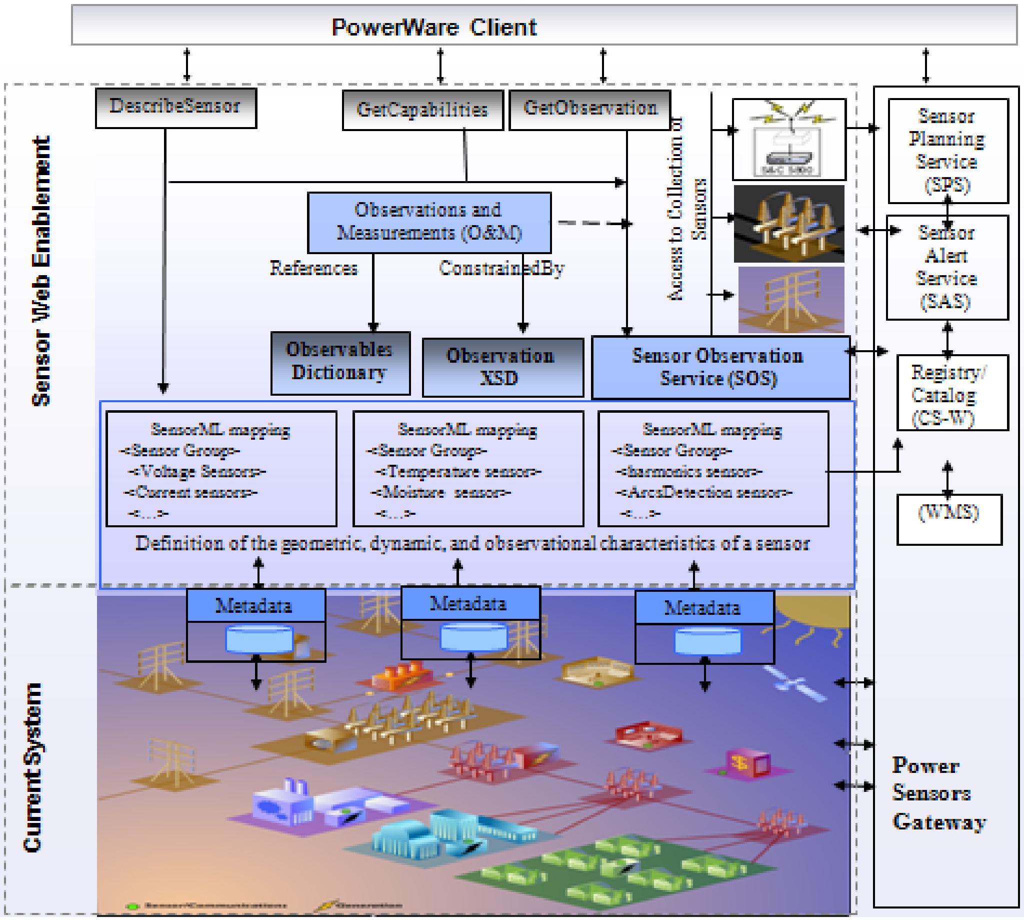
-Enables to incorporate standardized models.

-Loose coupling in a Services Oriented Architecture (SOA)-publish/subscribe mechanism.

-Cross-domain integration capabilities

-Development in JAVA for cross platform compatibility

Sensor Web Architecture



Architecture of the Power Sensor Web