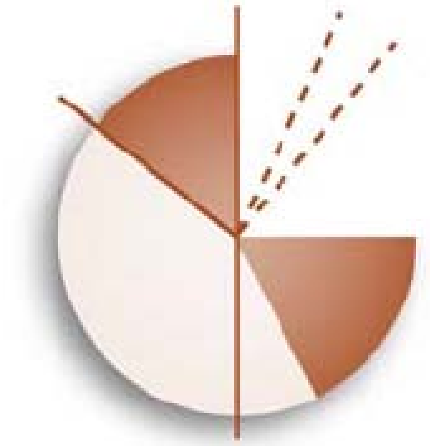
State Leadership In Clean Energy 2012



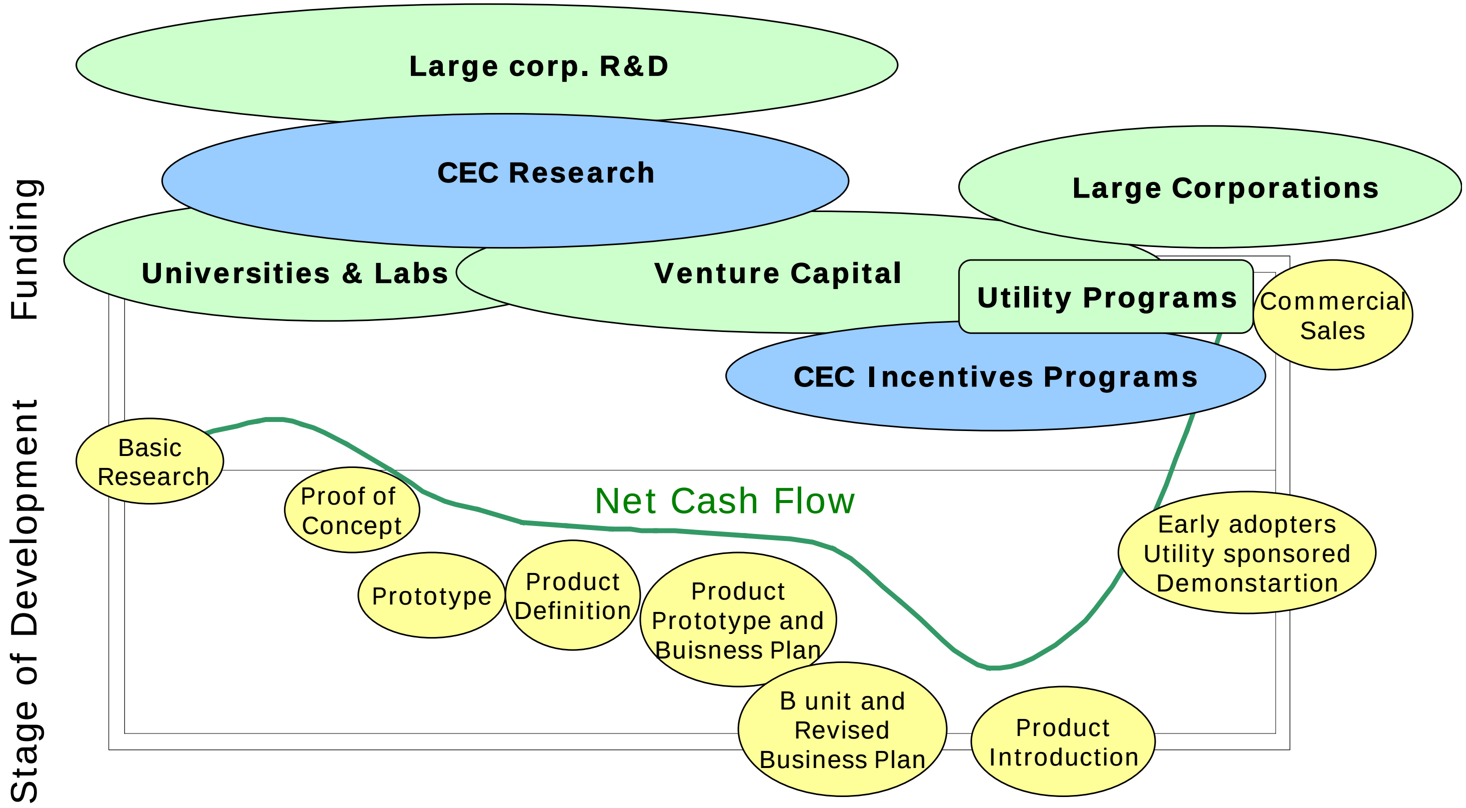
Consuelo Sichon
Jamie Patterson

11/27/2012

California Energy Commission Responsibilities

- Forecasting future energy needs and keeping historical energy data.
- Licensing thermal power plants 50 megawatts or larger.
- Promoting energy efficiency by setting the state's appliance and building efficiency standards and working with local government to enforce those standards.
- Supporting renewable energy by providing market support to existing, new, and emerging renewable technologies; providing incentives for small wind and fuel cell electricity systems; and providing incentives for solar electricity systems in new home construction.
- Implementing the state's Alternative and Renewable Fuel and Vehicle Technology Program.
- Planning for and directing state response to energy emergencies.
- Supporting public interest energy research that advances energy science and technology through research, development, and demonstration programs.

RD&D Projects Range from Early Research through Small-Scale Demonstrations



Smart Grid Research Ongoing at all Levels

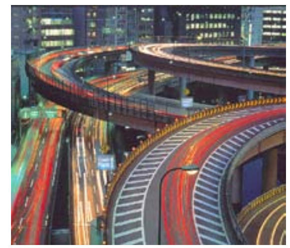
Transmission

- Phasor Measurement
- Advanced displays
- Advanced comm & controls
- MRTU interface
- Energy Storage
- Renewables

Distribution

- Distribution Automation
- AMI
- Advanced C&C
- MRTU
- Energy Storage
- Renewables

Integration

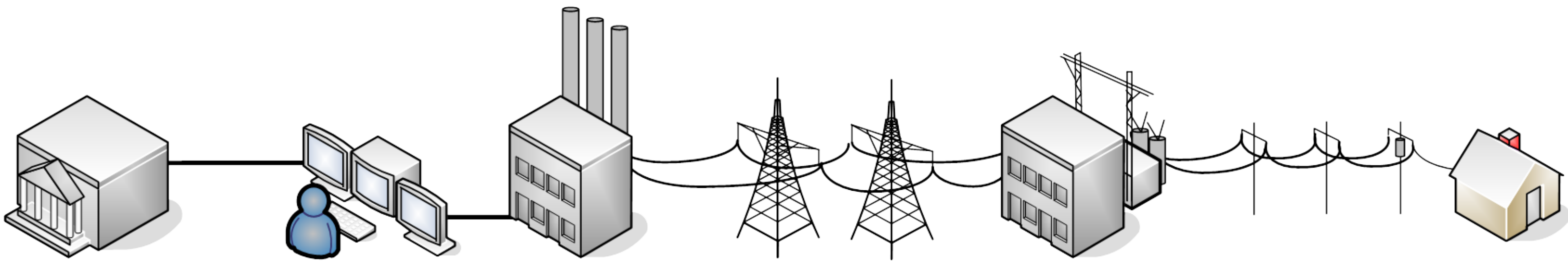


- Renewables
- Standards
- Protocols
- Reference designs
- Micro Grids
- Automation

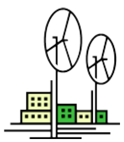
Consumer

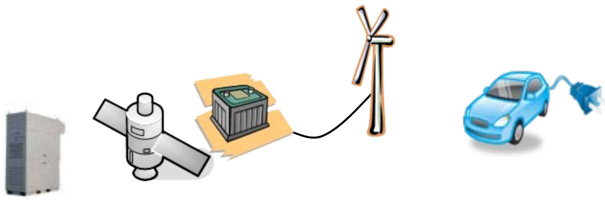
- Automating Demand Response
- AMI
- Dynamic Rates
- Home Area Networks
- Plug in Hybrids
- Renewables
- Energy Storage

Merging Two Infrastructures

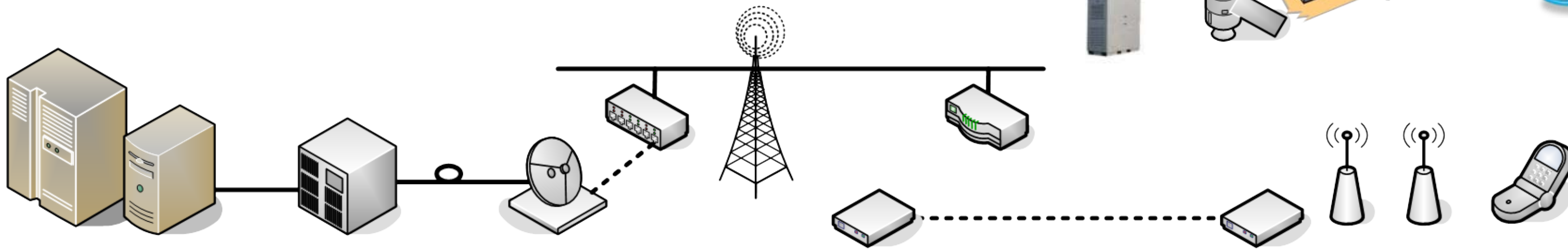


Electrical Infrastructure





"Intelligence" Infrastructure



Utility of the Future

Digital

Advanced communication

Self healing

Lots of sensors

Automated control

Smart Meters

SDG&E

A Sempra Energy utility

Good for the Environment

Enables renewable and clean energy

Enables Vehicle-to-Grid interface

Reduces spinning reserves

Supports customer choice

University of California, San Diego Microgrid

California Energy Commission
Energy Systems Research Office
Consuelo Sichon
November 27, 2012

Overview of UCSD Microgrid

With a daily population of over 45,000, UC San Diego is the size and complexity of a small city.

As a research and medical institution, UCSD has **TWO** times the energy density of commercial buildings.

12 million sq. ft. of buildings, $200M/yr of building growth

Self generate 92% of annual demand

- 30 MW natural gas Cogen plant
- 2.8 MW of Fuel Cells contracted
- 1.5 MW of Solar PV installed, with another 0.8 MW planned in 2012.

42 MW-peak Microgrid

Noted Progress Since 2007 from DER and EE Despite an Energy Demand Growth from $200M/yr Capital Construction

Year	SDG&E Rank	Direct Access kWh	SDG&E Bundled $
2007	11	96,109,193	$4,586,876
2011	13	83,010,466	$5,652,437
Delta	-2	-13.6%	+23.2%

The baseload 2.8 MW fuel cell utilizing renewable "directed biogas" began commercial operation in January 2012 and will probably contribute to at least an 8% reduction in annual direct access imports.

Project Team Members

- Power Analytics (formerly EDSA Corporation)
- Viridity Energy
- OSIsoft
- EnerNex
- CleanTECH San Diego
- San Diego State Foundation
- UC San Diego

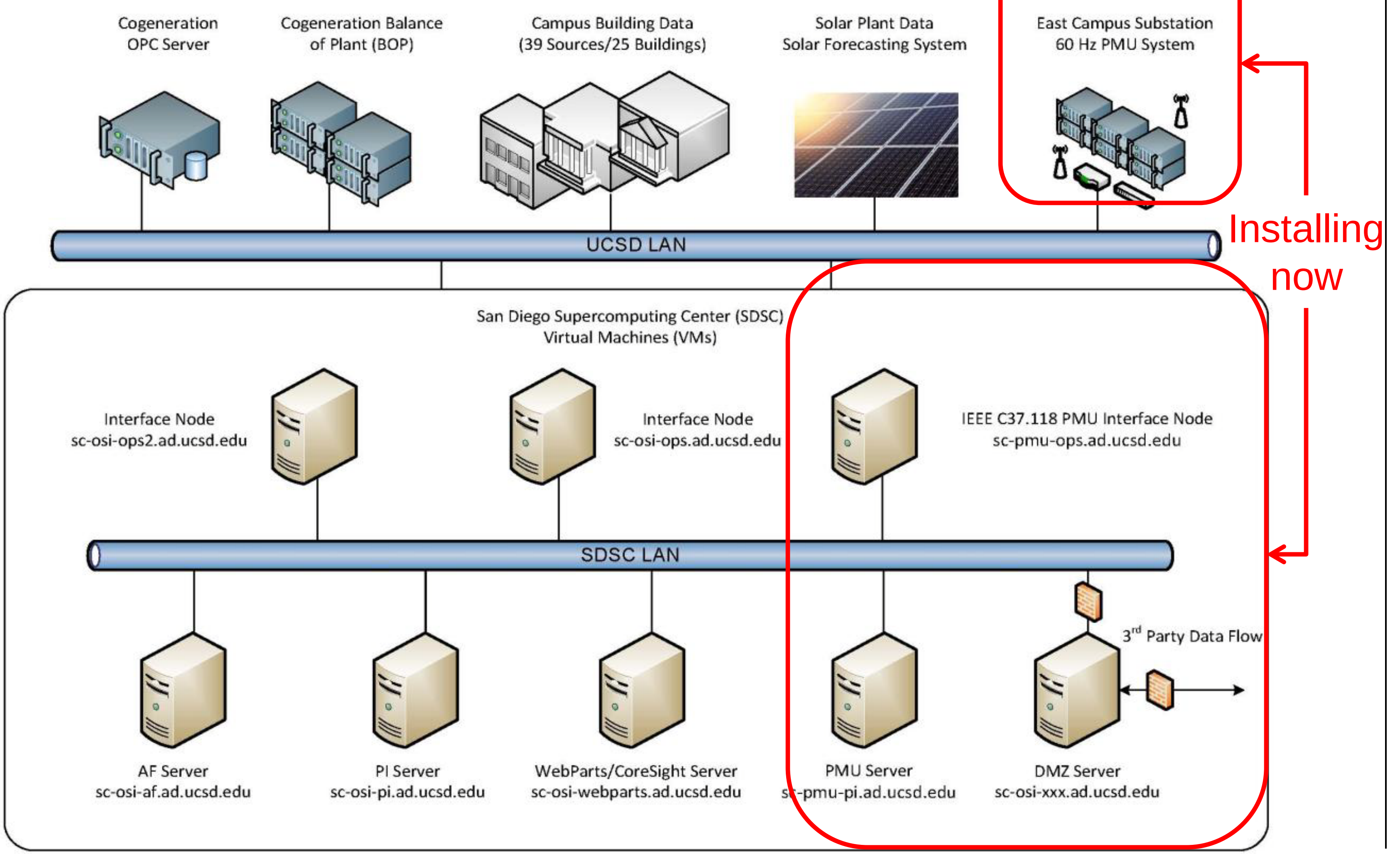
Project Goals

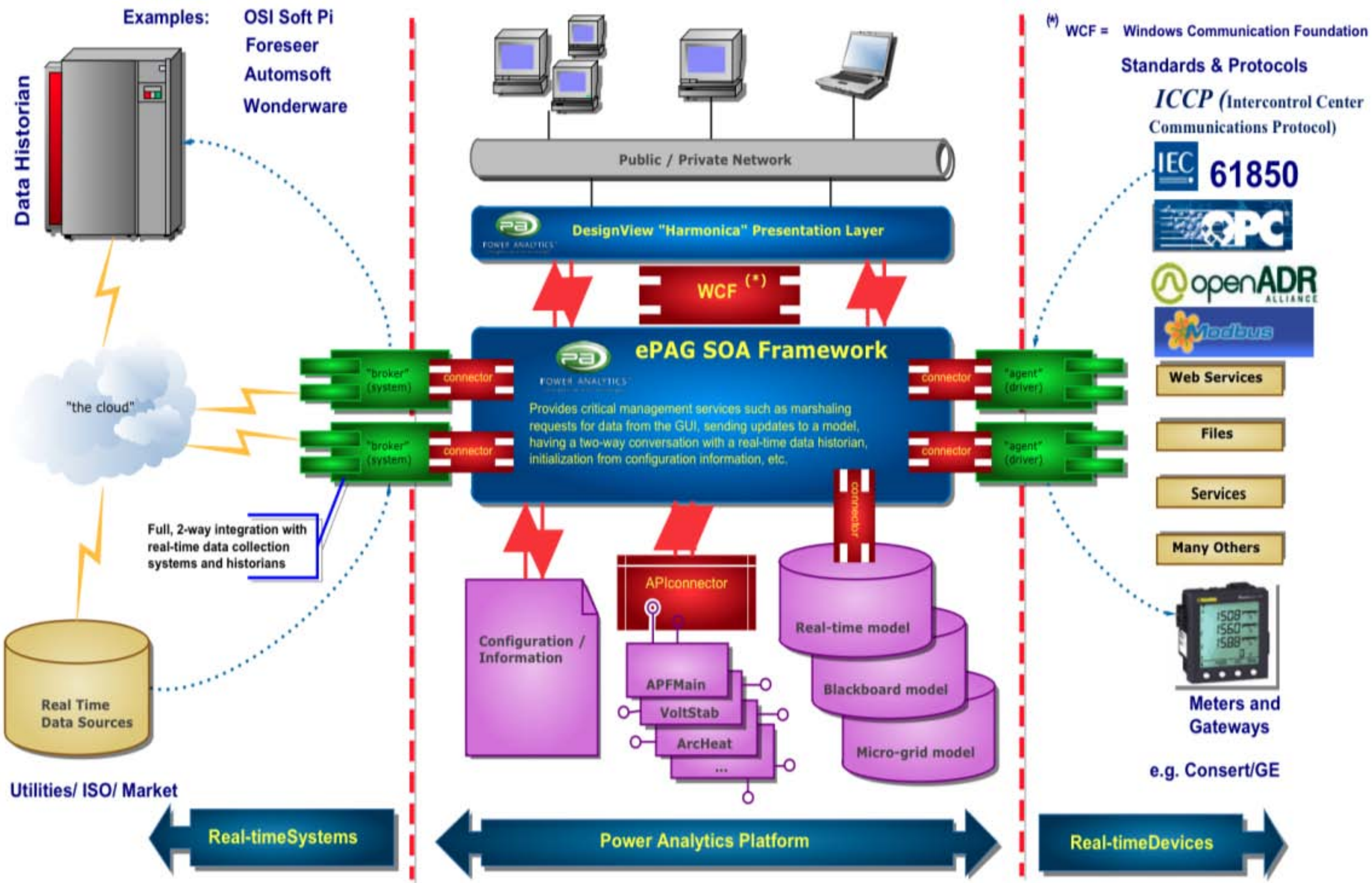
- Develop a fully-integrated master controller and optimizer that enable multiple and individual customers and renewable energy generators not only to reduce their electricity costs and carbon impact through increased awareness and better efficiency, but also to extract additional economic value by direct participation in the electricity markets.
- Enable the system to independently determine which sources of power to employ, and when, to ensure optimal performance, energy efficiency and overall reliability for the facility.
- Achieve multiple, prioritized smart grid objectives such as reliability, minimized environmental impact, optimum utilization of indigenous renewable energy resources, and optimized economics for a microgrid.

Project Objectives

- Develop and implement a replicable demonstration of semi-autonomous microgrid master controller and for real-time optimization and management of community scale smart grid infrastructures.
- Couple the master controller's real-time power analytics capabilities with optimization and scheduling software that will leverage UCSD's Advanced Metering Infrastructure, a communications and installed RE generation, and thermal & electricity energy storage assets.
- Develop "umbrella" solution that integrates several off-campus, unrelated RE and flex demand load sources with the entire UCSD community's power chain of optimization and management with a network intelligent, real-time environment.
- Lay the critical foundation for a commercialized master controller, optimizer/scheduler, and AMI product developed specifically for community-based smart grid planning.

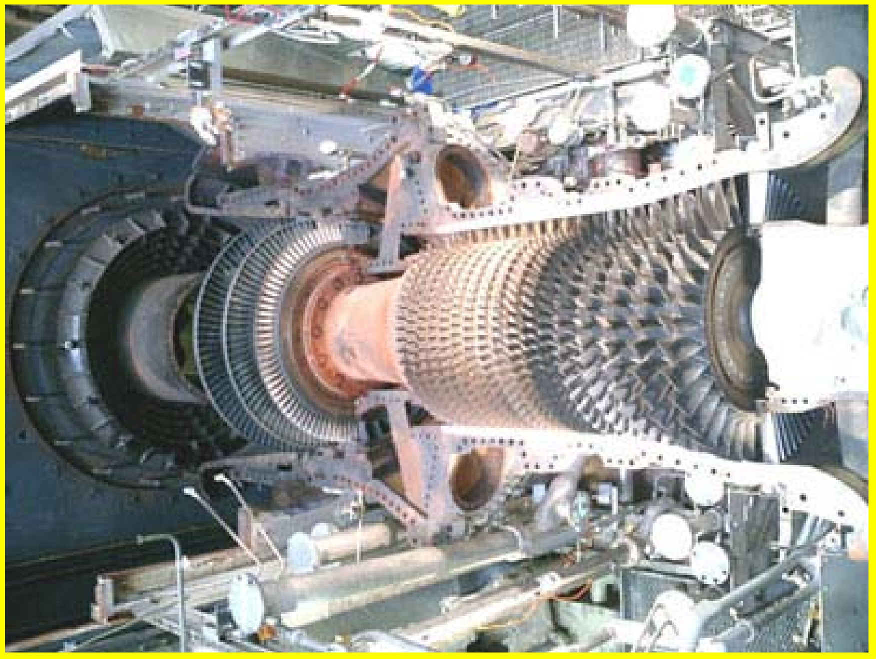
Project Overview - Architecture




Examples:
OSI Soft Pi
Foreseer
Automsoft
Wonderware
Data Historian
"the cloud"
Full, 2-way integration with real-time data collection systems and historians
Real Time Data Sources
Utilities/ ISO/ Market
Real-timeSystems
Public / Private Network
DesignView "Harmonica" Presentation Layer
WCF (*)
ePAG SOA Framework
"broker" (system)
connector
"agent" (driver)
Provides critical management services such as marshaling requests for data from the GUI, sending updates to a model, having a two-way conversation with a real-time data historian, initialization from configuration information, etc.
Configuration / Information
APIconnector
APFMain
VoltStab
ArcHeat
...
Real-time model
Blackboard model
Micro-grid model
Power Analytics Platform
(*) WCF = Windows Communication Foundation
Standards & Protocols
ICCP (Intercontrol Center Communications Protocol)
IEC 61850
OPC
openADR ALLIANCE
Modbus
Web Services
Files
Services
Many Others
Meters and Gateways
e.g. Consert/GE
Real-timeDevices

Central Utility Plant

- Provides 85% heating, cooling and electricity for most of the UCSD Campus
- Cogeneration system consists of two 13.5 Megawatt natural gas-fired turbine generators
- These two gas turbines provide 27 Megawatts of electricity for the campus buildings.
- 60,000Lb/Hr of Steam per unit, totaling 120,000 Lb/Hr produced as available waste heat, which provides heating and cooling energy for the Chiller Plant and the Heating Plant.
- Awarded 1 of 3 “Energy Star Awards” by EPA in 2010 for achieving 66% efficiency (LHV)




CAT

Campus Solar Power

- Currently have 1.5 MWs on campus
  - 1.2 MWs under PPA
  - 58 kW Demo sites
  - 63 kW Owned by campus
  - 190 kW Sustainable Comm. Program

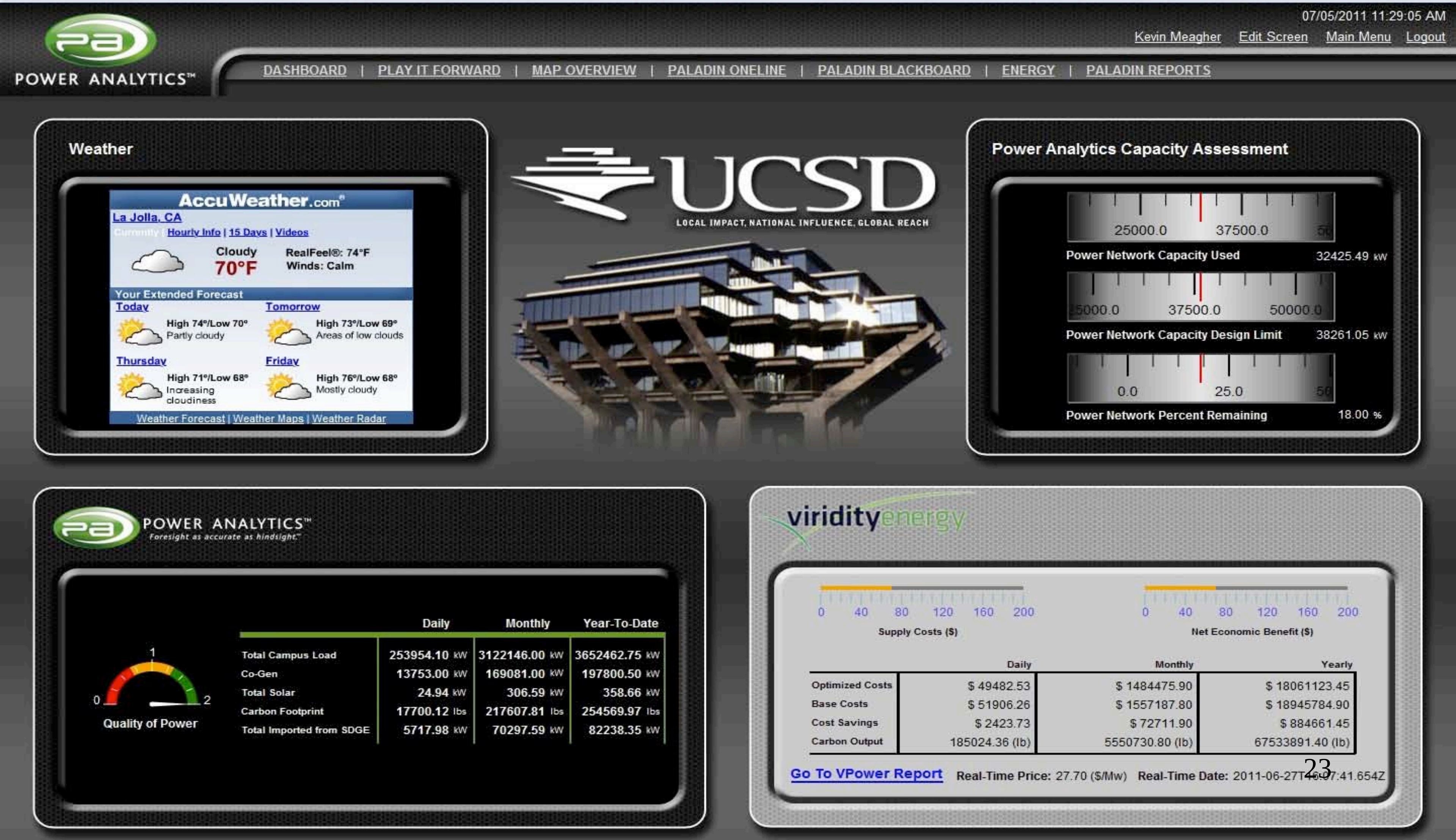
Potential for Another 0.8 MW of PV Integrated with Storage


© 2010 Google

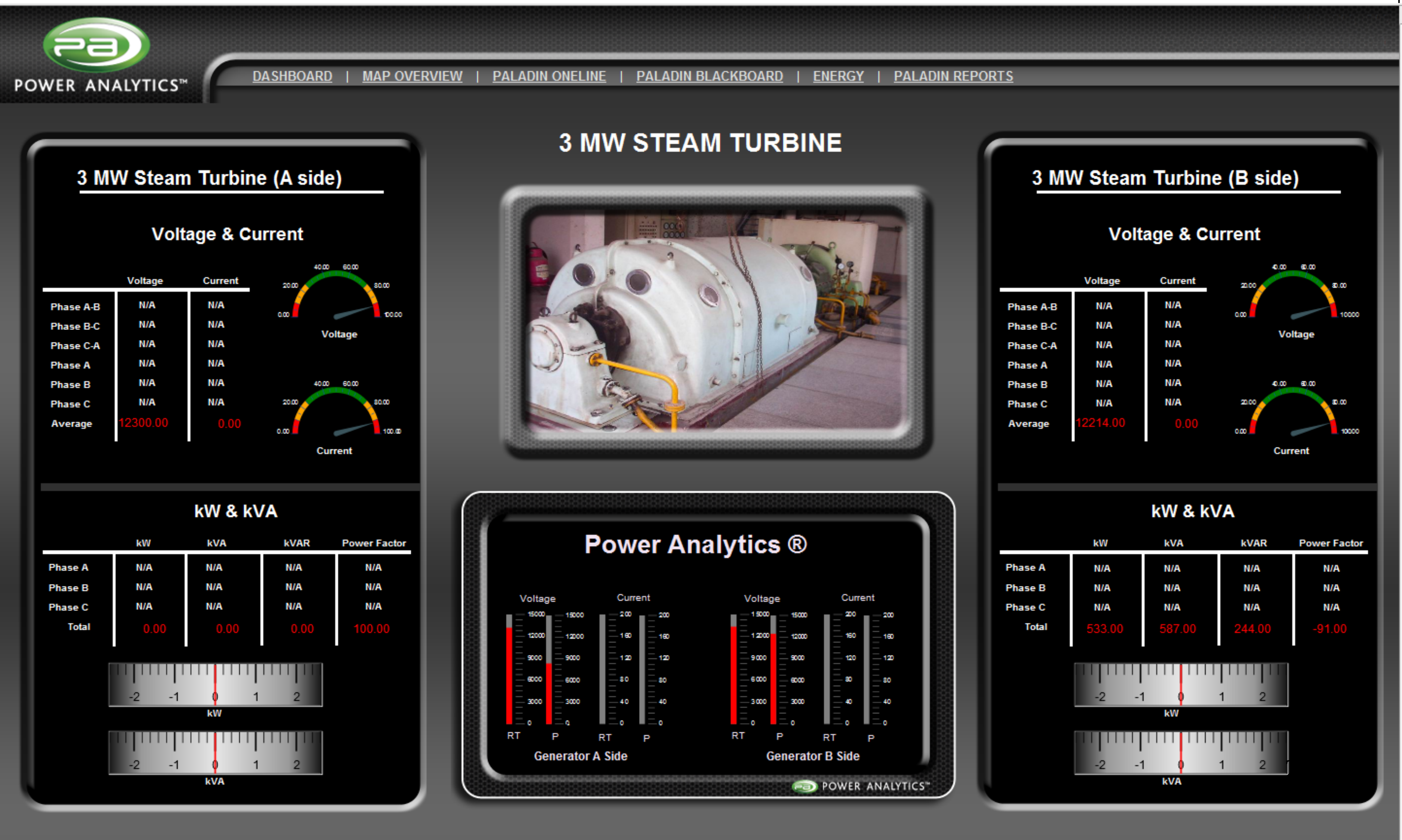
Smart Grid Master Controller and Optimizer/Scheduler (Power Analytics)

- Power Flow model for real-time master controller application
- Thin Client HMI Design
- Install and Boot Server
- Viridity Energy Inc. Controlled Power™ Integration.
- Interface Development and Testing

Real Time Control by Power Analytics of Rancho Bernardo, CA




POWER ANALYTICS™
DASHBOARD | MAP OVERVIEW | PALADIN ONELINE | PALADIN BLACKBOARD | ENERGY | PALADIN REPORTS
Paladin Energy Management ®
kW
kVAR
Cumulative Energy Daily
Cumulative Energy Weekly
Peak Power Daily
Cost Hourly
Cumulative Cost Daily
Cumulative Cost Weekly
Power Factor
PUE
Carbon Footprint
Blackboard Energy Management ®
kW
kVAR
Cumulative Energy Daily
Cumulative Energy Weekly
Peak Power Daily
Cost Hourly
Cumulative Cost Daily
Cumulative Cost Weekly
Power Factor
PUE
Carbon Footprint
Paladin NERC Analytics
Voltage Violations
Frequecy Violations
Power Interuptions
Day
Week
Month
paladin BLACKBOARD



POWER ANALYTICS™
DASHBOARD | MAP OVERVIEW | PALADIN ONELINE | PALADIN BLACKBOARD | ENERGY | PALADIN REPORTS
3 MW STEAM TURBINE
3 MW Steam Turbine (A side)
Voltage & Current
Voltage Current
Phase A-B N/A N/A
Phase B-C N/A N/A
Phase C-A N/A N/A
Phase A N/A N/A
Phase B N/A N/A
Phase C N/A N/A
Average 12300.00 0.00
Voltage
Current
kW & kVA
kW kVA kVAR Power Factor
Phase A N/A N/A N/A N/A
Phase B N/A N/A N/A N/A
Phase C N/A N/A N/A N/A
Total 0.00 0.00 0.00 100.00
kW
kVA
Power Analytics ®
Voltage Current Voltage Current
RT P RT P RT P RT P
Generator A Side
Generator B Side
POWER ANALYTICS™
3 MW Steam Turbine (B side)
Voltage & Current
Voltage Current
Phase A-B N/A N/A
Phase B-C N/A N/A
Phase C-A N/A N/A
Phase A N/A N/A
Phase B N/A N/A
Phase C N/A N/A
Average 12214.00 0.00
Voltage
Current
kW & kVA
kW kVA kVAR Power Factor
Phase A N/A N/A N/A N/A
Phase B N/A N/A N/A N/A
Phase C N/A N/A N/A N/A
Total 533.00 587.00 244.00 -91.00
kW
kVA

Simulation & Optimizer (Viridity)

- UCSD campus load, generation and storage resources modeled and optimized using VPower™:

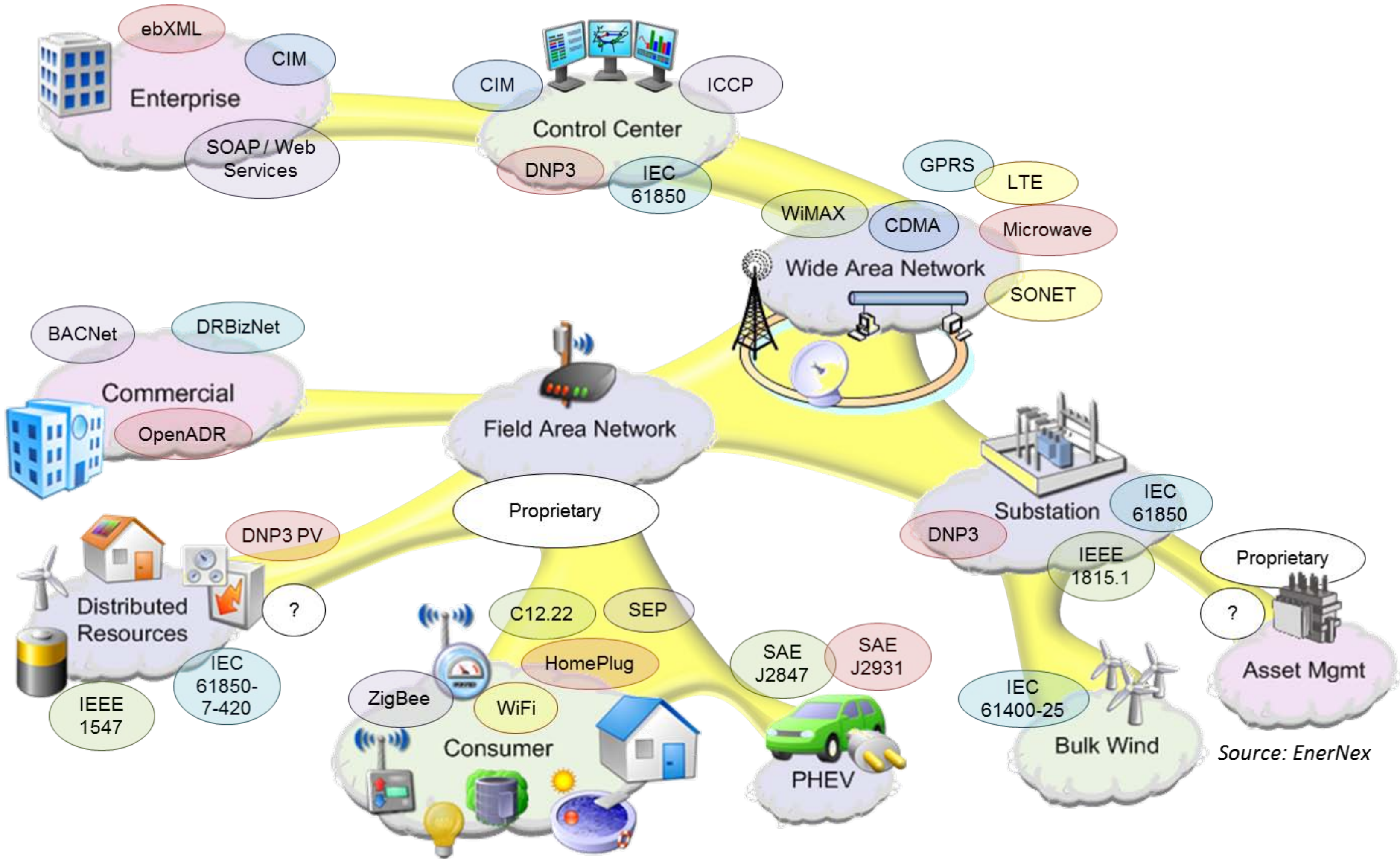
Campus Supply Contract	2.8MW Fuel Cell
Campus Electric Demand	7 - PhotoVoltaic sites (1.2 MW)
Hot and Cold Water Requirements	Backup Diesel Generators
Chillers	1 - Thermal Storage Unit (stratified water tank)
2- 13.5MW Gas Turbines	EV Charging Stations Batteries
1 - 3MW Steam Turbine	PV Storage Batteries

- Master Controller at UCSD – VPower™ and Power Analytics' Paladin System Interface
  - Exchange Optimized Resource Schedules, Resource Status and Constraints
  - Dashboard summary view
- External data links - CA ISO price signal, Weather (cloud cover, temperature, solar irradiance, humidity, wind information)
- Carbon Calculator – VPower™ calculates emission output on a resource by resource level
- Economically optimized resource schedules can be produced for user defined time period (24-hour)

Interoperability (EnerNex)

- Conduct a requirements analysis of the overall system
- Evaluate and Map Interoperability Requirements
- Evaluate and adopt an information and transaction model framework.
- Map the information and transaction models
- Develop a field testing and acceptance methodology
- Validate concepts and preliminary decisions at each step

Recommended Communications Standards

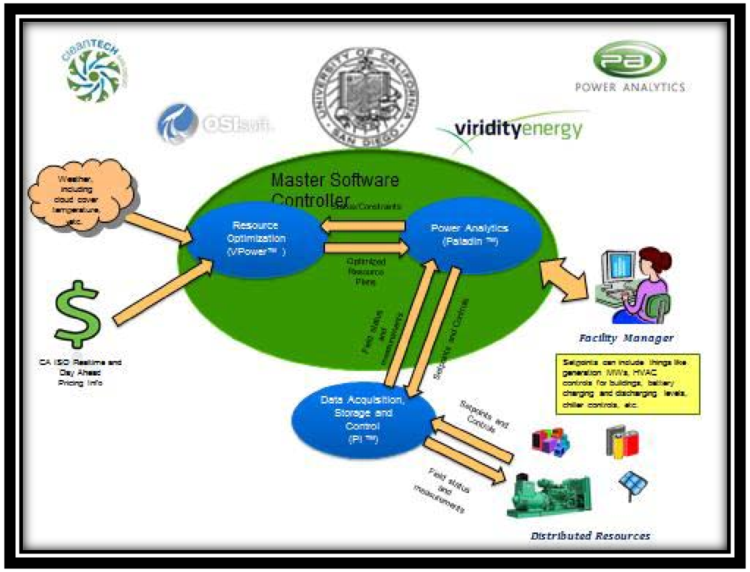


Interface Standards

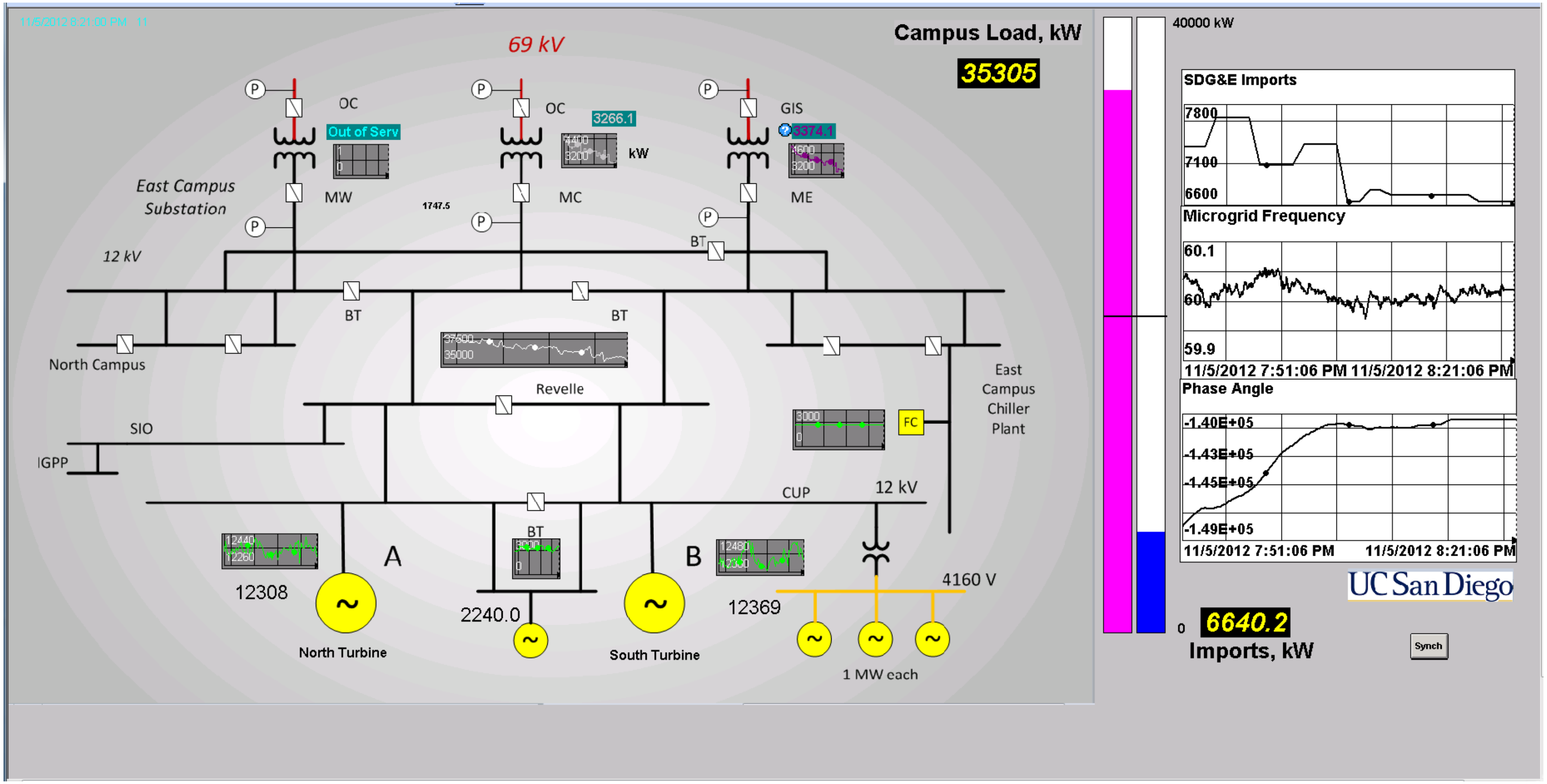
System/Device	Standard	Status
Plug-in Electric Vehicles	SAE J1772	Adopted
	SAE J2836/1	Adopted
	SAE J2846/1	Adopted
Meters	ANSI C12.19, IEC 61850-7-420	Adopted
RTUs	IEEE 1815-DNP 3.0, IEC 61850-7-420, IEC 61850-90-7	Pending Adopted
Field Devices	IEC 61850	Adopted
Electric Storage Interconnection Guidelines	IEEE 1547.4, 1547.7, 1547.8	Under Development
PV Controllers	IEEE 1547-8	Under Development
IETF	Smart Grid Informational IETF RFCs	Adopted
Common Information Model for Distribution Grid Management	IEC 61968 CIM, IEC 61850-7-420, MultiSpeak V4	Adopted
Common Price Communication Model	Oasis EMIX, ZigBee Smart Energy Profile 2.0, NAESB Requirements	Pending
Common Scheduling Mechanism	OASIS-WS	Pending
Standard DR and DER Signals	NAESB WEQ015, OASIS EMIX, OpenADR, Open AMI-ENT, ZigBee SEP 2.0	Under Development
Standard Energy Usage Information	NAESB Energy Usage Information, OpenADE, ZigBee SEP 2.0, IEC 61968-9, ASHRAE SPC 201p	Under Development
Building Automation	ASHRAE BACNET, SPC201p	Pending, Under Development

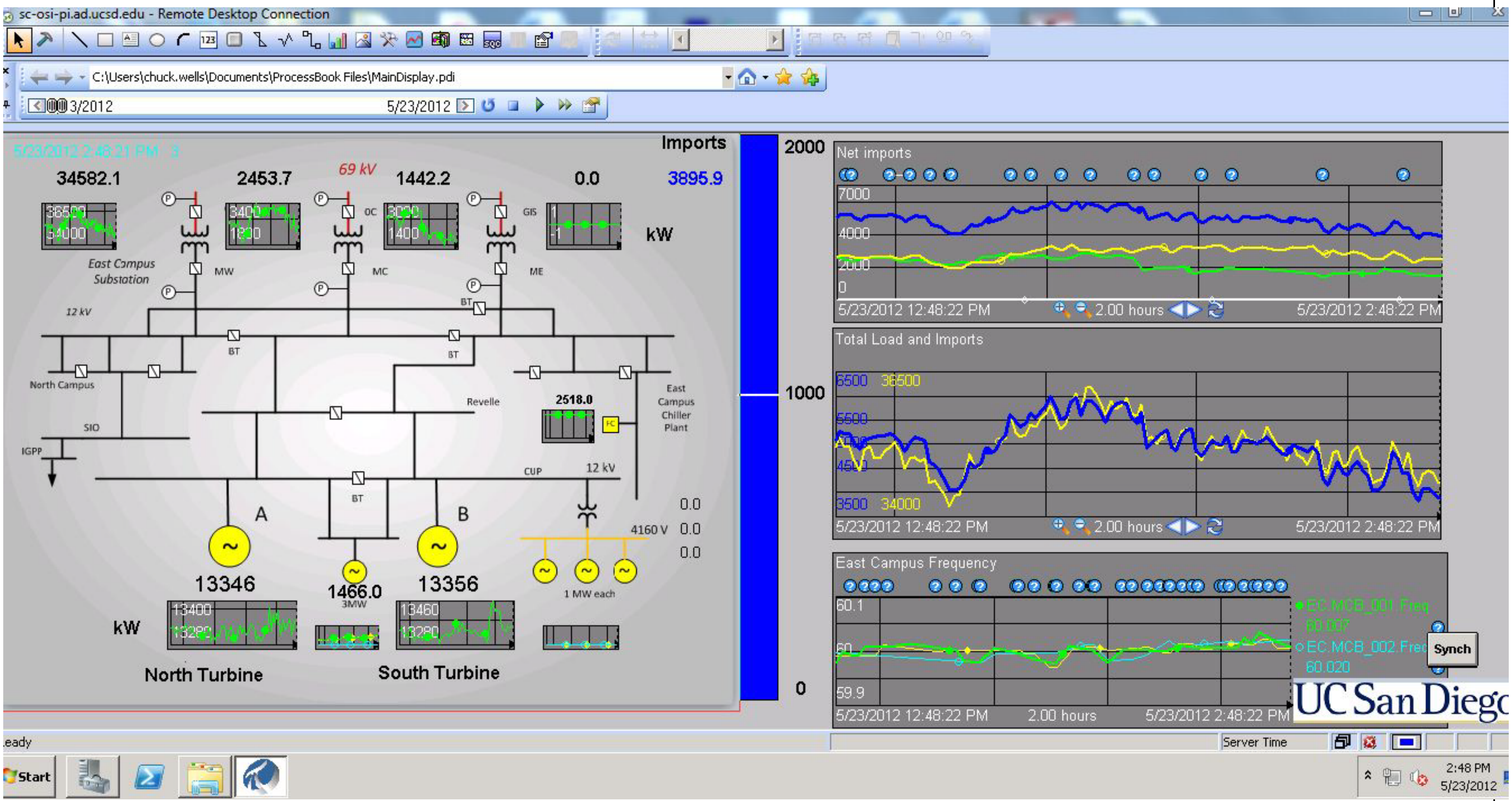
Data Collection, Data Processing, and User Interface (OSIsoft)

- Integration
  - >84,000 data streams across campus
  - Microgrid Controller Integration (Power Analytics' Paladin)
- Demonstration/Scaling
  - Site visits
  - Industry Events
  - Exposing data for Open Innovation



Microgrid Single Line Diagram




sc-osi-pi.ad.ucsd.edu - Remote Desktop Connection
C:\Users\chuck.wells\Documents\ProcessBook Files\MainDisplay.pdi
Imports
34582.1
2453.7
69 kV
1442.2
0.0
3895.9
kW
East Campus Substation
12 kV
MW
MC
ME
BT
North Campus
SIO
IGPP
Revelle
2518.0
East Campus Chiller Plant
CUP
12 kV
4160 V
A
B
13346
1466.0
3MW
13356
1 MW each
kW
North Turbine
South Turbine
2000
1000
0
Net imports
5/23/2012 12:48:22 PM
2.00 hours
5/23/2012 2:48:22 PM
Total Load and Imports
East Campus Frequency
EC.MCB_001.Freq
60.007
EC.MCB_002.Freq
60.020
Synch
UC San Diego
Server Time
Start
2:48 PM
5/23/2012

Publicly Accessible, Real-Time Energy Data on Campus

You Can’t Manage What You Don’t Measure

http://energy.ucsd.edu/campus/graphset.php?setID=1&mode=pastday

Elements for Success

- Support from Chancellor's Office
- Cooperation from Operations
- Relationship with local utility (SDG&E)
- "Living Laboratory"
- Continuing to build on previous successes

East Campus Energy Park

- Integration of East Campus Energy Park
  - 2.8 MW fuel cell. PPA being assigned to BioFuels Energy LLC
  - 113 kW of non-concentrating PV installed Dec. 2008
  - Pt. Loma secondary treatment waiver and methane transportation issues. Site being reconfigured to eliminate trucking.
  - 7 kW, 2-axis CPV array installed Jul 2009, 22 kW Nov. 2012
  - CNG refueling station installed for shuttle & fleet ops
  - 2.8 MW / 12 MWh Advanced Energy Storage reservation for $3.8M

2.8 MW Fuel Cell Demonstration

- Molten Carbonate fuel cell technology from FuelCell Energy of Danbury CT
- CA's first and only "directed biogas" project
- Largest commercially available design
- Commenced commercial operations in Dec 2011
- Installed and operated under a PPA with BioFuels Energy LLC at a cost that is parity with the grid
- 10% of the campus' baseload energy supply has a footprint the size of a tennis court


AIR LIQUIDE


07/21/2011 20:49

Soitec Concentrating PV

- Sparsely-known German Concentrix installs at UCSD its 5.5 kW CPV module (July 2009)
- French Soitec acquires Soitec and begins design of 22 kW Concentrating PV module
- SDG&E enter into a PPAs for 305 MW that are approved by CPUC in (Nov 2010)
- Soitec dedicates San Diego factory for 400 direct and 1000 indirect jobs, (Dec 2011)
- DOE awards Soitec $25M Manufacturing grant for what is now the world's largest CPV company


Soitec

Additional Distributed Energy Resources Enabled on the Microgrid (follow-on projects)

Panasonic/Sanyo 30 kW/30 kWh PV Integrated Storage

- 100% cost shared
- First fully PV-integrated Storage system
- Operational since July 2011
- Analysis of operational performance co-funded by the Energy Commission
- Live operational performance at http://live.deckmonitoring.com/?id=ucsd_mandell_weiss

Sanyo 30 kW/30 KWH PV Integrated Storage System

30 kWh Energy Storage

Campus Solar Power

- Completed 830 kWs at 5 off-campus sites.
- Used Federal Clean Renewable Energy Bonds & CA Solar Initiative incentive to help offset costs.
- Will save about $2M over 20 years.

Electrification of Transportation at UCSD (other CA funding, AB 118)

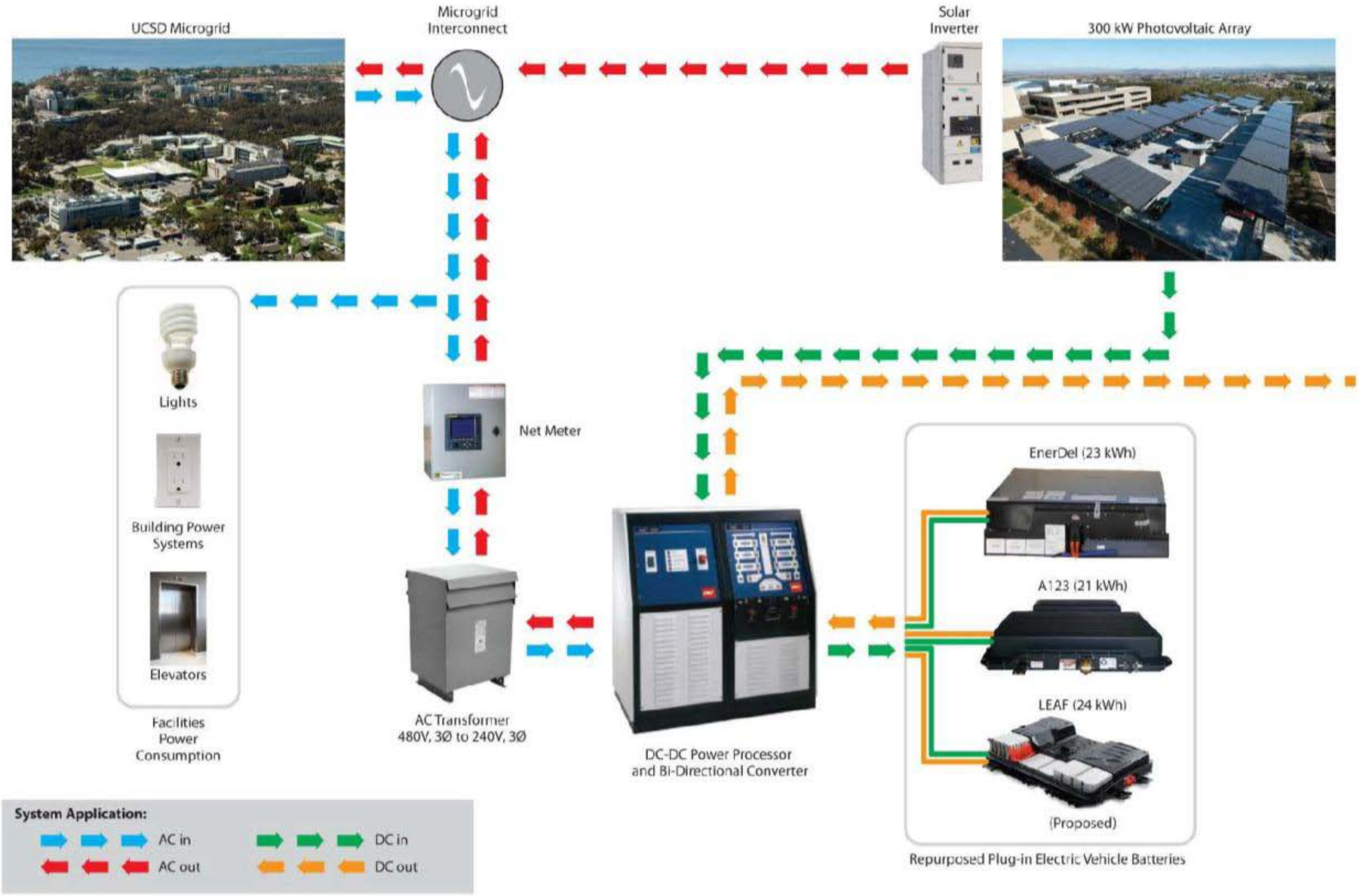
- Currently installing 25 ECOtality/Blink Level 2 systems for works and fleet applications
- Installed 3 Coulomb Level 2 systems for workplace applications
- 16 RWE Level 2 systems for workplace applications
- 10 RWE Level 2 systems for fleet applications
- 3 RWE DC Fast Chargers for public access
- ***When completed, UC San Diego will have the largest, most diversified portfolio of Electric Vehicle Supply Equipment at any university in the world***

2nd Life EV Battery Testing

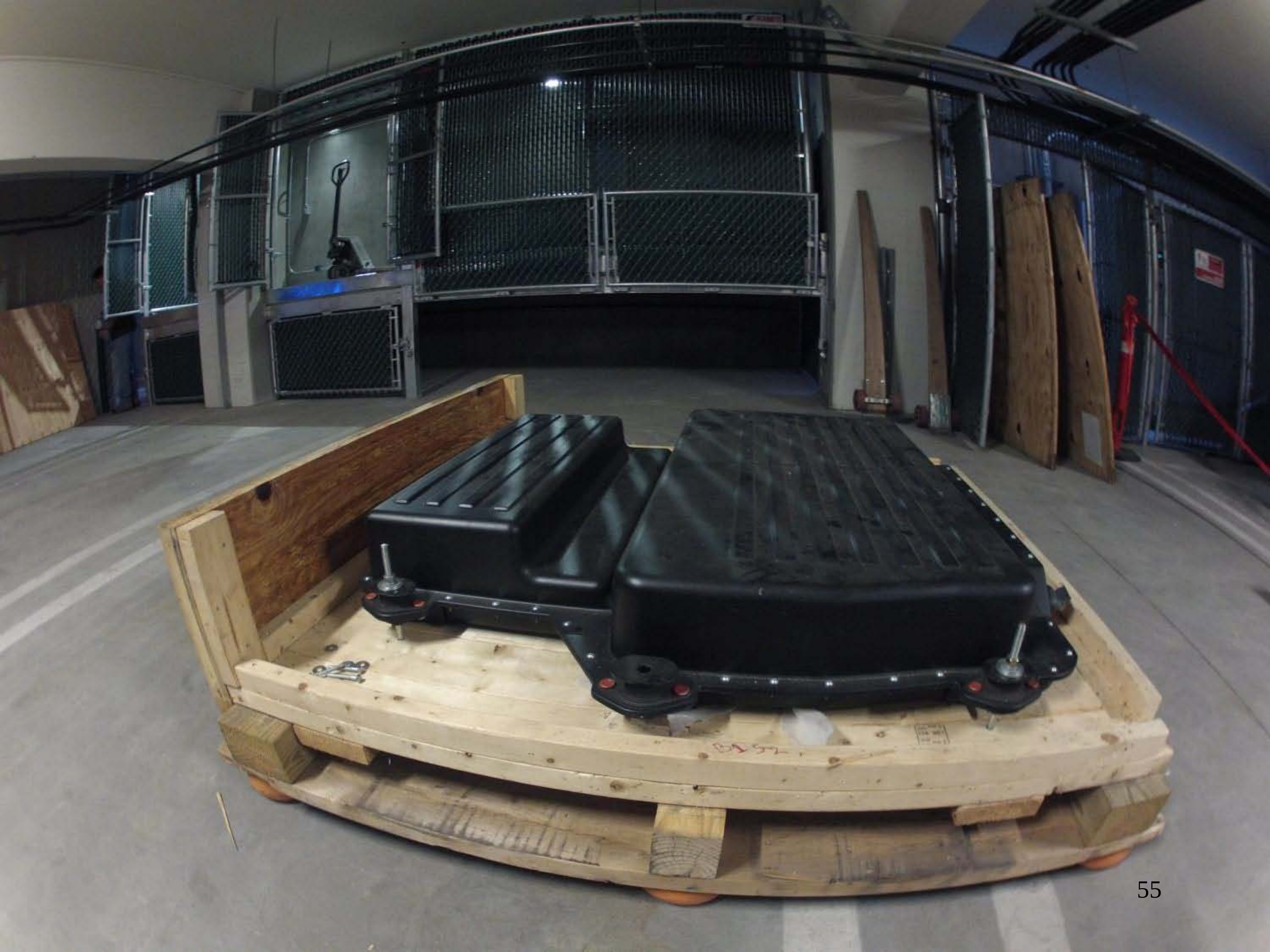
Long-Term Field Testing

- Battery operations designed for response to:
  - Building and transformer loads
  - Intermittent photovoltaic generation output
  - Solar forecasting
  - SDG&E wholesale energy pricing
  - PMU generated frequency data

- Long-term testing began March 2012, funded through March 2013; likely through 2015

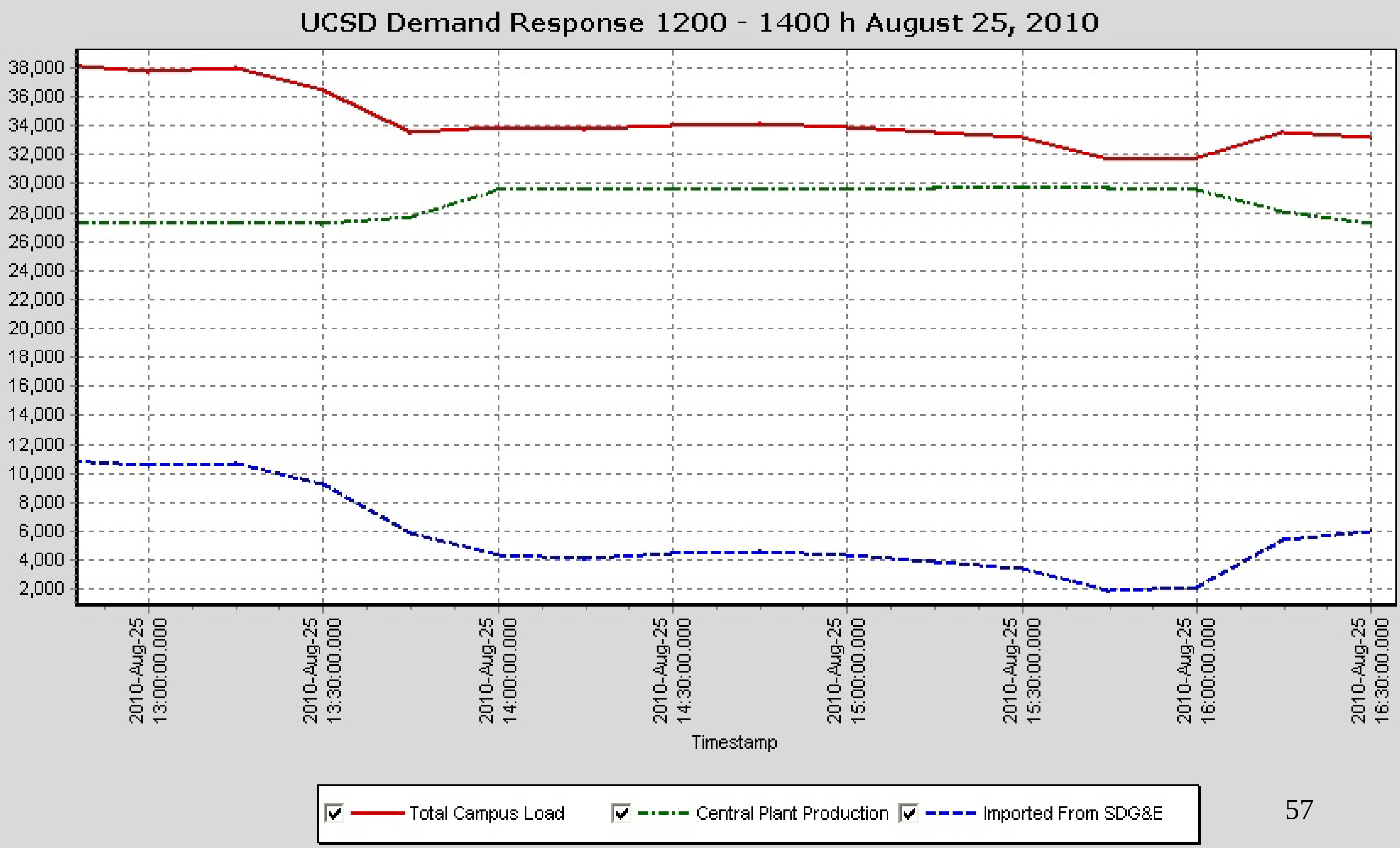

UCSD Microgrid
Microgrid Interconnect
Solar Inverter
300 kW Photovoltaic Array
Lights
Building Power Systems
Elevators
Facilities Power Consumption
Net Meter
AC Transformer 480V, 3Ø to 240V, 3Ø
DC-DC Power Processor and Bi-Directional Converter
EnerDel (23 kWh)
A123 (21 kWh)
LEAF (24 kWh)
(Proposed)
Repurposed Plug-in Electric Vehicle Batteries
System Application:
AC in
AC out
DC in
DC out

World's Largest 2nd Life EV Battery Testing Station at UCSD



2012 Demand Response Performance During Forced Outage of San Onofre Nuclear Generating Station

- Participated in a special SDG&E DR tariff
  - Conservatively bid 5 MWH/hr on each day ahead
  - SDG&E would only pay for levels < 150% of bid
  - $500/MWH incentive for the 4 hr periods
- 8/14/12 avg 7.1 MWH/hr, earned $14,557
- 9/14/12 avg 9.1 MWH/hr, earned $15,269
- 10/2/12 avg 8.7 MWH/hr, earned $12,643


UCSD Demand Response 1200 - 1400 h August 25, 2010
38,000
36,000
34,000
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
2010-Aug-25 13:00:00.000
2010-Aug-25 13:30:00.000
2010-Aug-25 14:00:00.000
2010-Aug-25 14:30:00.000
2010-Aug-25 15:00:00.000
2010-Aug-25 15:30:00.000
2010-Aug-25 16:00:00.000
2010-Aug-25 16:30:00.000
Timestamp
Total Campus Load
Central Plant Production
Imported From SDG&E

UCSD Microgrid Awards

- EPA Energy Star Award for achieving 66% efficiency for combined cooling, heating and natural gas power plant
- 1st Annual Climate Leadership Award for Institutional Excellence from the American College & University Presidents' Climate Commitment Group
- Gold STARS Rating from AASHE and being the first CA university and 10th in the nation to receive it
- Ranked 3rd Greenest University by Sierra Magazine

Questions?

Consuelo.Sichon@energy.ca.gov

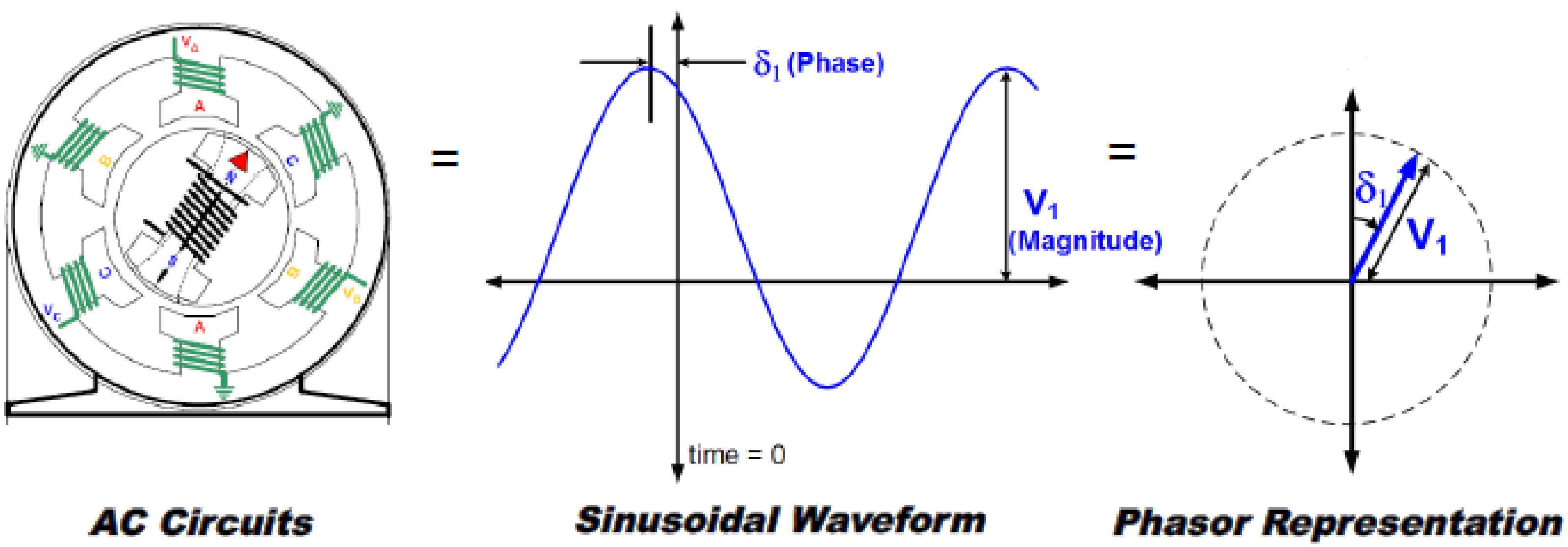
Synchrophasor Research and Development Program

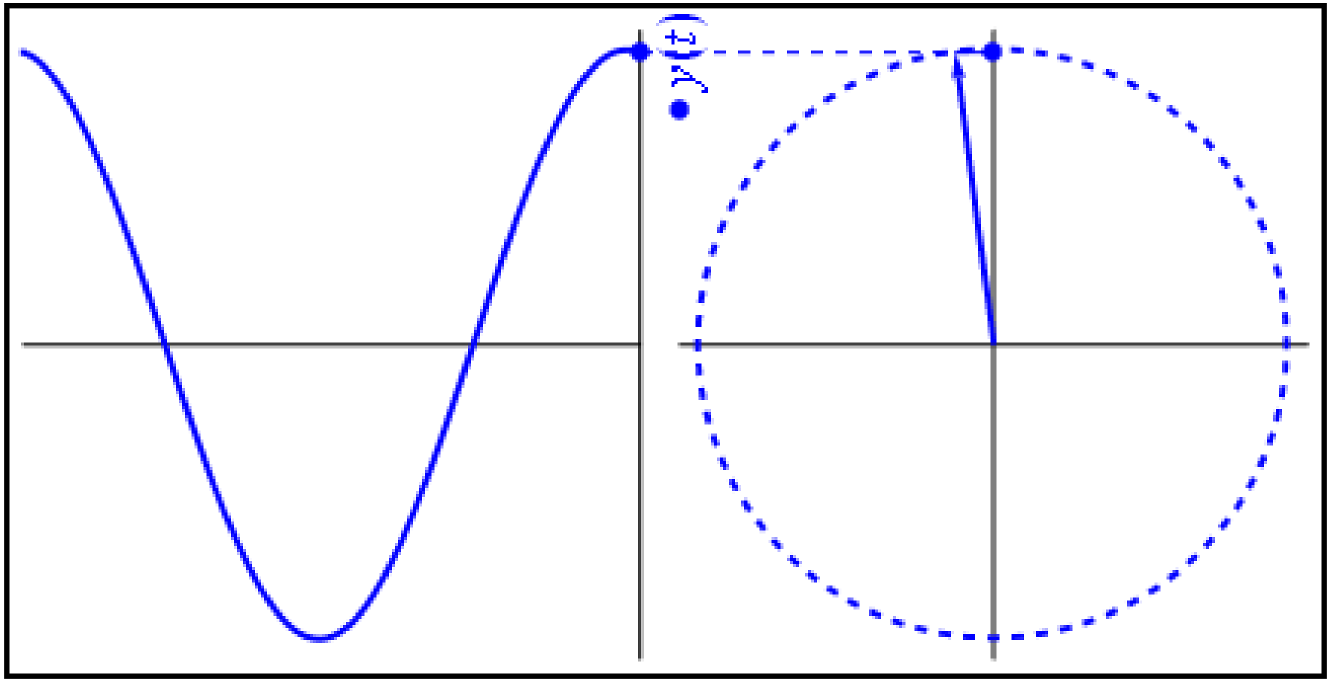
California Energy Commission
Energy Systems Research Office
Jamie Patterson
November 27, 2012

Phasor …Not Phaser!

It all started with the *phasor*

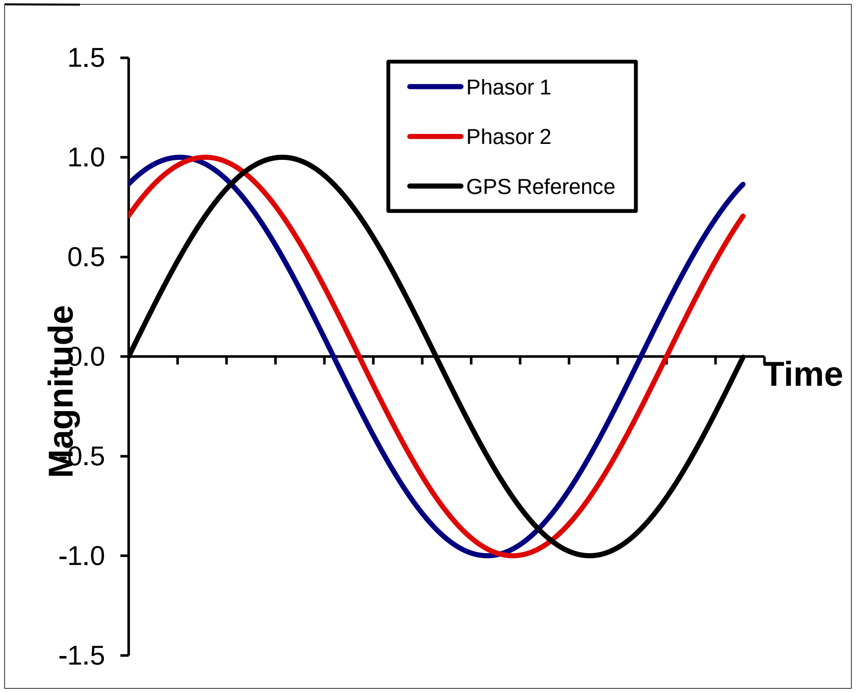
- In 1893, *Charles P. Steinmetz* presented a simplified mathematical representation for ac waveforms which he named *phasor*.
- A phasor is a vector characterized by a magnitude and a phase angle

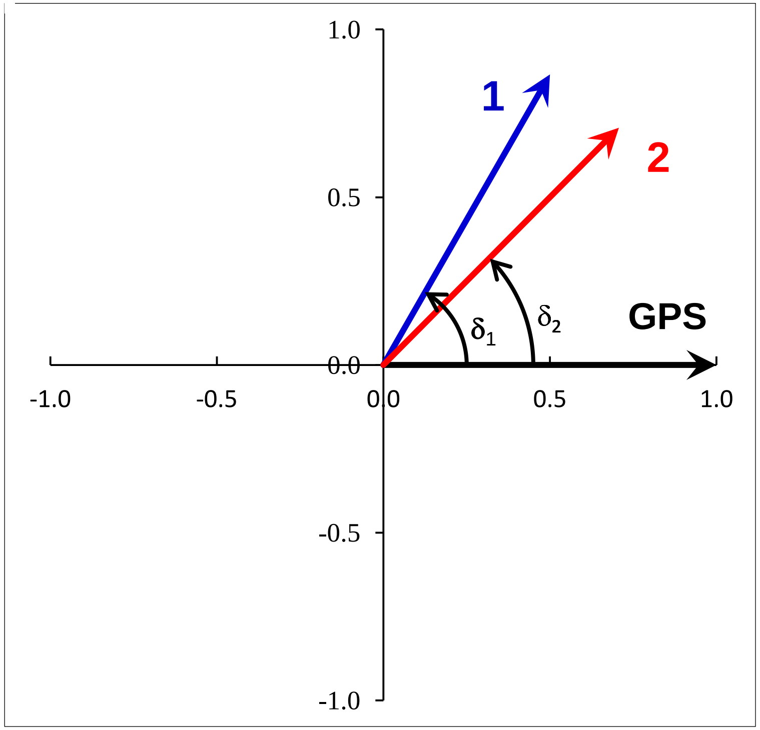




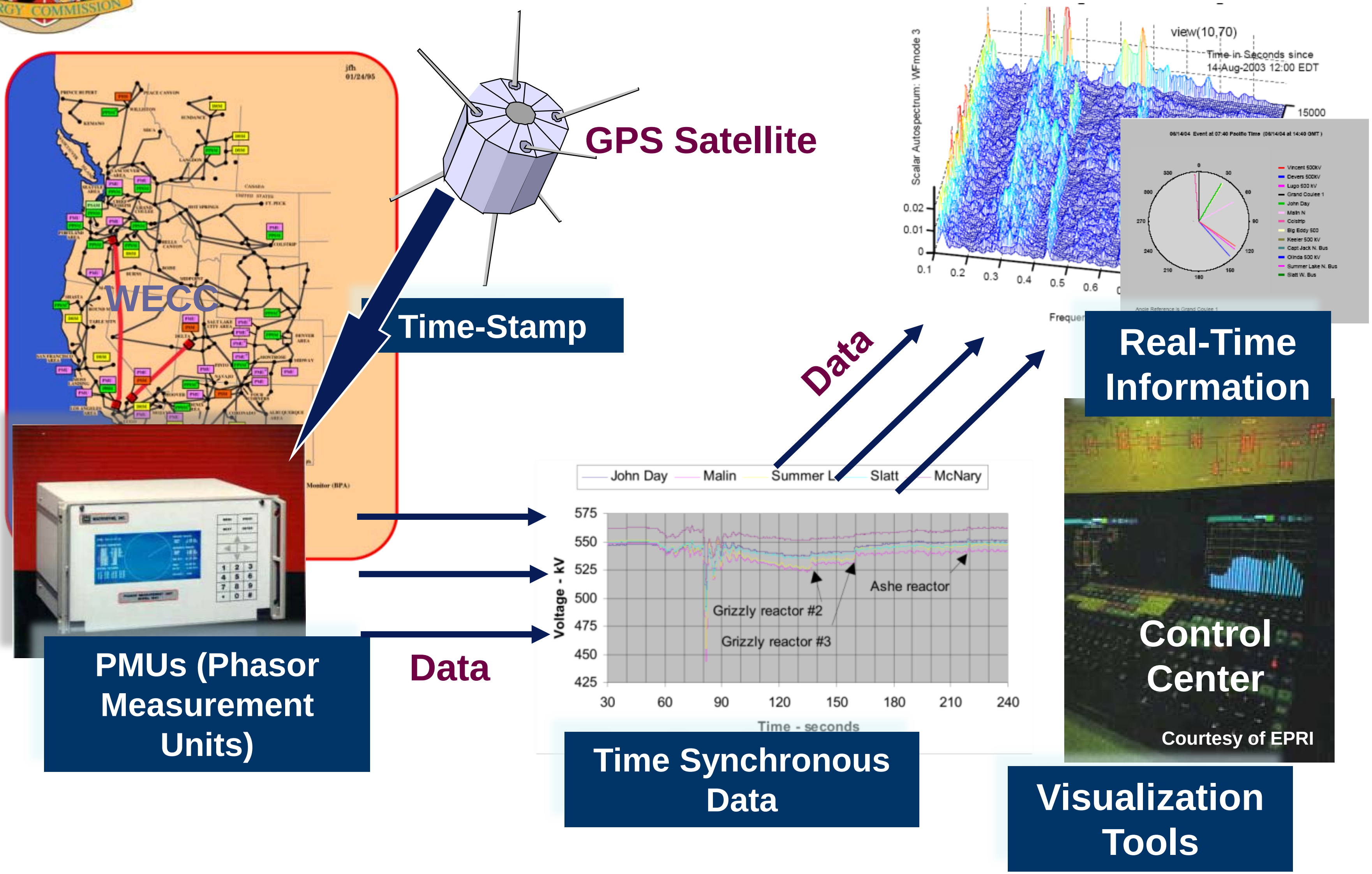
- A phasor can be seen as a rotating vector
- The (non-animated) graphical representation is at a fixed time (*t* = 0)

A **phasor** is a quantity such as voltage or current that varies as a sine wave. In the electric power system, the nominal frequency of the sine wave is 60 cycles/sec (Hz).





A **synchrophasor** is a phasor that is time-stamped to an extremely precise and accurate time reference, such as a GPS clock, in order to compare phasors at different locations (different PMUs) to each other.


GPS Satellite
WECC
Time-Stamp
PMUs (Phasor Measurement Units)
Data
John Day
Malin
Summer L
Slatt
McNary
Voltage - kV
Time - seconds
Grizzly reactor #2
Grizzly reactor #3
Ashe reactor
Time Synchronous Data
Data
view(10,70)
Time in Seconds since 14-Aug-2003 12:00 EDT
Scalar Autospectrum: WFmode 3
Real-Time Information
Control Center
Courtesy of EPRI
Visualization Tools

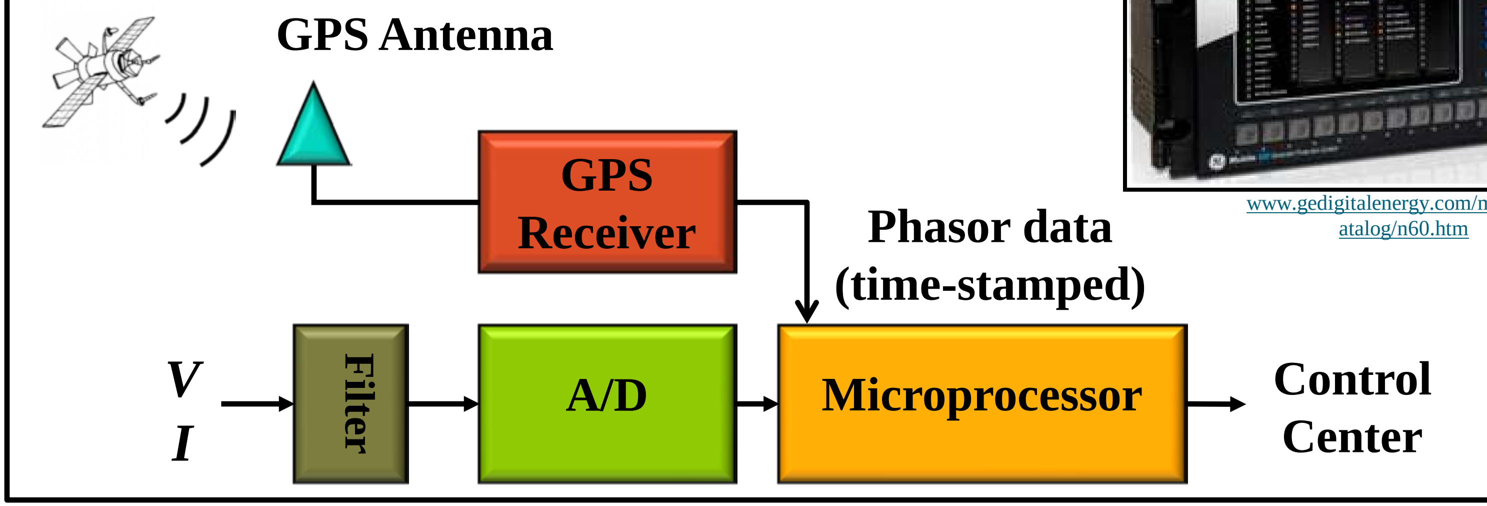
Phasor Measurement Unit

- In 1988, the first Phasor Measurement Unit (PMU) was developed at Virginia Tech University.
- Commercialization of the GPS and improvement of high speed communication network led to commercial use of PMUs.

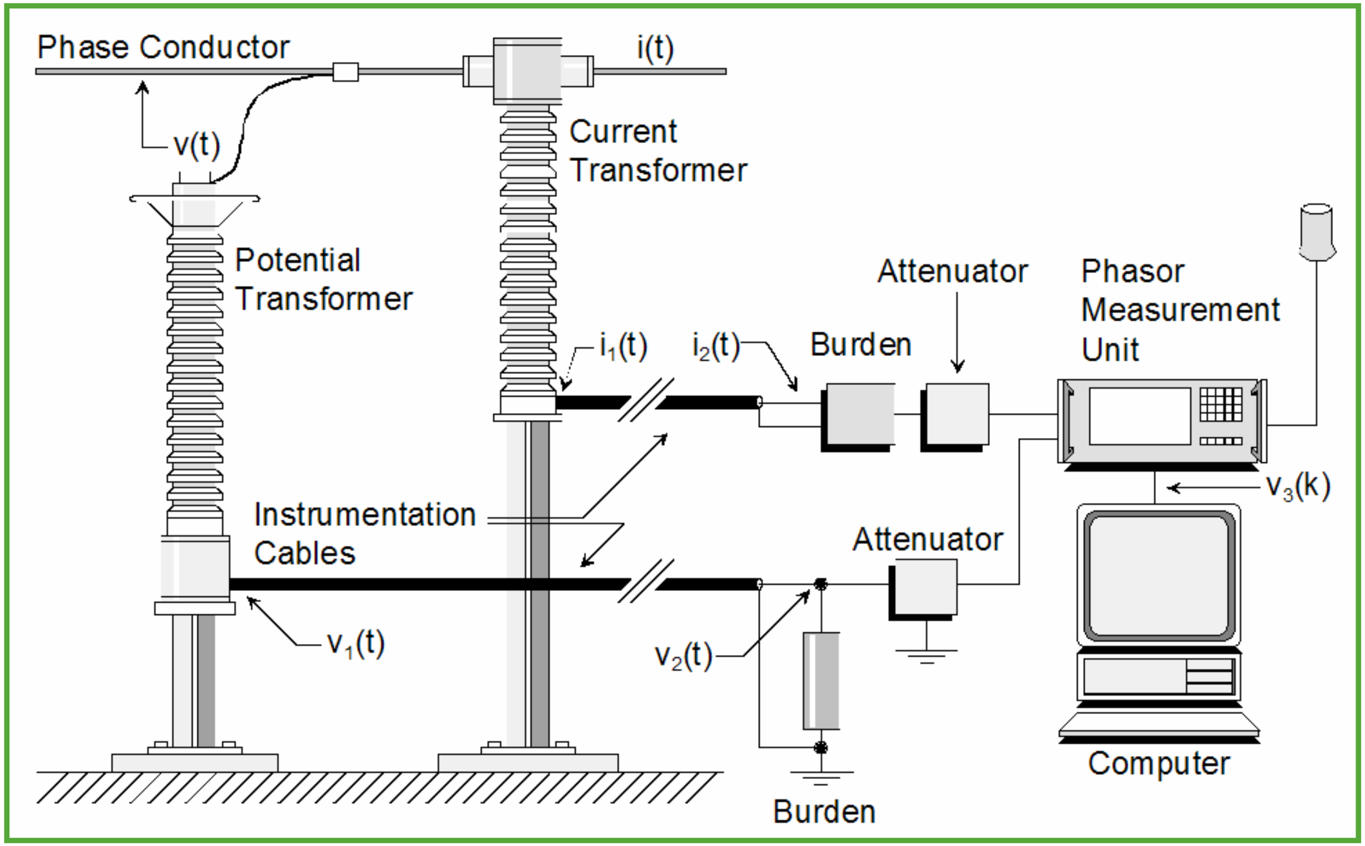
Phasor Measurement Unit

- GPS receiver provides the 1 pulse-per-second signal and time tag information
- Voltage and current analog signals are derived from standard current and potential transformers in the field
- Microprocessor assigns id tag to measurements

www.gedigitalenergy.com/multilin/catalog/n60.htm



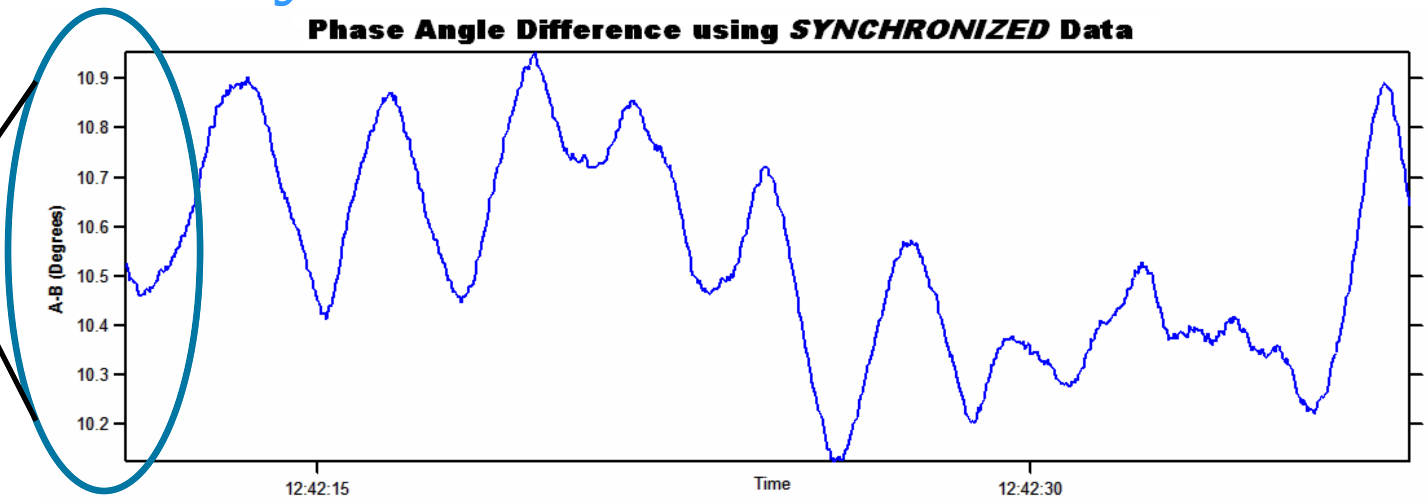
Typical PMU installation



SCADA vs. Synchrophasors

	SCADA	Synchrophasors
Measurement	Magnitude	Magnitude Phase angle
Resolution	1 measurement every 4 seconds	Up to 60 measurements per second
	Static analysis/studies	Dynamic analysis/studies
Time Synchronization	No	Yes
	Local view	Wide area view

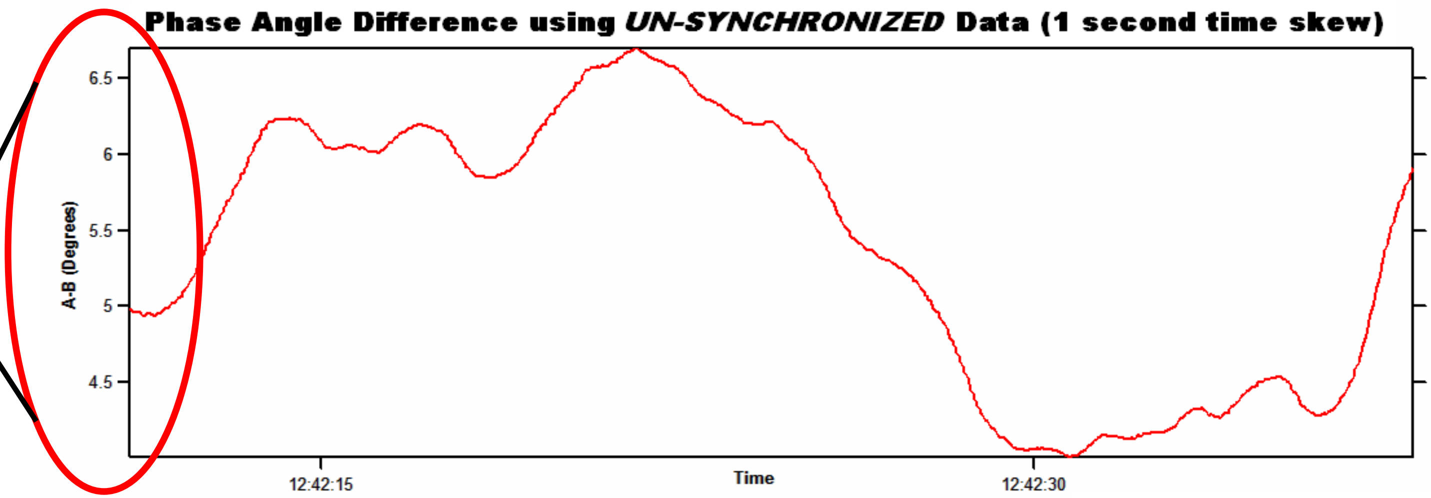
Is time synchronization critical?



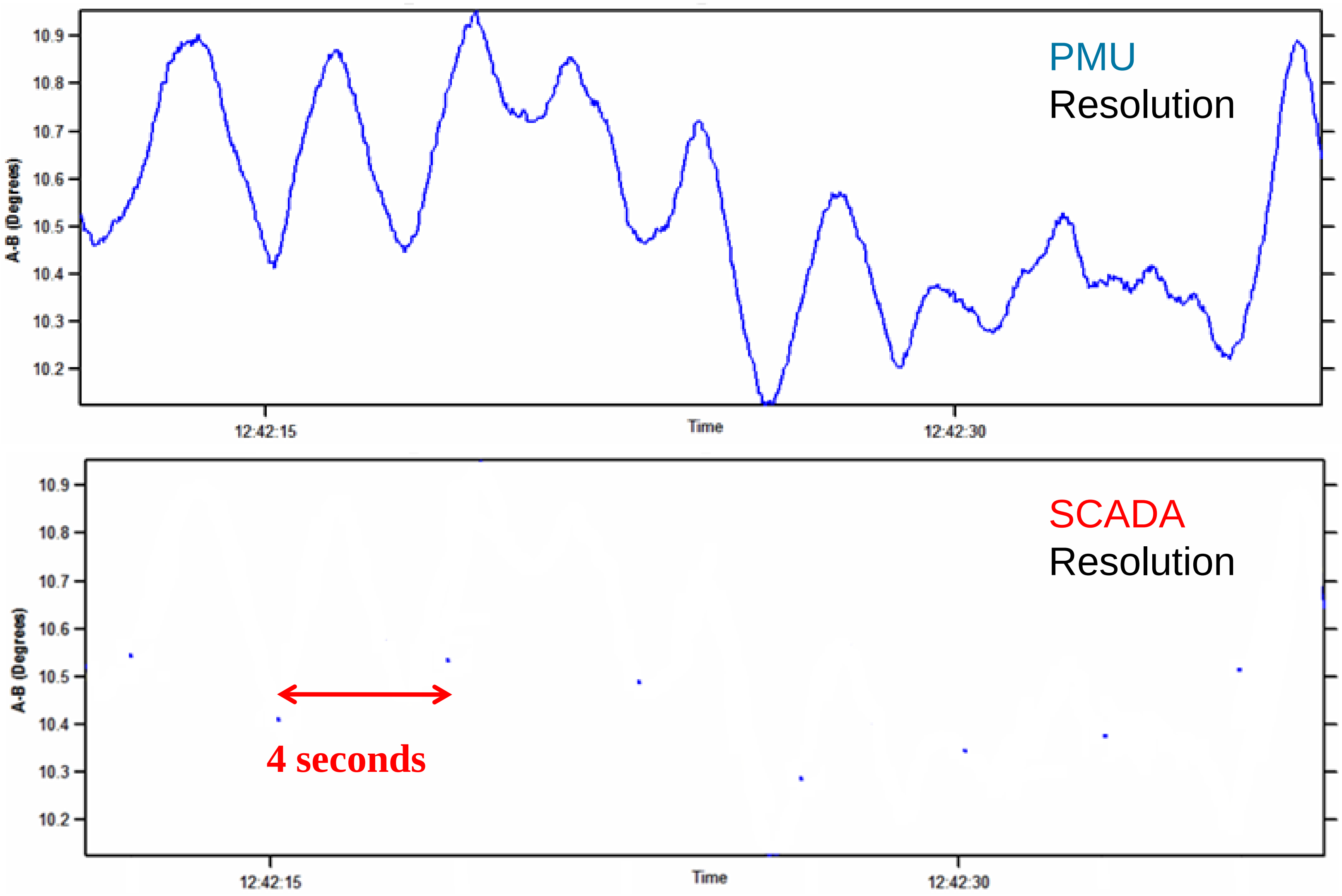
10 degrees

Average angle difference

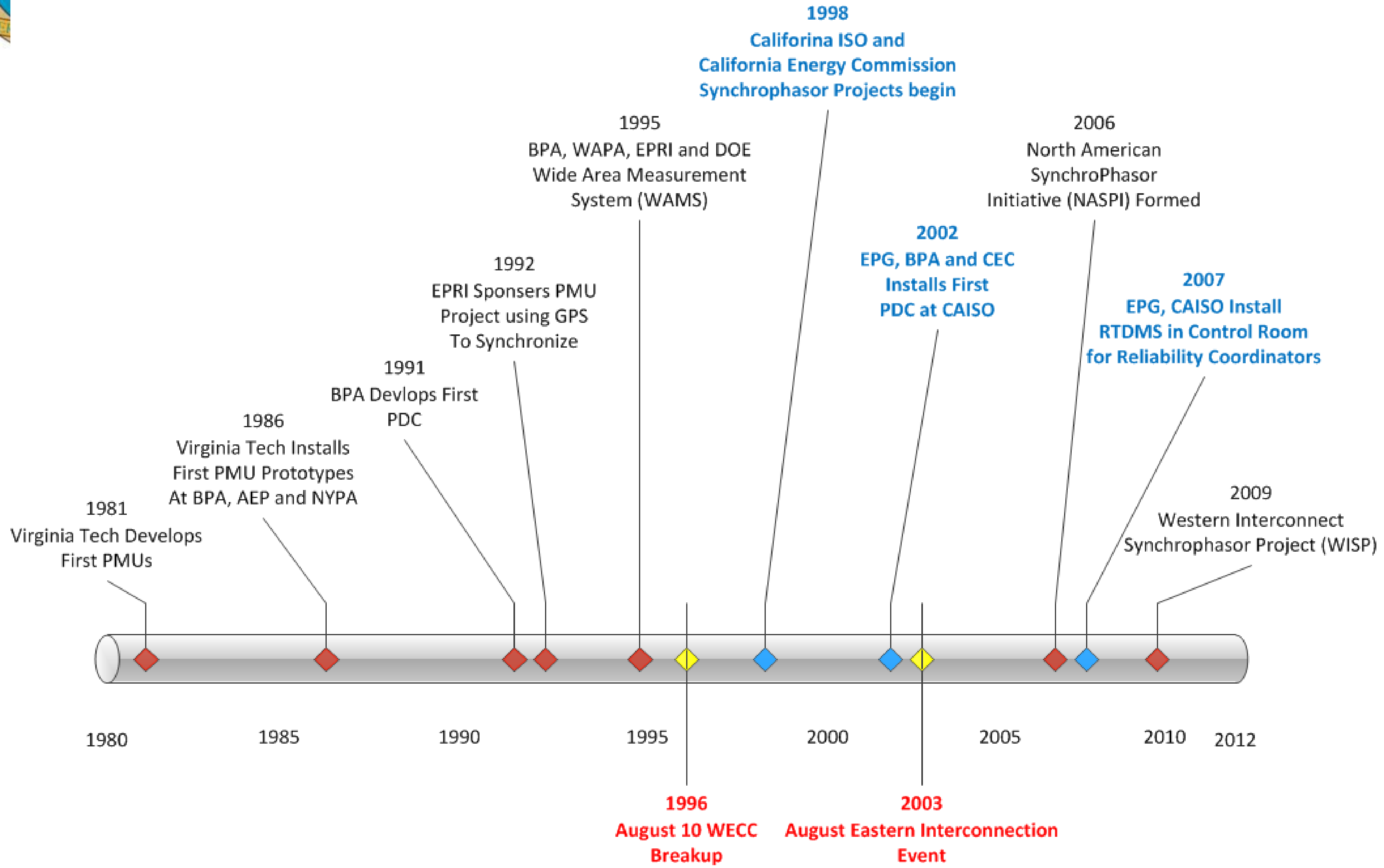
5 degrees



What about resolution?



Synchrophasor Development and Initiatives


1998
Califorina ISO and
California Energy Commission
Synchrophasor Projects begin
1995
BPA, WAPA, EPRI and DOE
Wide Area Measurement
System (WAMS)
2006
North American
SynchroPhasor
Initiative (NASPI) Formed
2002
EPG, BPA and CEC
Installs First
PDC at CAISO
2007
EPG, CAISO Install
RTDMS in Control Room
for Reliability Coordinators
1992
EPRI Sponsers PMU
Project using GPS
To Synchronize
1991
BPA Devlops First
PDC
1986
Virginia Tech Installs
First PMU Prototypes
At BPA, AEP and NYPA
1981
Virginia Tech Develops
First PMUs
2009
Western Interconnect
Synchrophasor Project (WISP)
1980
1985
1990
1995
2000
2005
2010
2012
1996
August 10 WECC
Breakup
2003
August Eastern Interconnection
Event

Western Interconnection Synchrophasor Project (WISP)

- Created in 2009 when WECC was awarded $53.9 million from the U.S. Department of Energy (awarded under ARRA)
- Matches dollars already committed by nine WISP participants (CAISO included)
- Total project budget of $107.8 million
- Equipment:
  - 300 Phasor Measurement Units (PMUs)
  - 50 Phasor Data Concentrators (PDCs)
  - Transmission systems communication

Western Electricity Coordinating Council

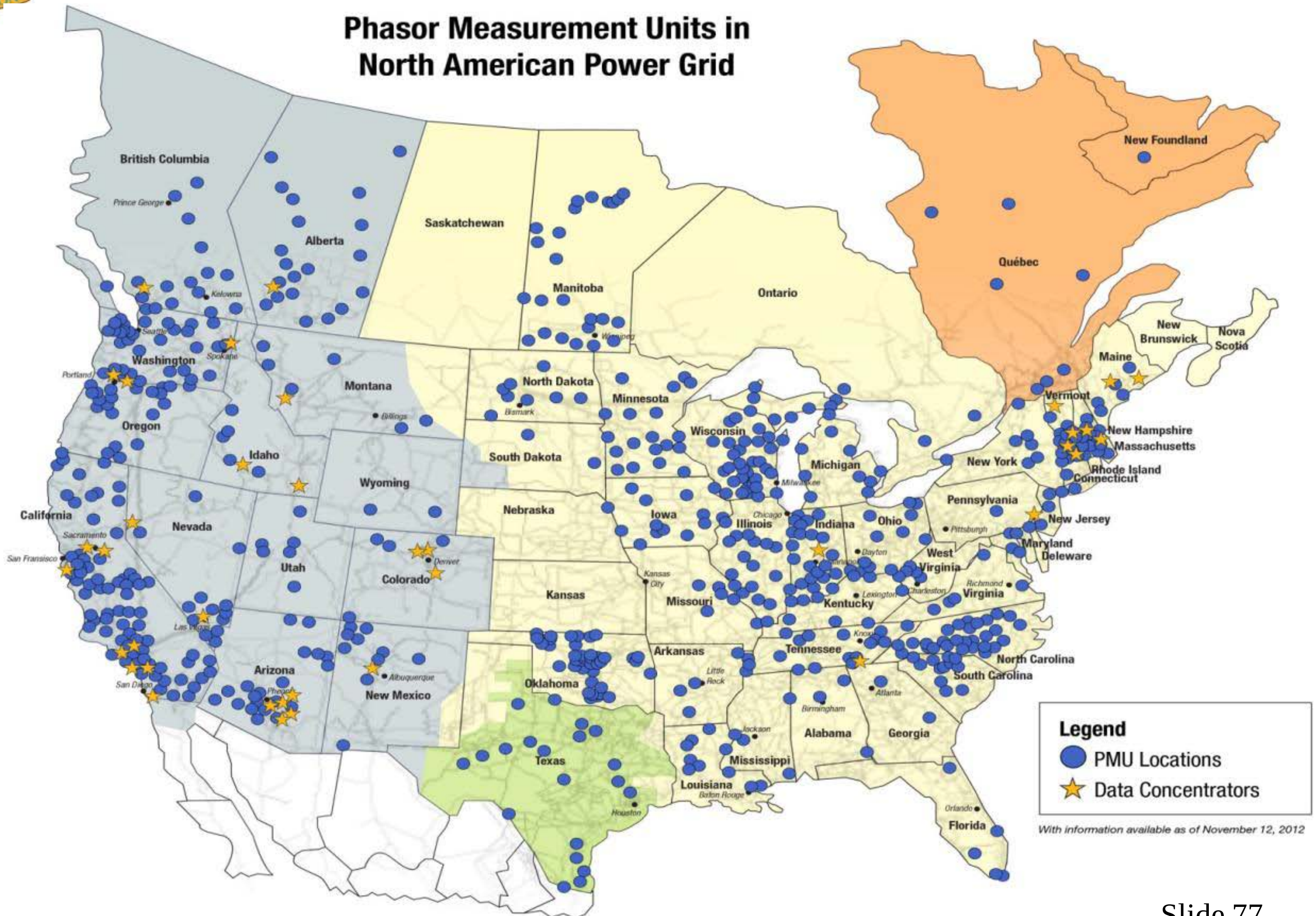
Western Interconnection Synchrophasor Project (WISP)

- Advanced Applications:
  - Angle and frequency monitoring
  - Voltage stability monitoring
  - Post-mortem analysis
  - Oscillation & mode meter monitoring
  - Reactive reserves monitoring & device control
  - Model validation & improvement
  - Path loading and congestion management

WISP participants

Cost Share Participants	PMUs	PDCs
• Bonneville Power Administration	132	4
• California ISO/CEC	0	2
• Idaho Power Corporation	4	1
• NV Energy	14	5
• Pacific Gas & Electric	158	26
• PacifiCorp	3	2
• Salt River Project	21	2
• Southern California Edison	32	gateways
• WECC	0	6
TOTAL	**364**	**48**

Phasor Measurement Units in North American Power Grid

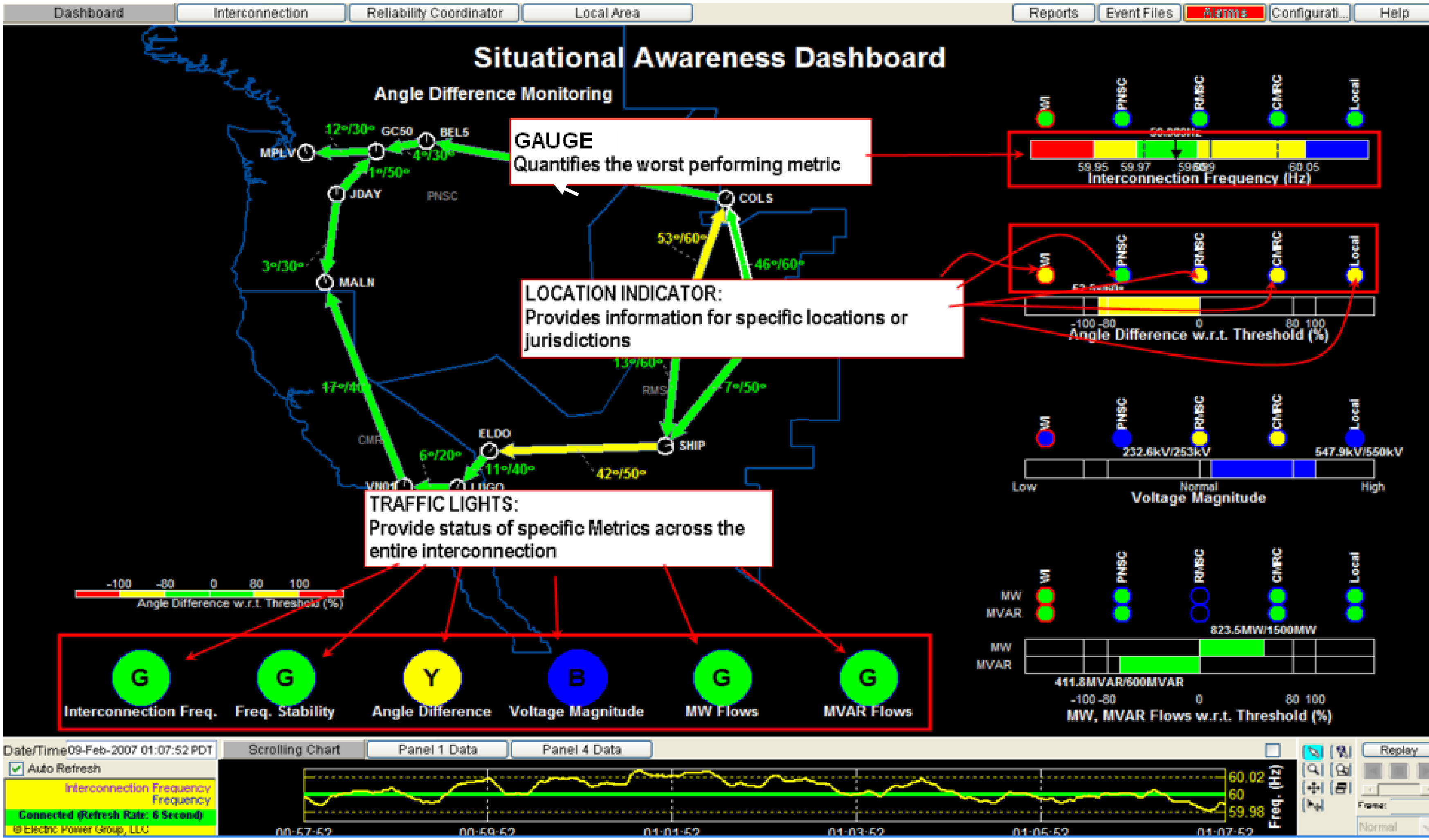


North American SynchroPhasor Initiative (NASPI)

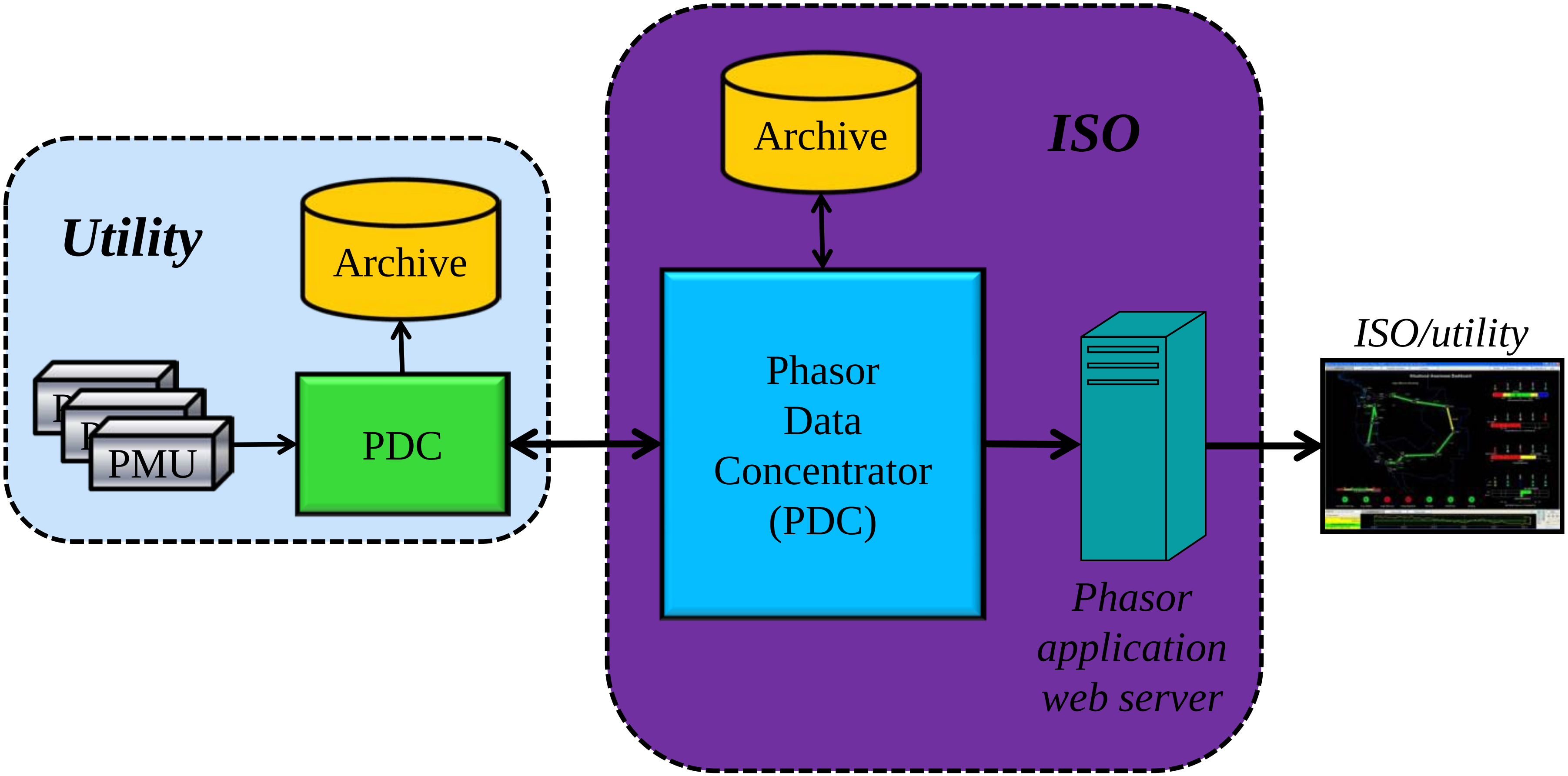
- Collaborative effort between the Department of Energy (DOE), the North American Electric Reliability Corporation (NERC), and electric utilities, vendors, consultants and researchers from across the nation
- Funded primarily by DOE and NERC
- Vision: Improve power system reliability and visibility through wide area measurement and control.
- Goals:
  - Advance the deployment and use of networked phasor measurement devices
  - Facilitate phasor data sharing
  - Advance the applications development
  - Promote synchrophasor research and analysis

Synchrophasor Activities at the CAISO

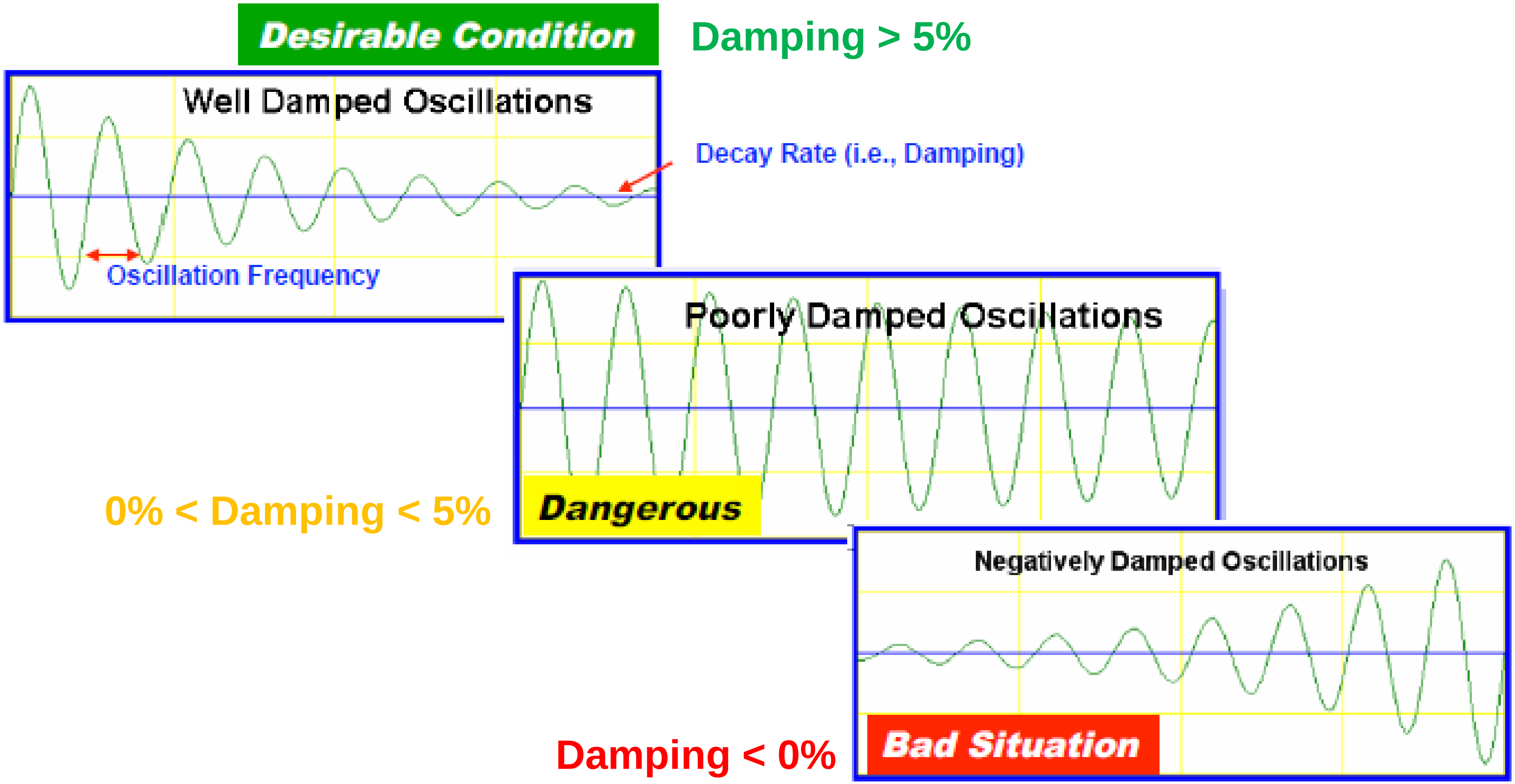
Visual Display at CAISO



General synchrophasor network



Oscillations and damping

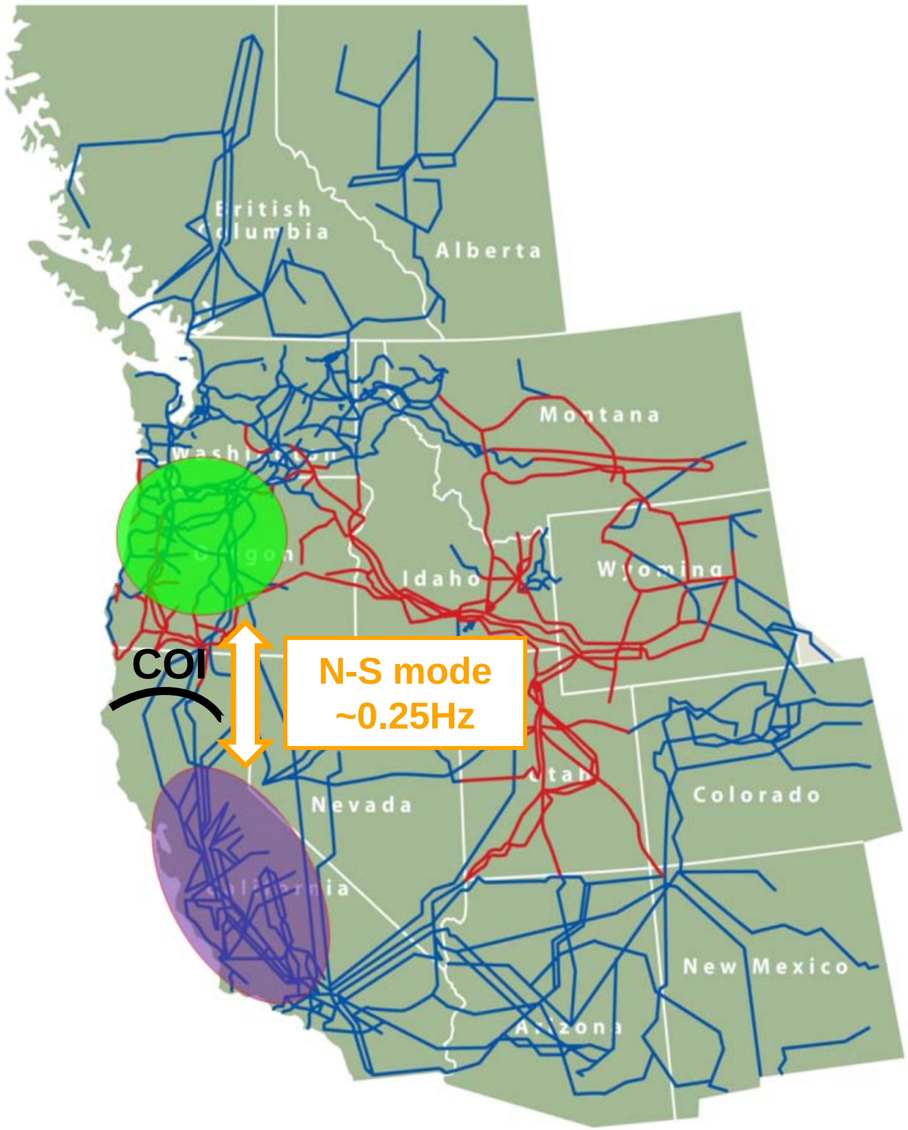


[Example: Tacoma Bridge]

Oscillations and systems

Inter-area oscillations: associated with groups of synchronous generators that are connected with relatively weak or long transmission tie lines

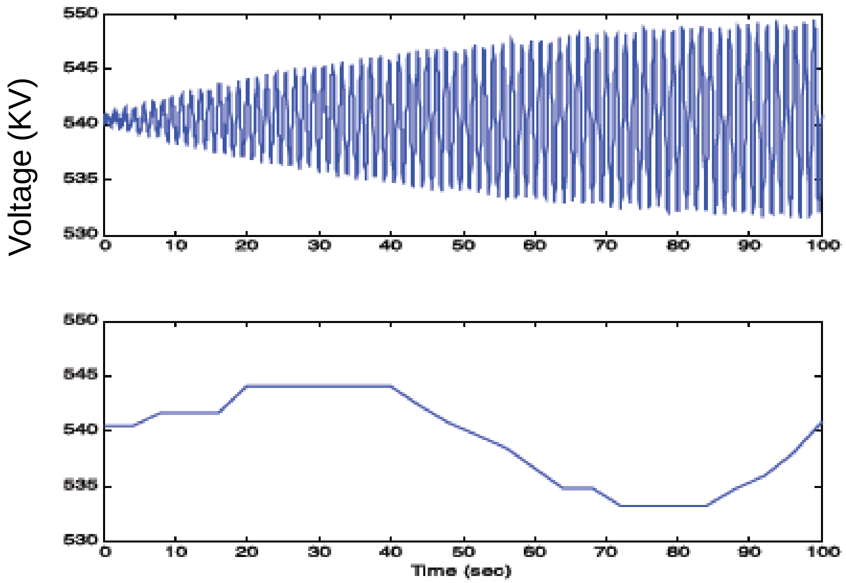
– E.g. consider the North area oscillating against the South area in the WECC system



Goal: Real-time identification of undesirable oscillatory modes and low damping conditions from ambient data

Oscillations seen by synchrophasor data

- SCADA measurements cannot see most oscillations (even worse they can give a misleading impression)
- Synchrophasors are needed to observe oscillations because of faster data sampling, greater data resolution, and wide area visualization

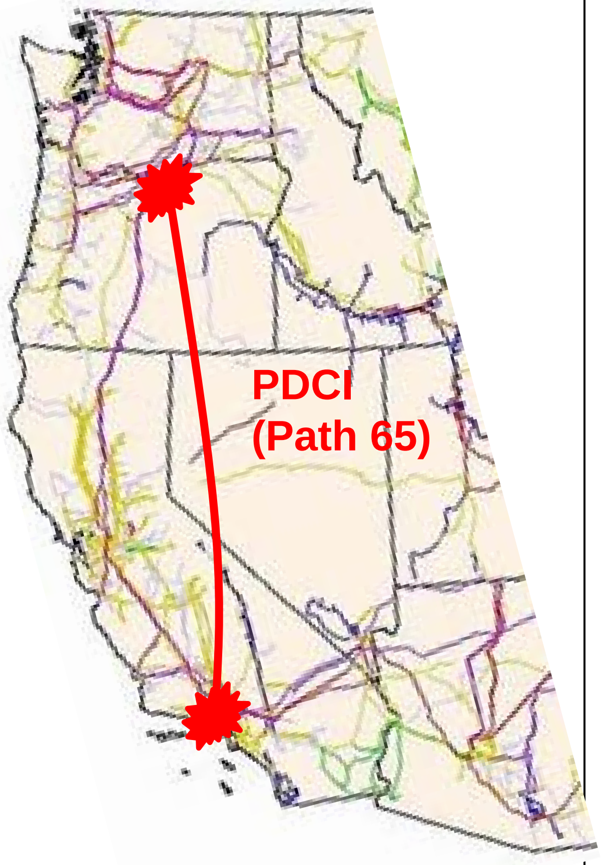


<< Synchrophasors

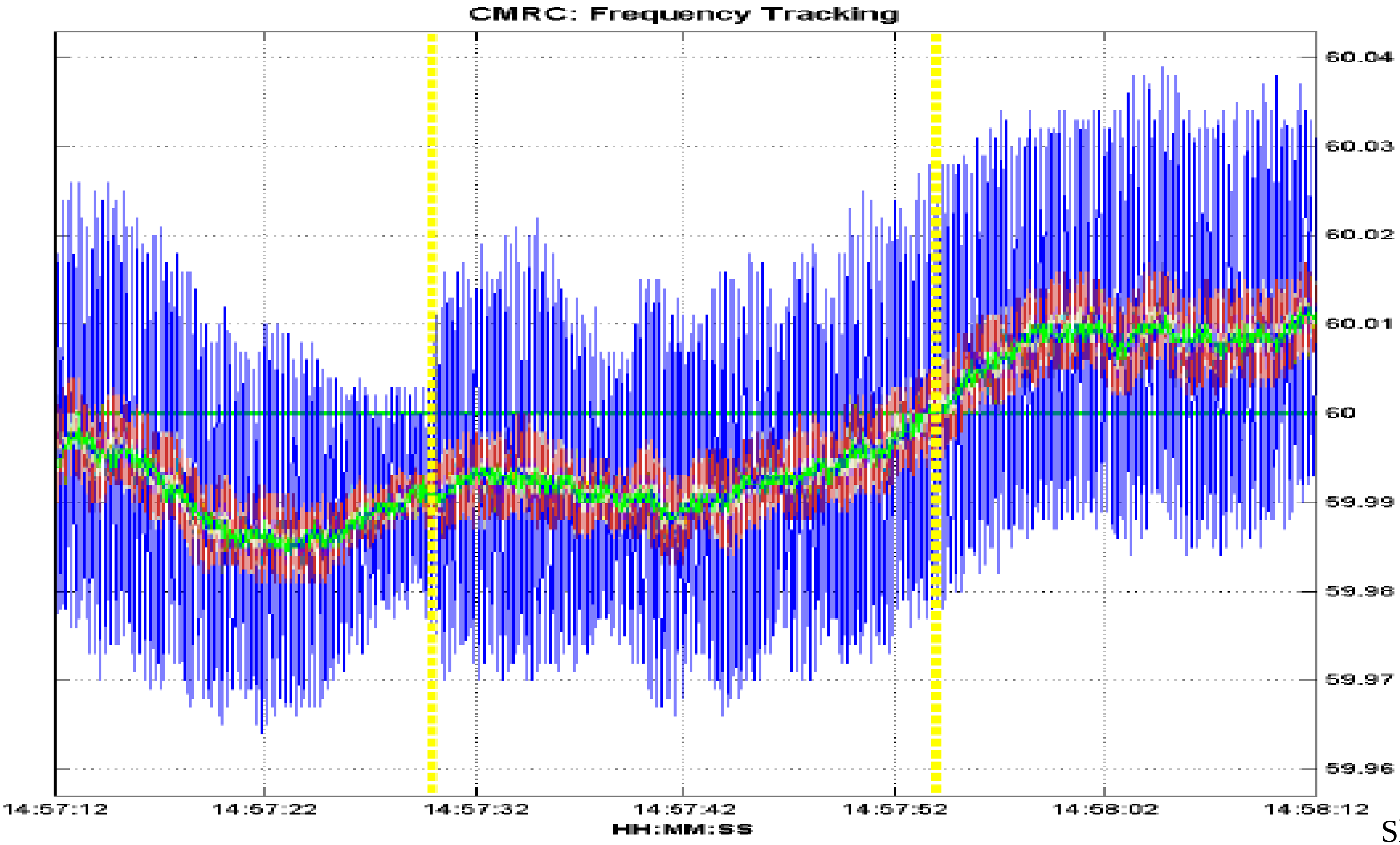
<< SCADA

January 26, 2008 PDCI event

- PDCI (Path 65) line was carrying 1,700 MW South to North flow
- Short circuit at Big Eddy substation (Northern Oregon) - oscillations started occurring on the DC line.
- SCE operator noticed the oscillations (Southern California) on the analog recorder but the oscillations were not visible on SCADA.
- CAISO Reliability Coordinator noticed the oscillations on the Phasor Monitoring System. They were not visible on SCADA or the Local High Speed Frequency Monitor.
- The Reliability Coordinator reduced flow on Path 65 and eventually had to shut it down.



January 26, 2008 PDCI event – Frequency oscillation synchrophasor display



Examples and Success Stories

PMUs could help prevent costly major blackouts

- WECC August 10th, 1996 separation event
- Eastern Interconnect August 14th, 2003 event

WECC August 10th, 1996 separation

- **Load lost:**

  30,489 MW

- **Generation lost:**

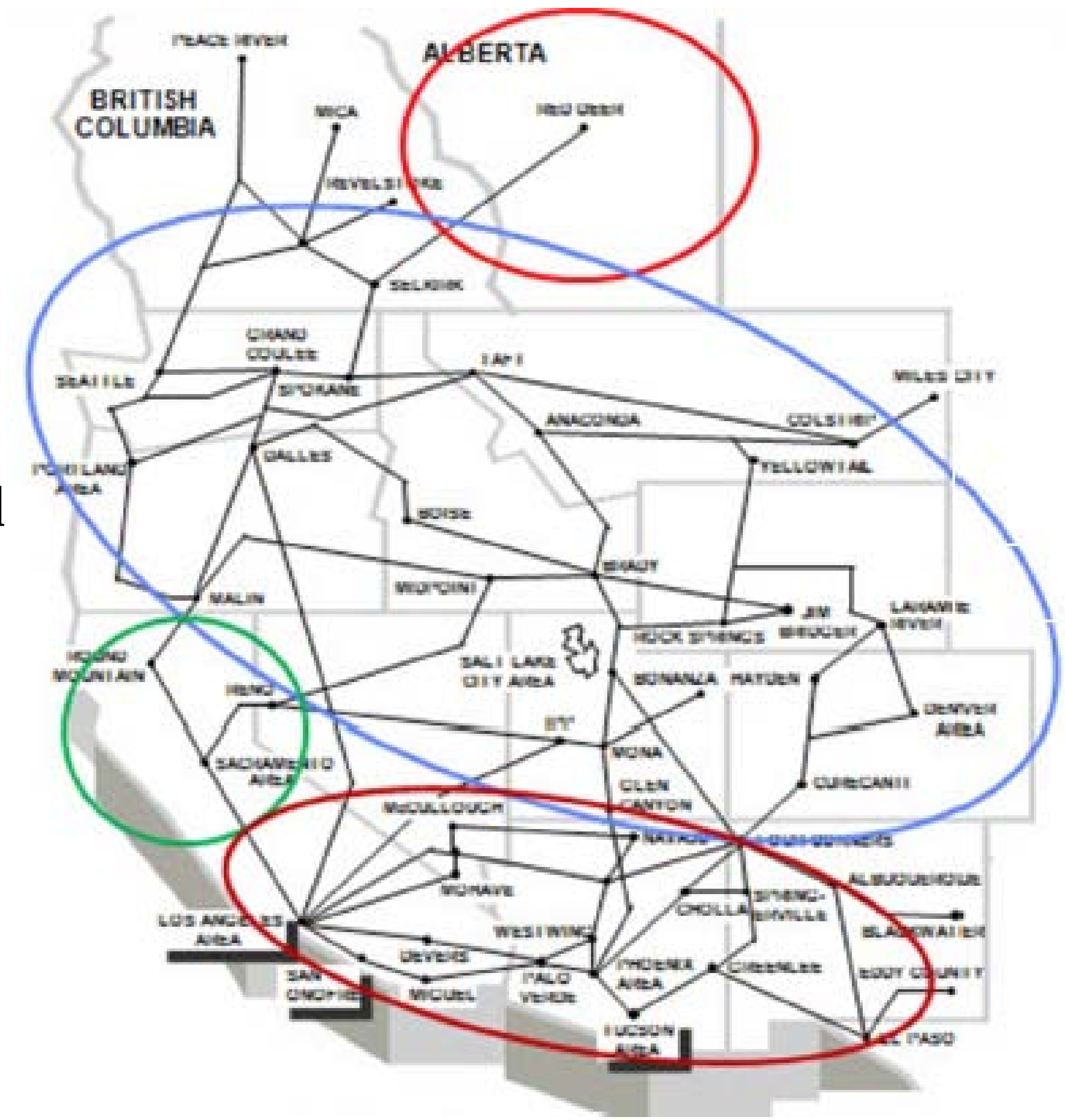
  27,269 MW

- **Customers affected**

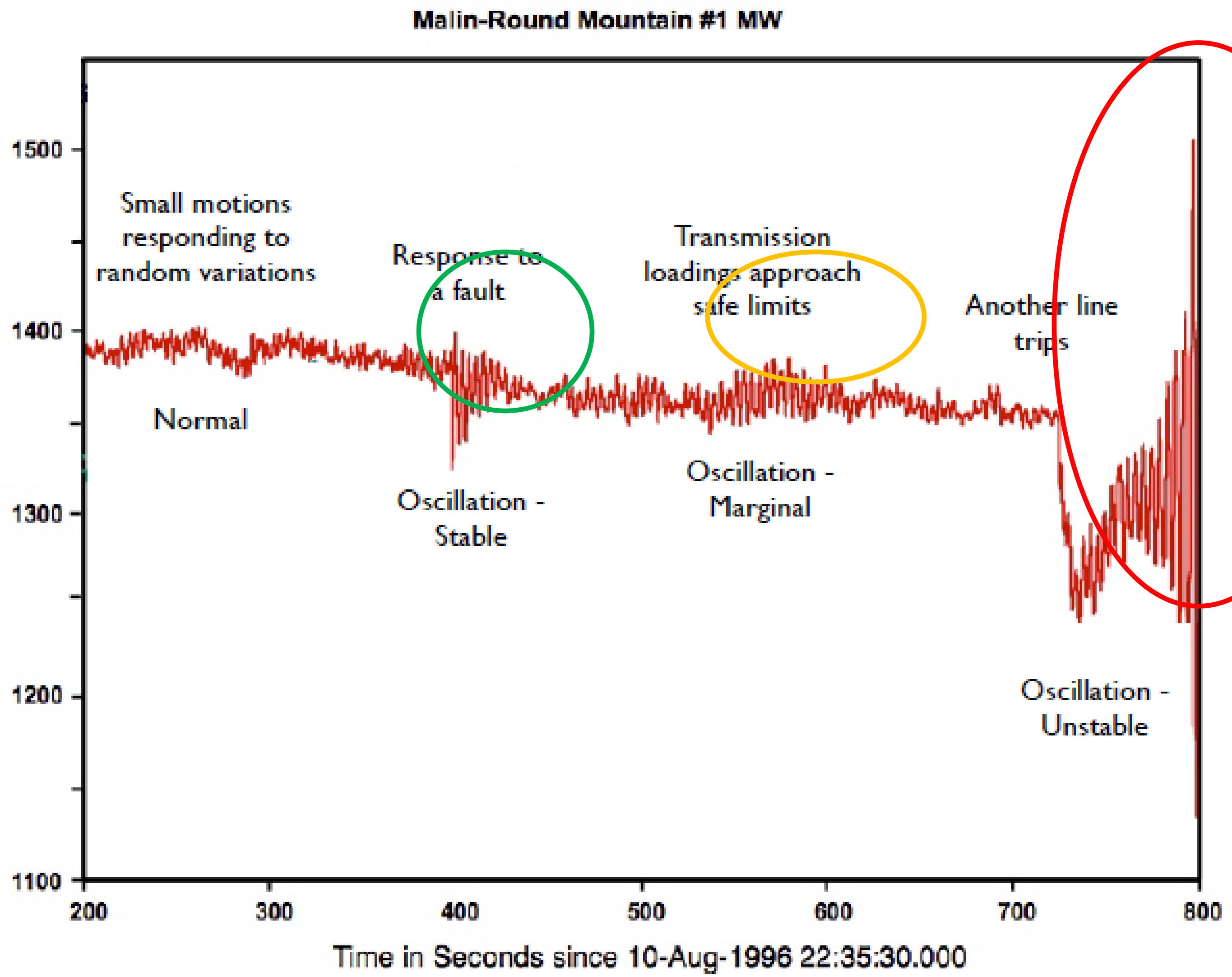
  7.49 million

- **Outage time:**

  Up to 9 hours

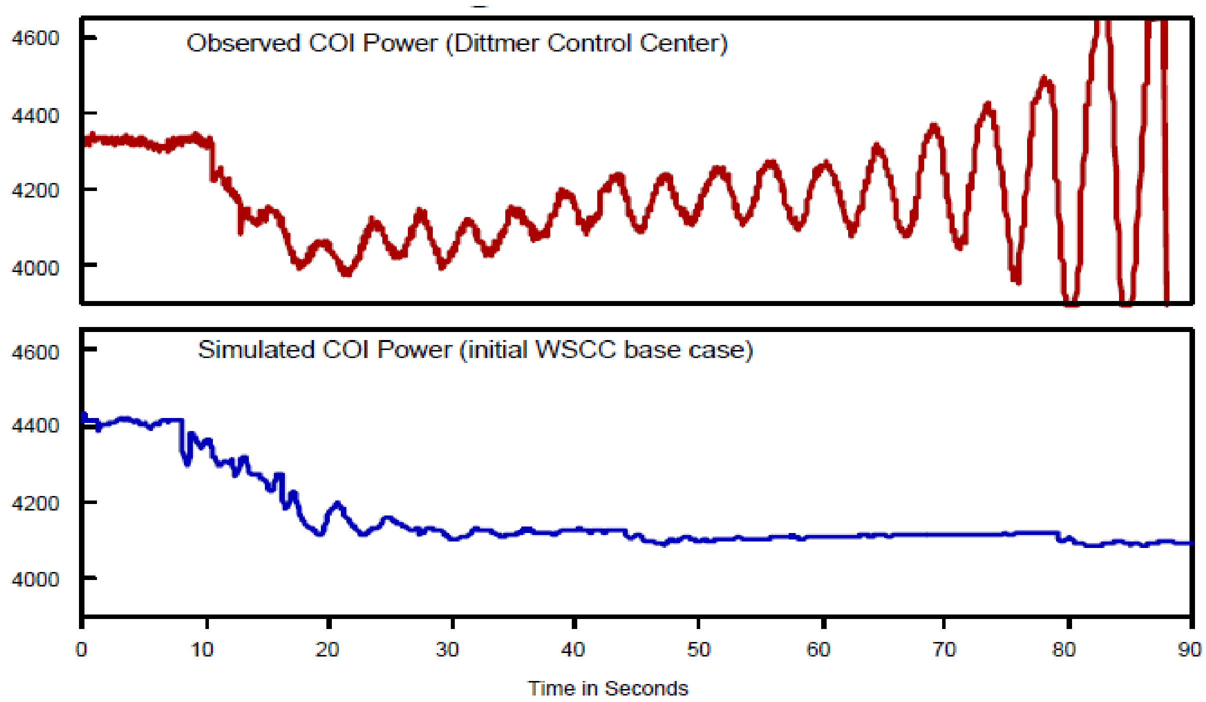


WECC August 10, 1996 separation



WECC August 10, 1996 separation

Actual system performance showed ***unstable*** behavior



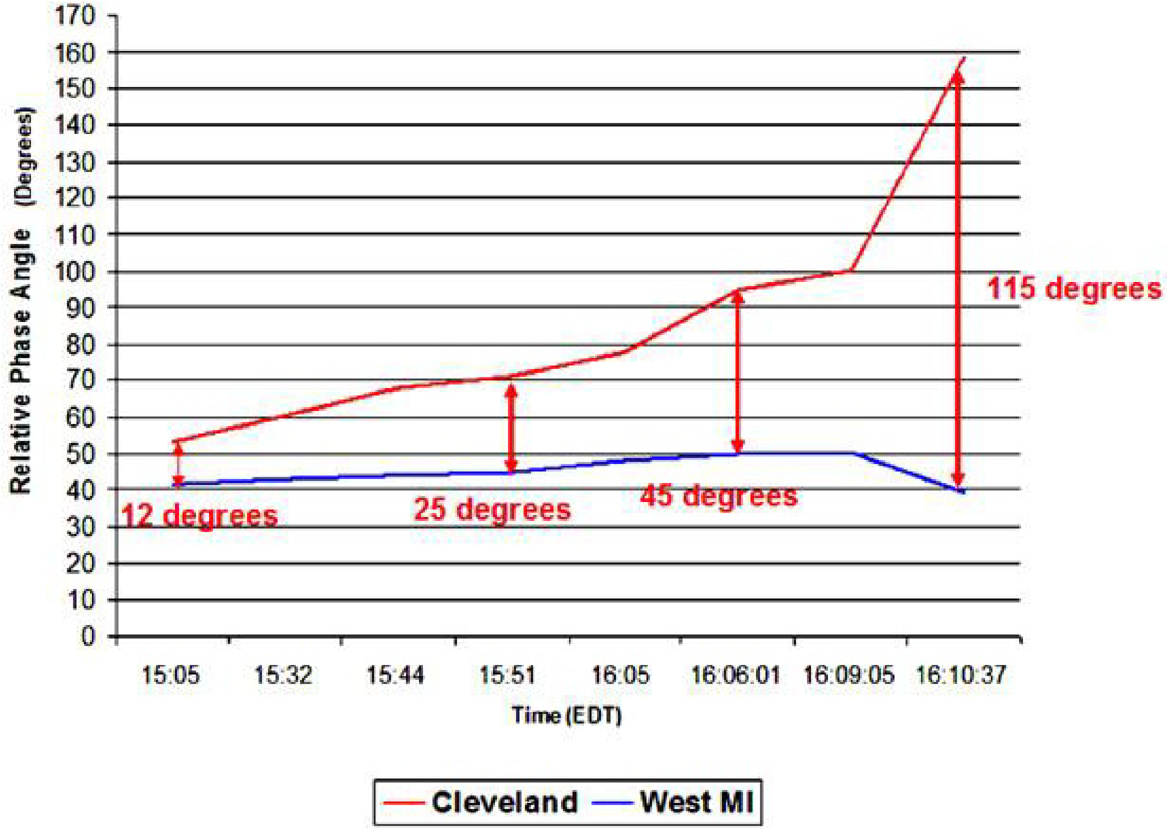
Engineering studies predicted ***stable*** behavior

Eastern Interconnect August 14, 2003

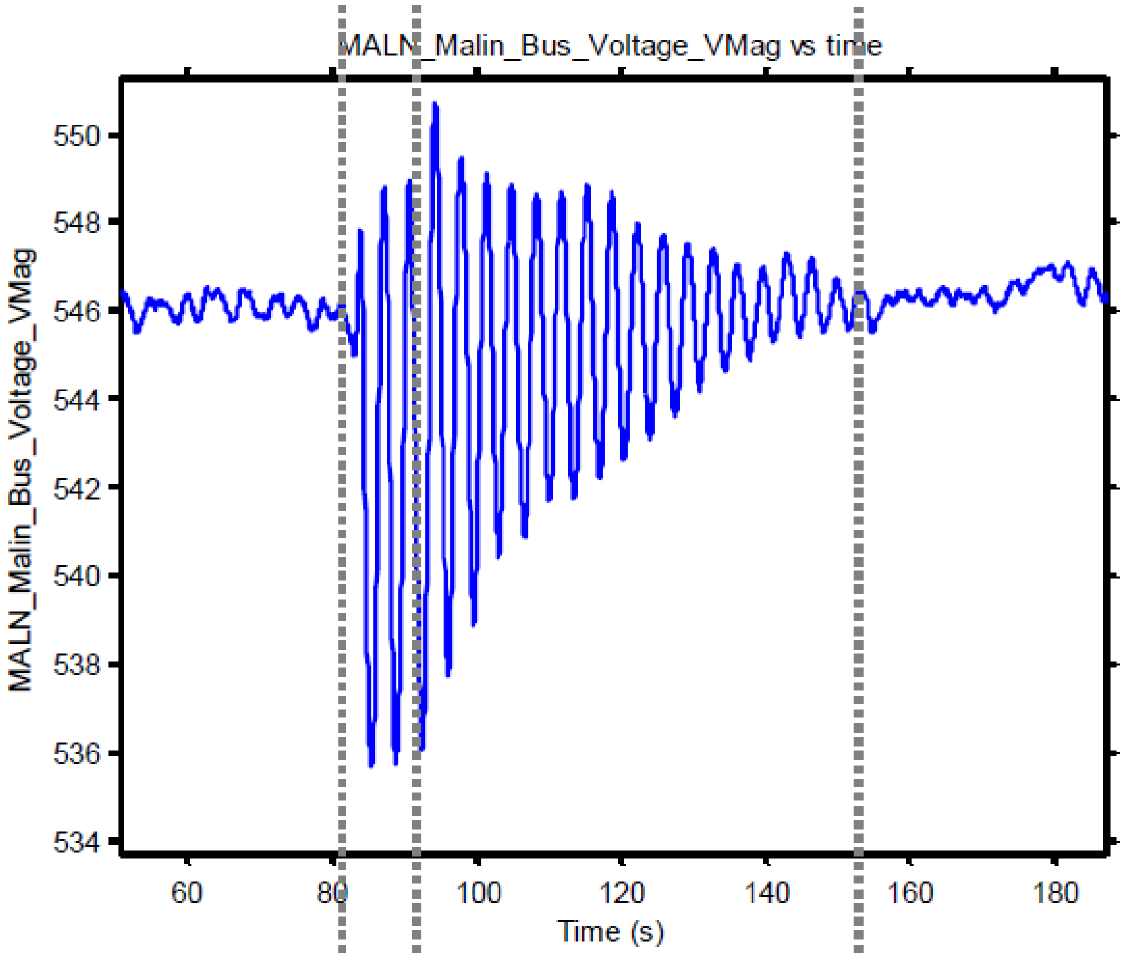
- **Load lost:**
  61,800 MW
- **Generation lost:**
  55,000 MW (508 units)
- **Customers affected:**
  50 million
- **Outage time:**
  Few hours up to 2 weeks
- **Cost:**
  $7-14 Billion

Eastern Interconnect August 14, 2003

Relative phase angle at Cleveland continued to grow for more than an hour



WECC August 4th, 2000 disturbance



- Alberta system separation
- North – South (COI) mode was poorly damped

Summary of PMU benefits

Monitoring:

- Wide-area visibility beyond local control areas
- Monitor oscillations and system damping
- Angle of separation across regions to assess static grid stress
- Estimation of generation trip or load drop location
- Improved state estimation

Planning:

- Dynamic model validation
- Post-mortem analysis

Protection and Control:

- Automatic arming of remedial action schemes

Benefits of synchrophasors

- Enhanced system reliability
- Increased utilization of intermittent renewable generation
- Reduced capacity cost for supporting intermittent renewable generation
- Enable cost-effective solutions to substantially improve transmission system planning, operation, maintenance, and energy trading
- Improved asset utilization

Resources

www.naspi.org
www.wecc.biz
www.phasor-rtdms.com

Questions?

Consuelo Sichon Consuelo.Sichon@energy.ca.gov

Jamie Patterson Jamie.Patterson@energy.ca.gov