Wide Area Measurement Systems - Monitoring and Control for the Grid of the Future

Department of Energy
Transmission Reliability Program

Third Annual Carnegie Mellon Conference on the Electricity Industry

March 13-14, 2007

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Office of Electricity Delivery and Energy Reliability

Transmission Reliability Mission

Develop technologies and technically-based policy options to enhance the reliability and economic efficiency of the Nation's electric power delivery system under competitive electricity markets

Transmission Reliability Projects Summary

- ➢ Real Time Grid Reliability Management
  - – Reliability Adequacy Tools
    - • NERC - Performance metrics research, standards development support, and compliance monitoring prototypes, including visualization
  - – Advanced Measurement and Control
    - • North American Synchro-Phasor Initiative

- ➢ Reliability and Markets
  - – Market Design and Market Monitoring
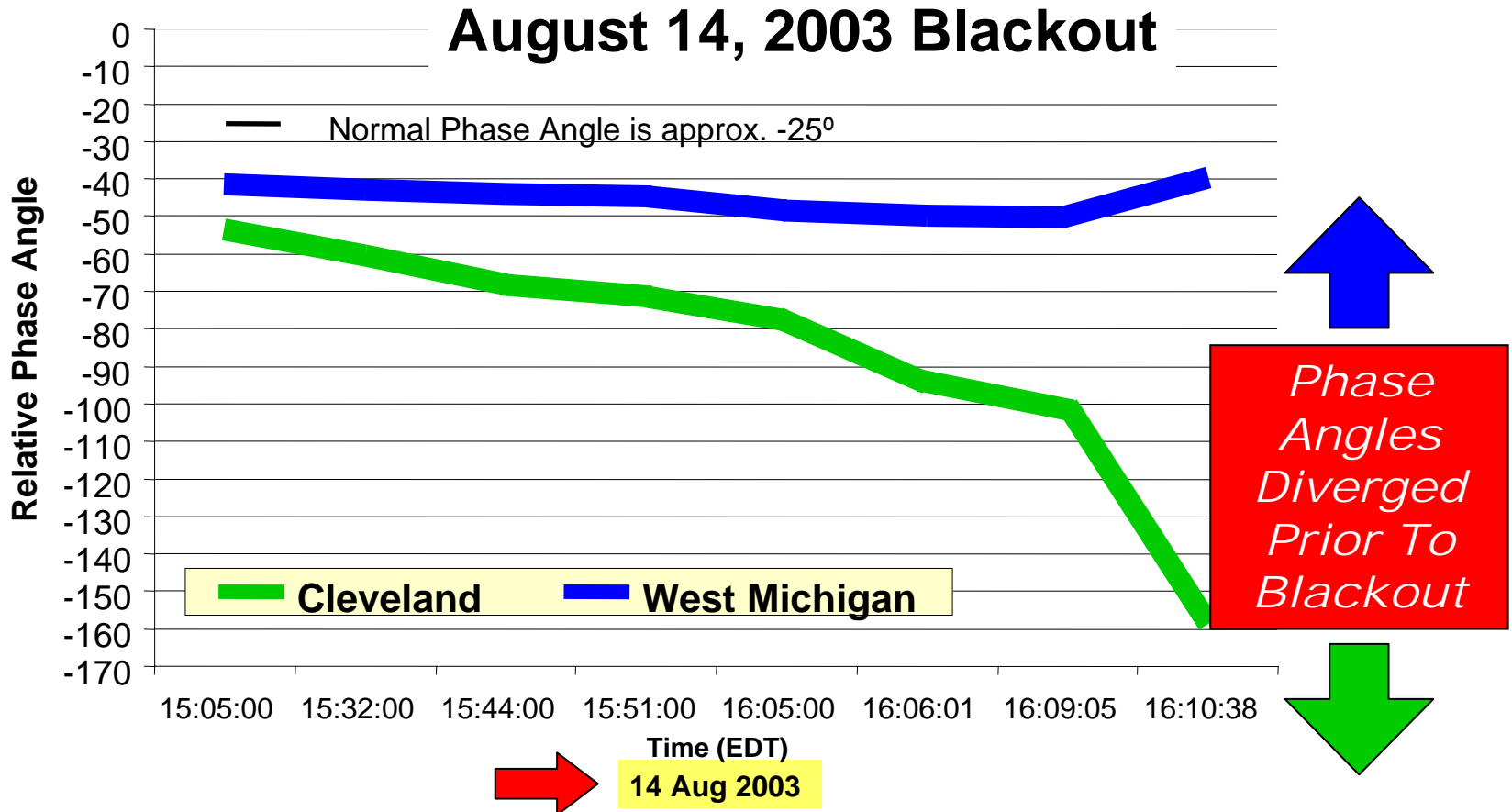
- ➢ Load as a Resource

Power System Reliability Analysis Gaps

➢ Lack of wide-area visibility

➢ Lack of situational awareness

➢ Need for time-synchronized data recorders

– Phasor measurement technology is the solution

Lack of Visibility and Situational Awareness Led to Aug. '03 Blackout

August 14, 2003 Blackout

Normal Phase Angle is approx. -25º

Relative Phase Angle (y-axis, from 0 to -170)

Legend:
- **Cleveland** (green)
- **West Michigan** (blue)

Time (EDT): 15:05:00, 15:32:00, 15:44:00, 15:51:00, 16:05:00, 16:06:01, 16:09:05, 16:10:38

Time (EDT)

14 Aug 2003

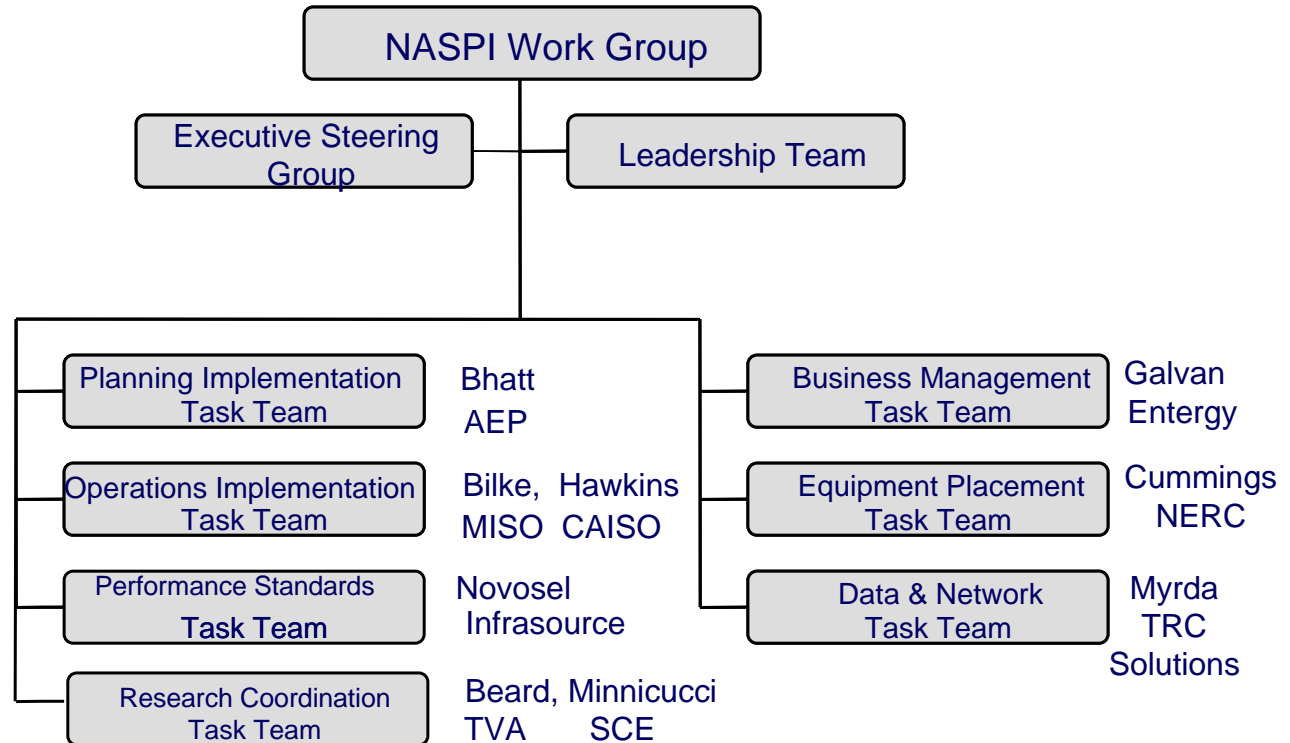**Phase Angles Diverged Prior To Blackout**

Notes:
Angles are based on data from blackout investigation.
Angles are calculated from a Powerflow Simulation.
Angle reference is Browns Ferry.

North American Synchro-Phasor Initiative (NASPI) Elements

- ➢ Leadership Team (led by Phil Overholt/DOE and Stan Johnson/NERC)
- ➢ Participating operating entities investing in equipment and communications
- ➢ Executive Steering Group

NASPI Work Group

Executive Steering Group — **Leadership Team**

Planning Implementation Task Team	Bhatt AEP
Operations Implementation Task Team	Bilke, Hawkins MISO CAISO
Performance Standards Task Team	Novosel Infrasource
Research Coordination Task Team	Beard, Minnicucci TVA SCE

| Business Management Task Team | Galvan Entergy |
| Equipment Placement Task Team | Cummings NERC |
| Data & Network Task Team | Myrda TRC Solutions |

NASPI Work Group
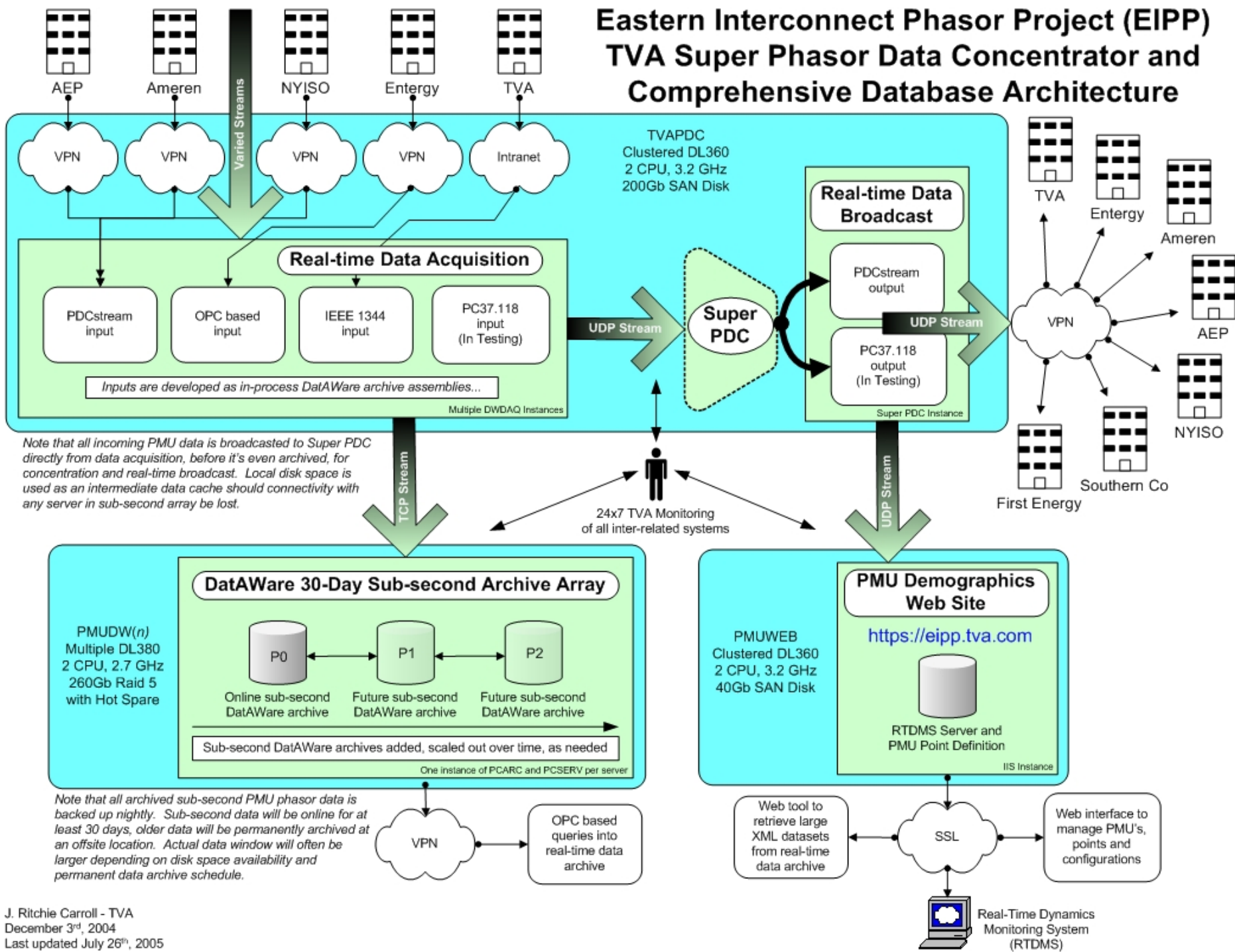
➢ The Work Group's mission is to create a robust, widely available and secure synchronized data measurement exchange network over the North American grid with associated analysis and monitoring tools for better planning and operation, and improved reliability.
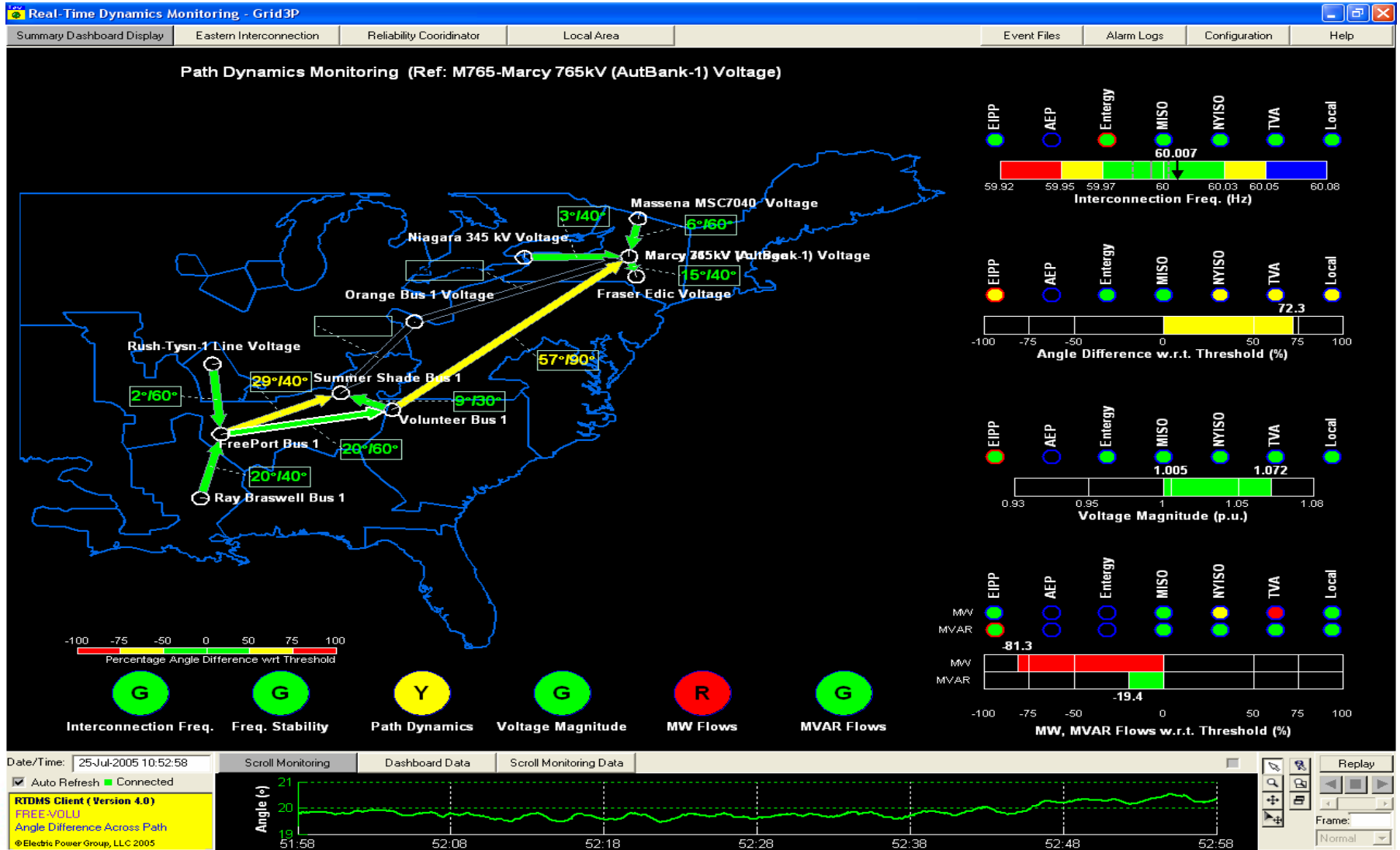
PMU Deployment
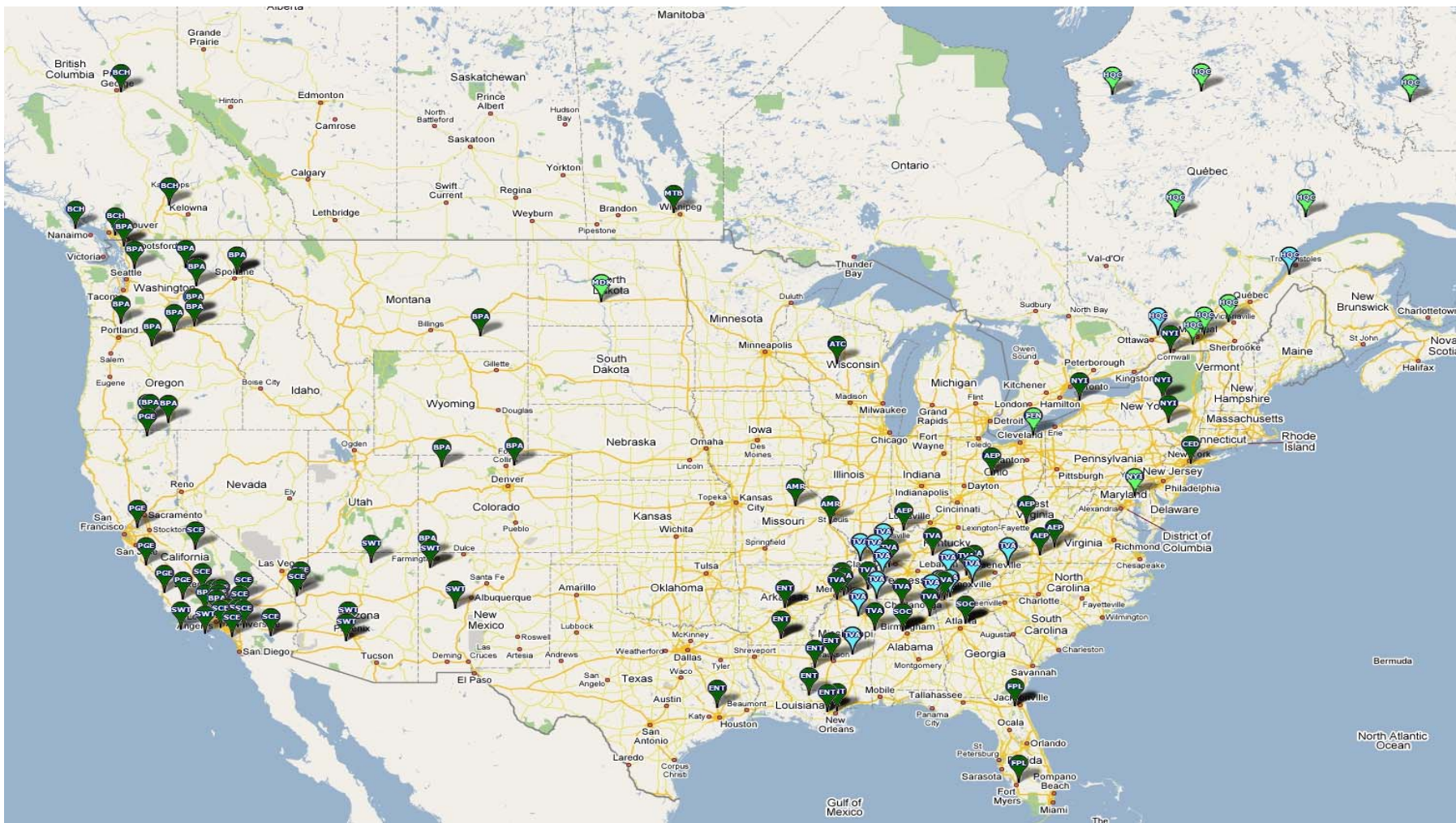
Eastern Interconnect Phasor Project (EIPP) TVA Super Phasor Data Concentrator and Comprehensive Database Architecture

AEP | Ameren | NYISO | Entergy | TVA

VPN | VPN | VPN | VPN | Intranet

Varied Streams

TVAPDC
Clustered DL360
2 CPU, 3.2 GHz
200Gb SAN Disk

Real-time Data Acquisition

PDCstream input | OPC based input | IEEE 1344 input | PC37.118 input (In Testing)

Inputs are developed as in-process DatAWare archive assemblies...

Multiple DWDAQ Instances

Real-time Data Broadcast

PDCstream output | PC37.118 output (In Testing)

Super PDC Instance

UDP Stream → **Super PDC** → UDP Stream → VPN

TVA | Entergy | Ameren | AEP | NYISO | Southern Co | First Energy

Note that all incoming PMU data is broadcasted to Super PDC directly from data acquisition, before it's even archived, for concentration and real-time broadcast. Local disk space is used as an intermediate data cache should connectivity with any server in sub-second array be lost.

TCP Stream

24x7 TVA Monitoring of all inter-related systems

UDP Stream

DatAWare 30-Day Sub-second Archive Array

PMUDW(n)
Multiple DL380
2 CPU, 2.7 GHz
260Gb Raid 5
with Hot Spare

P0 → P1 → P2

Online sub-second DatAWare archive | Future sub-second DatAWare archive | Future sub-second DatAWare archive

Sub-second DatAWare archives added, scaled out over time, as needed

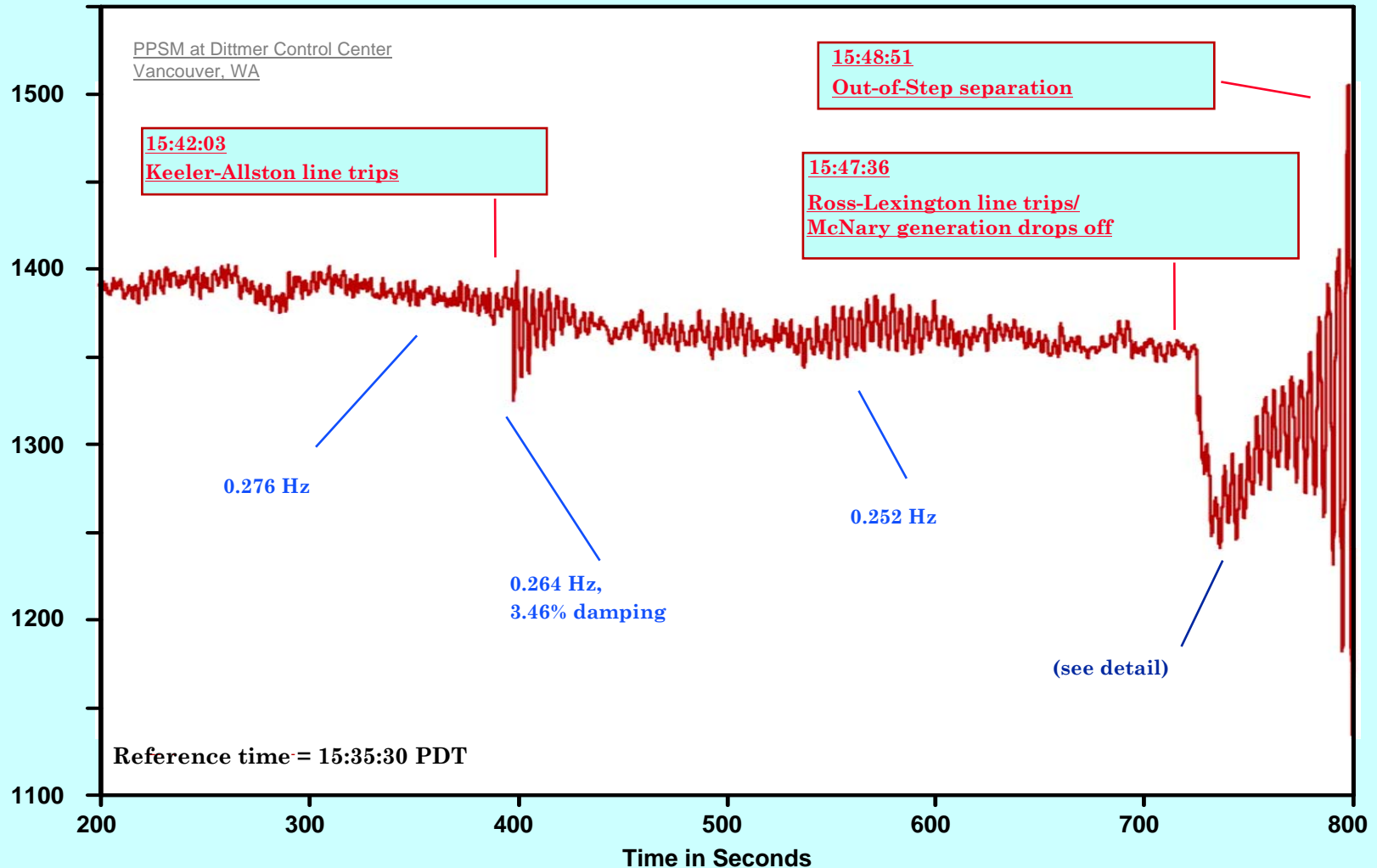One instance of PCARC and PCSERV per server

Note that all archived sub-second PMU phasor data is backed up nightly. Sub-second data will be online for at least 30 days, older data will be permanently archived at an offsite location. Actual data window will often be larger depending on disk space availability and permanent data archive schedule.

VPN → OPC based queries into real-time data archive

PMU Demographics Web Site

https://eipp.tva.com

PMUWEB
Clustered DL360
2 CPU, 3.2 GHz
40Gb SAN Disk

RTDMS Server and PMU Point Definition

IIS Instance

Web tool to retrieve large XML datasets from real-time data archive ← SSL → Web interface to manage PMU's, points and configurations

Real-Time Dynamics Monitoring System (RTDMS)

J. Ritchie Carroll - TVA
December 3rd, 2004
Last updated July 26th, 2005

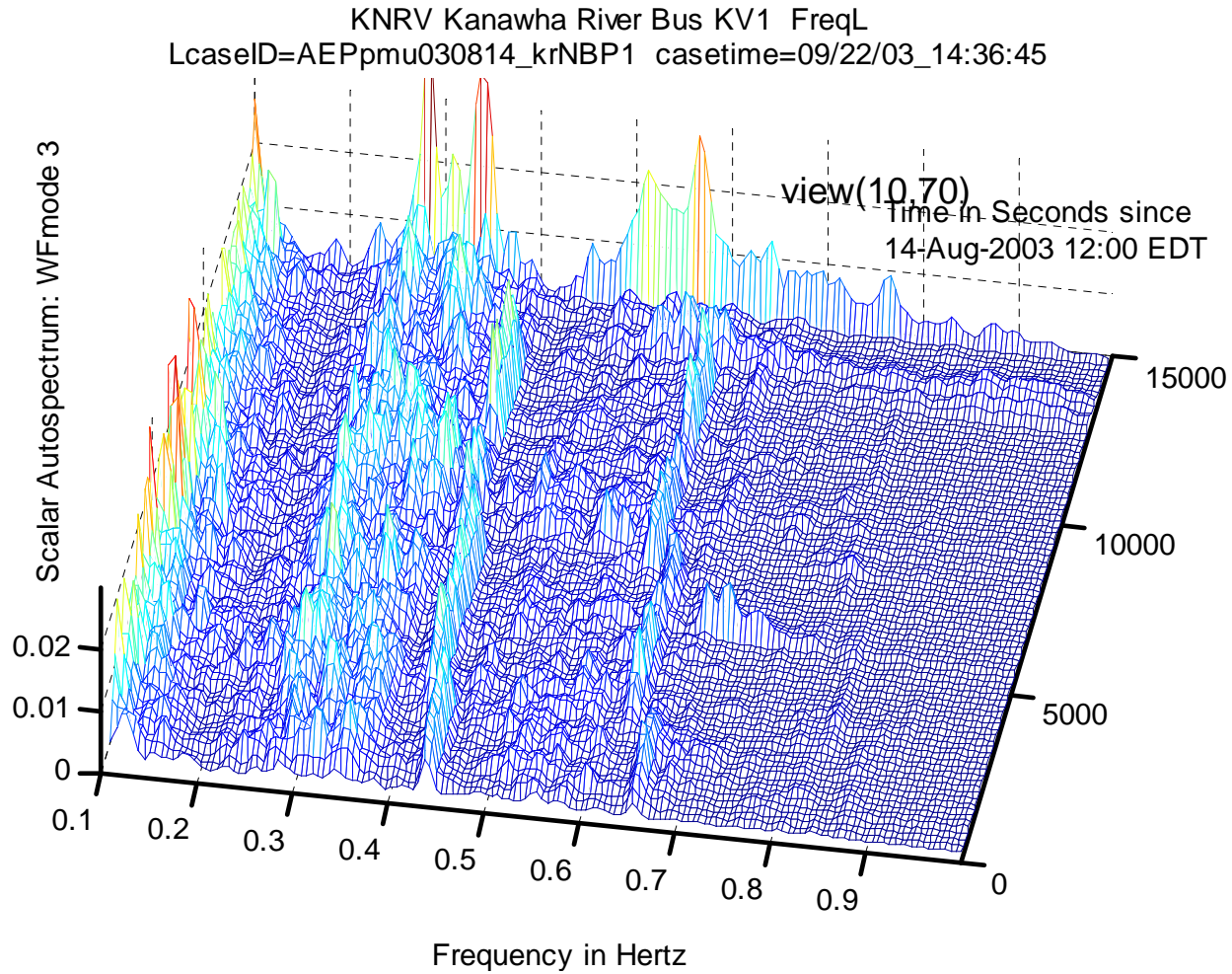# *Real Time Dynamic Monitoring System for Wide Area Phasor Monitoring*

Warning Signs of the August 10, 1996 WSCC Breakup

008 Malin-Round Mountain #1 MW
caseID=Aug10E5loadPF   casetime=04/16/98_14:41:48

PPSM at Dittmer Control Center
Vancouver, WA

15:48:51
Out-of-Step separation

15:42:03
Keeler-Allston line trips

15:47:36
Ross-Lexington line trips/
McNary generation drops off

0.276 Hz

0.264 Hz,
3.46% damping

0.252 Hz

(see detail)

Reference time = 15:35:30 PDT

Time in Seconds

AEP Kanawha River bus frequency for Aug14 Blackout 12:00-16:10 EDT

KNRV Kanawha River Bus KV1 FreqL
LcaseID=AEPpmu030814_krNBP1 casetime=09/22/03_14:36:45

Visualization and Control -- Challenges and Needs for an Evolving Industry Structure

CURRENT AND PROPOSED LEVELS:

MONITORING AND CONTROL:

Wide-Area Level 3

DOE Situation Awareness

Situation Awareness for Emergency Response

Wide Area Level 2

FERC Reliability Standards Performance

Standards Performance, Monitoring, Notification and Reporting

Wide-Area Level 1

NERC Emerging Wide-Area Reliability Performance Monitoring and Compliance

Real Time Wide-Area Monitoring and Compliance for Interconnections Load-Generation, Inter-Area Schedules, And Transmission Adequacy

Level 3

ENERGY MANAGEMENT SYSTEMS (EMS) RTO, ISO, CONTROL AREA

System State Estimation, Security Analysis, and Security Constraint Dispatch

Level 2

SCADA - REGIONAL CONTROL CENTER

Regional Load-Generation and Grid Switching Control

Level 1

LOCAL CONTROL SUBSTATIONS   **LOCAL CONTROL GENERATION PLANTS**
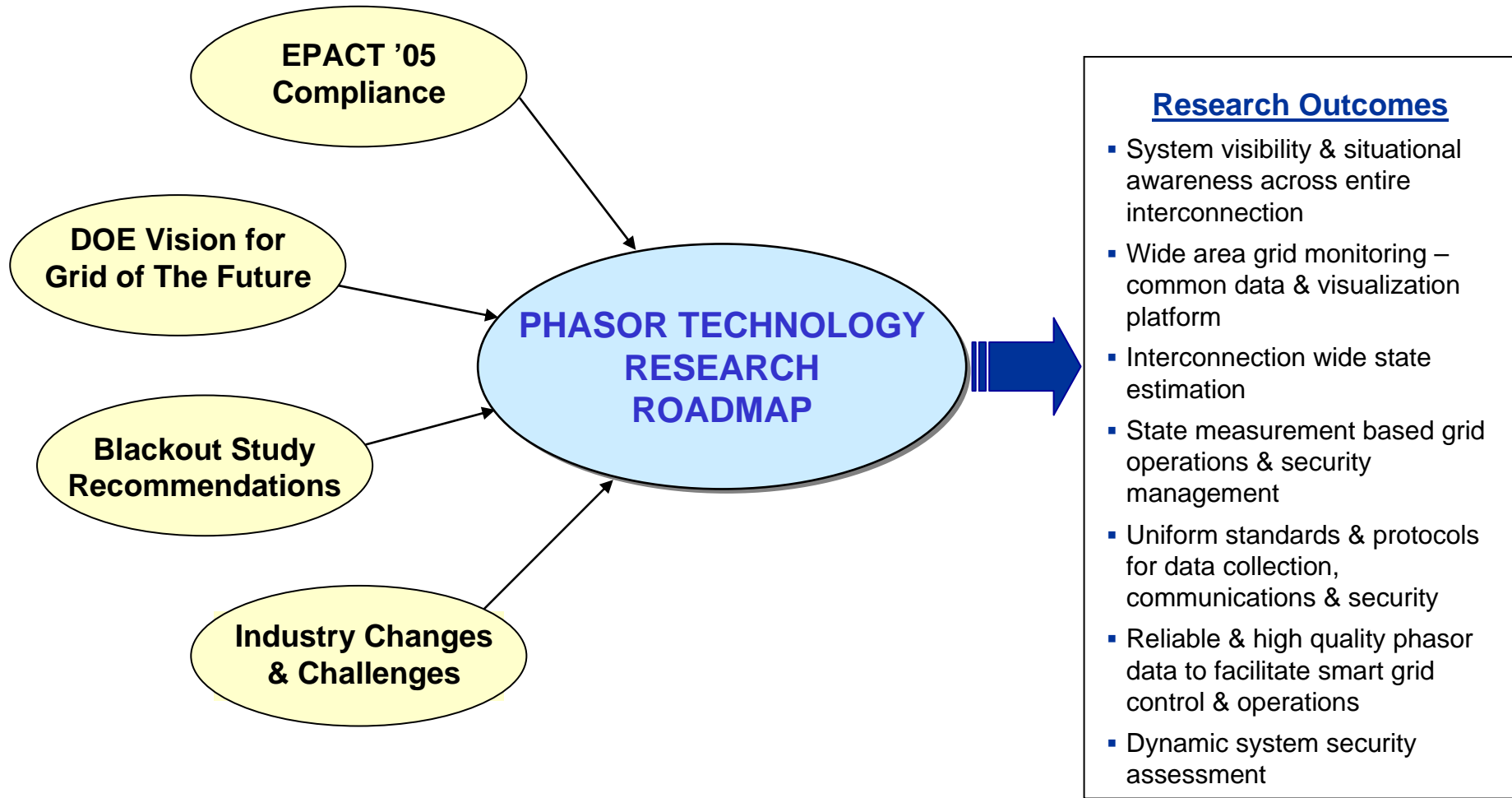
Local Generation and Substation Control

Summary of Research Goals and Milestones

Research Areas	Near-Term(1-2 Years)	Mid-Term (2-5 Years)	Long-Term (5-10 Years)
▪ Visualization ▪ Monitoring ▪ Planning ▪ Phasor Infrastructure Management ▪ Control ▪ Protection ▪ Switching	▪ Wide-area visibility with common situational awareness screens ▪ Baseline normal operating conditions, limits and alarms for EI ▪ Demonstrate improved state estimation with phasor measurements ▪ Model validation for better system understanding ▪ Identify human factors & visualization needs for phasor based operations tools ▪ Define best practices for enhanced grid "forensics" ▪ Design next generation data and communications infrastructure ▪ Define research and demonstration approach for real-time control ▪ Identify research needs for federal investment	▪ Wide-area visibility with full coverage ▪ Approaching real-time state measurement for operators ▪ Dynamic system security assessment tools ▪ Common operator tools deployed ▪ Congestion management ▪ Dynamic ratings ▪ Improved LMP ▪ Work with industry to initiate major demonstration of real-time control for dynamic security ▪ Work with industry to demonstrate adaptive islanding protection concepts to improve protection from wide-area blackouts ▪ Develop strategy for next-generation operational tool concepts	▪ Real-time protection ▪ Distributed closed loop control ▪ Automatic smart-switchable networks
	2006 - 2007	**2007 - 2010**	**2010 - 2015**

Phasor Technology Vision & Roadmap -- Summary

EPACT '05 Compliance

DOE Vision for Grid of The Future

Blackout Study Recommendations

Industry Changes & Challenges

PHASOR TECHNOLOGY RESEARCH ROADMAP

Research Outcomes

- System visibility & situational awareness across entire interconnection
- Wide area grid monitoring – common data & visualization platform
- Interconnection wide state estimation
- State measurement based grid operations & security management
- Uniform standards & protocols for data collection, communications & security
- Reliable & high quality phasor data to facilitate smart grid control & operations
- Dynamic system security assessment

Advanced Energy Initiative

➢ Develop advanced batteries for plug-in hybrid-electric vehicles

➢ Complete clean coal technology research funding and move resulting innovations into the marketplace

➢ Develop a new Global Nuclear Energy Partnership to address spent nuclear fuel, eliminate proliferation risks, and expand the promise of clean, reliable, and affordable nuclear energy

➢ Reduce the cost of solar photovoltaic technologies,….. and expand access to wind energy through technology

www.eere.energy.gov/cleancities/toolbox/pdfs/energy_booklet.pdf