

Development of A Comprehensive Software Suite for Stability Monitoring and Analysis Based on Synchrophasor Measurement (DOE-OE0000700)

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Burns & McDonnell Introduction

- ▶ Founded in 1898
- ▶ A full-service engineering, architecture, construction, environmental and consulting solutions firm
- ▶ Headquartered in Kansas City, Missouri
- ▶ 5000+ full-time employee-owners
- ▶ 100% employee-owned since 1986
- ▶ 39 offices around the world
- ▶ **Business & Technology Services (BTS)**

- ▶ BTS Resources

- Professional engineers
 - EEs, MEs, CEs, IEs
- Business consultants
 - Finance, economics, MBA
- Information management experts
- Computer programmers
- Security consultants
 - Certified Protection Professionals (CPP)
 - Physical Security Professionals (PSP)
 - Certified Information Systems Security Professionals (CISSP)

- ▶ BTS Consulting Services

- Transmission & Distribution
- Utility Operations
- Due Diligence
- Renewables Integration
- Smart Grid
- Information Technology
- Physical Security
- Critical Infrastructure Protection

Project Overview

- ▶ Project Title: Development of A Comprehensive Software Suite for Stability Monitoring and Analysis Based on Synchrophasor Measurement
- ▶ DOE Award #: DOE-OE0000700
- ▶ In response to “DOE FOA-0000970 - Pre-Commercial Synchrophasor Research and Demonstration”
- ▶ Project Duration 24 months (10/1/2014 - 9/30/2016)
- ▶ DOE Funds: \$1,458,181
- ▶ Recipient cost share: \$1,541,936

Project Objectives

▶ Project Objectives

- Advance the pre-commercial development and deployment of synchrophasor-based stability monitoring applications **to improve Southern Company's near real-time stability monitoring and analysis** in its control centers.
- Develop training materials, operating manuals, and core technology **to enhance the reliability of bulk power system operations and planning.**

▶ Key Activities

- **Develop a production level comprehensive software suite** (named Grid Stability Awareness System - GSAS) for power system near real-time stability monitoring and analysis based on synchrophasor measurement
- **Deploy the software suite to one of Southern Company's control centers** by the end of the project
- **Establish relevant operating guidelines**, training materials, training sessions for grid operators and engineers

Project Benefit Opportunities

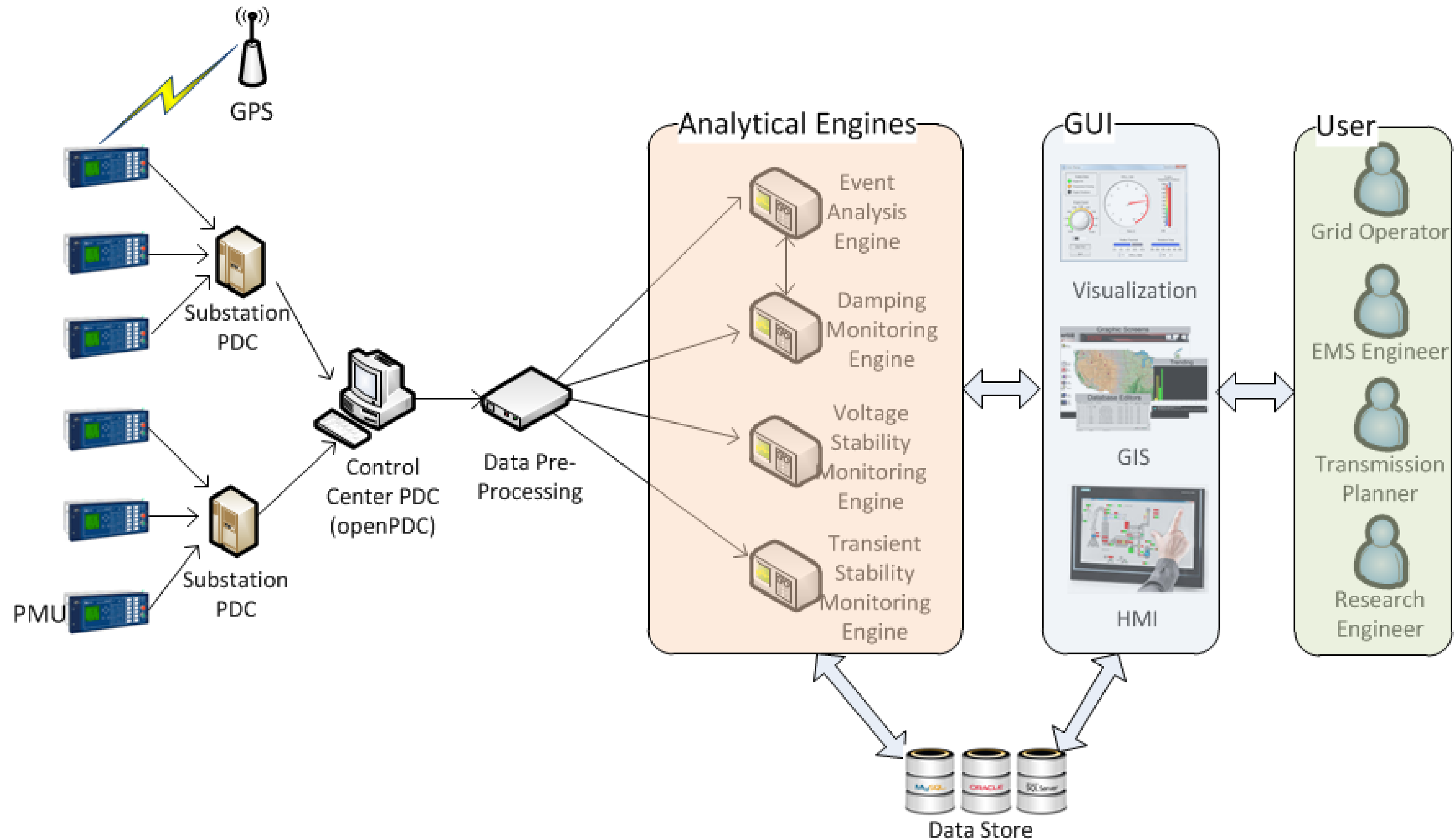
- ▶ Improve:
 - Oscillation detection
 - Voltage stability monitoring
 - Transient instability prediction
- ▶ Enhance situational awareness of grid operators
- ▶ Progress operating standards for synchrophasor technology

Project Team Members

- ▶ **Burns & McDonnell – Grant Recipient, software development and deployment**
 - Manage project budget and schedule, and coordinate all activities among all team members and subcontractors
 - Design, develop, test and deploy the software suite in an operating environment
 - Develop training materials for grid operators
- ▶ **Southern Company - Software demonstration host**
 - Host the demonstration of the software suite
 - Work with software development and deployment team to collect requirements and operator feedback
 - Develop relevant operating guidelines
- ▶ **Washington State University - Technology provider**
 - Develop and provide executable analytical engines
 - Improve on the methodologies, algorithms ,and performance of the analytical engines
 - Assist in the development of training materials
- ▶ **Grid Protection Alliance - Data layer product consultant**
 - Provide technical support for using openPDC
 - Coordinate in the development of data pre-processing modules

Overview of System Architecture

► Grid Stability Awareness System (GSAS)



Key Modules of GSAS

▶ Analytical Engines

- **Event Analysis Engine** – Detect events resulting in sudden changes in damping. Use multiple algorithms and rule base.
- **Damping Monitoring Engine** - Monitor synchrophasor data in real-time to detect growing or poorly damped oscillations in the early stages of an event.
- **Voltage Stability Monitoring Engine** - Indicate voltage stability stress, estimates voltage stability margin for a large area of the system.
- **Transient Stability Monitoring Engine** - Detect transient events, transient instability trends, and fast separation of phase angles among the critical areas automatically.

▶ Graphic User Interface (GUI)

- **Visualization** - Visualize real-time synchrophasor data, analytical outputs (including both static information and time-series data), etc.
- **Human-Machine Interaction (HMI)** - Show warning messages, perform historical event and data analysis, etc.
- **Geographic Information System (GIS)** - Show topology of high voltage transmission network, and PMU and event location information, etc.

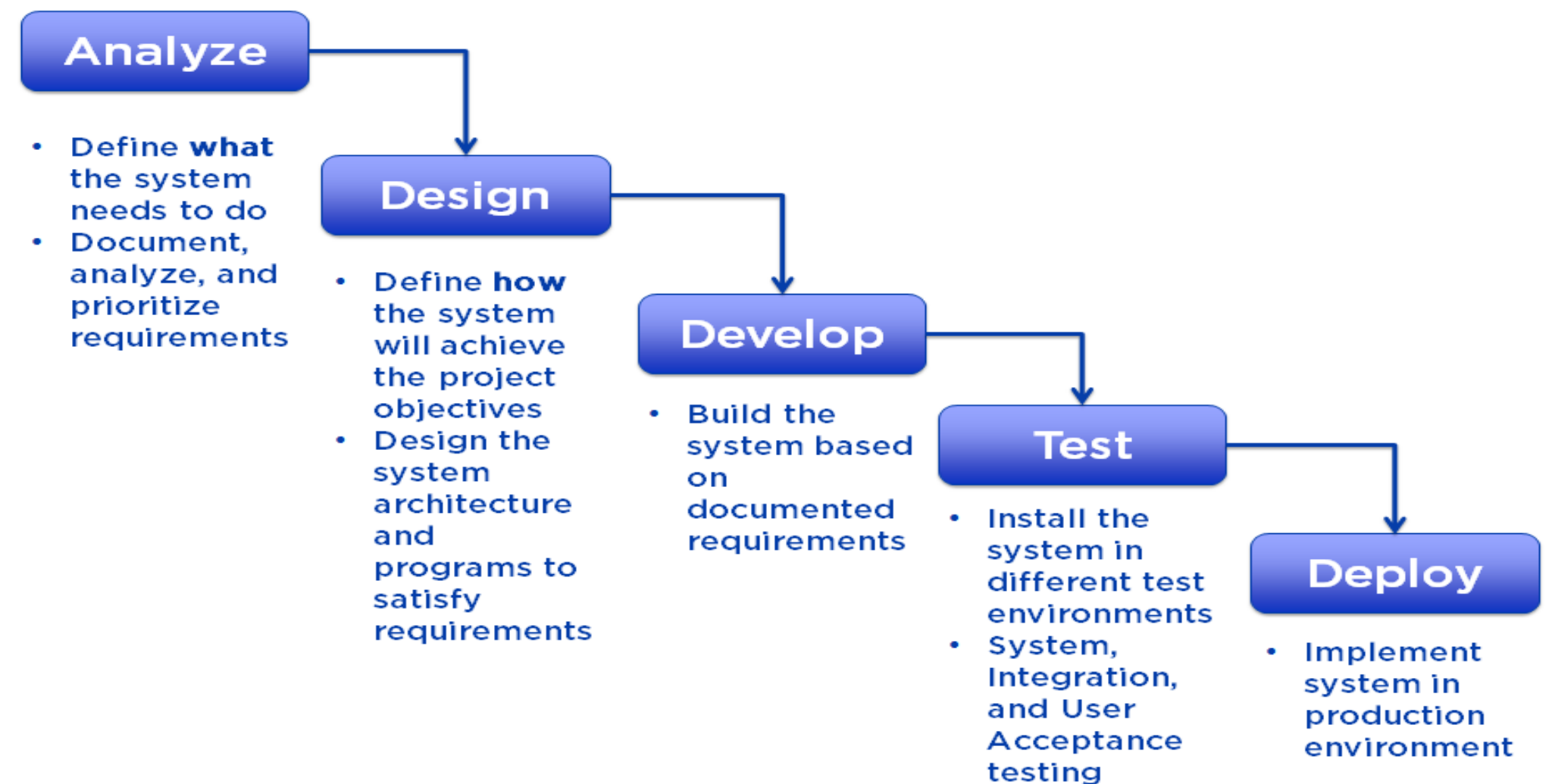
▶ Data Processing

- **Data Pre-Processing** - Detect and processes bad or missing data in a real-time mode.
- **Data Store** - Archive synchrophasor data before and after an event's occurrence.

Iterative Development Approach

▶ Traditional Waterfall Process

- No working software is produced until late in the product life cycle
- Difficult to implement user change requests
- Labor and time intensive



▶ Agile Development Process

- Iterative and incremental development
- Develop/deliver incremental executable releases of the solution with each iteration
- Receive timely feedback from users
- Clearly define requirements and decrease the number of user change requests

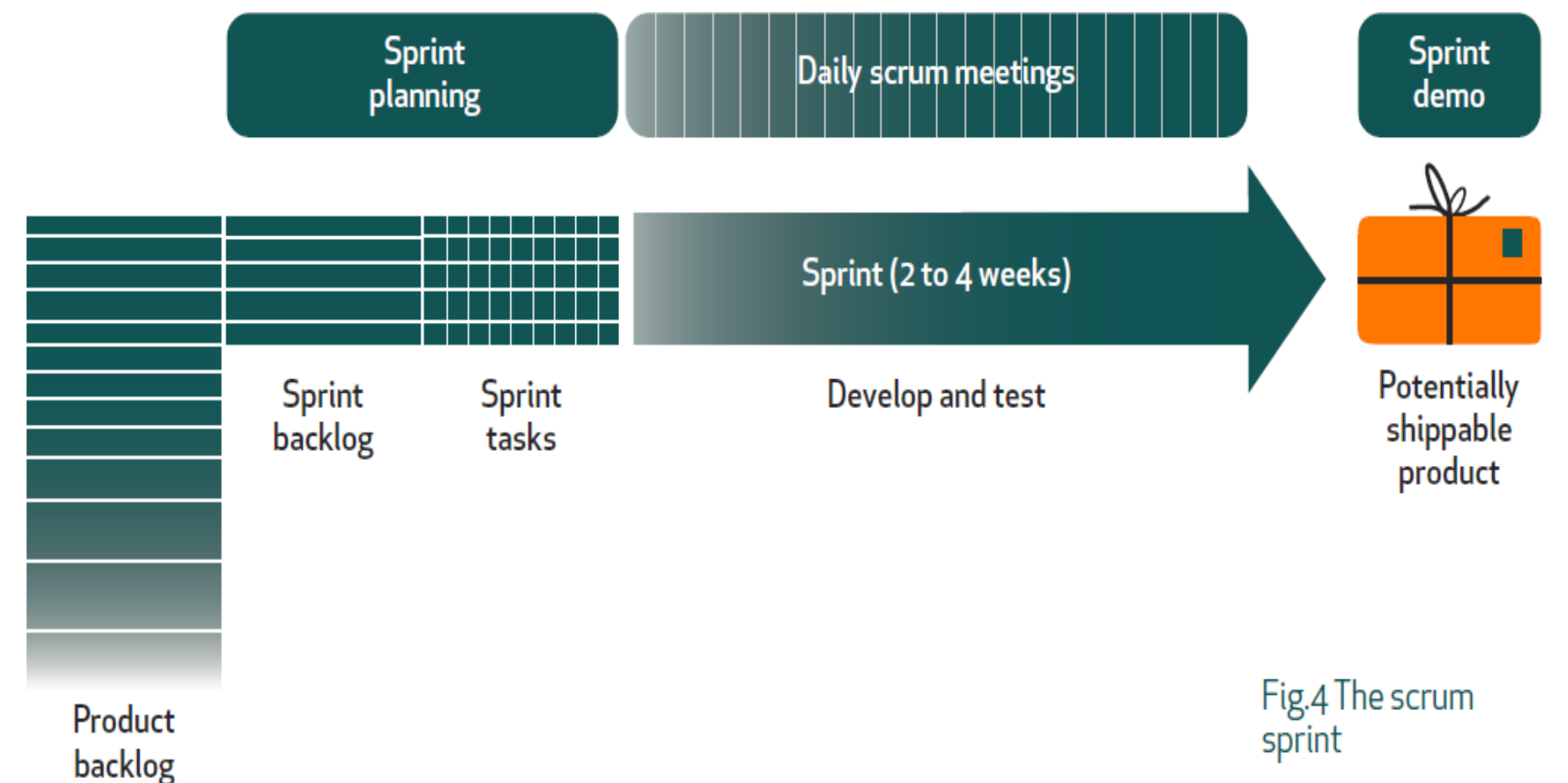


Fig.4 The scrum sprint

Project Progress

► Project Tasks

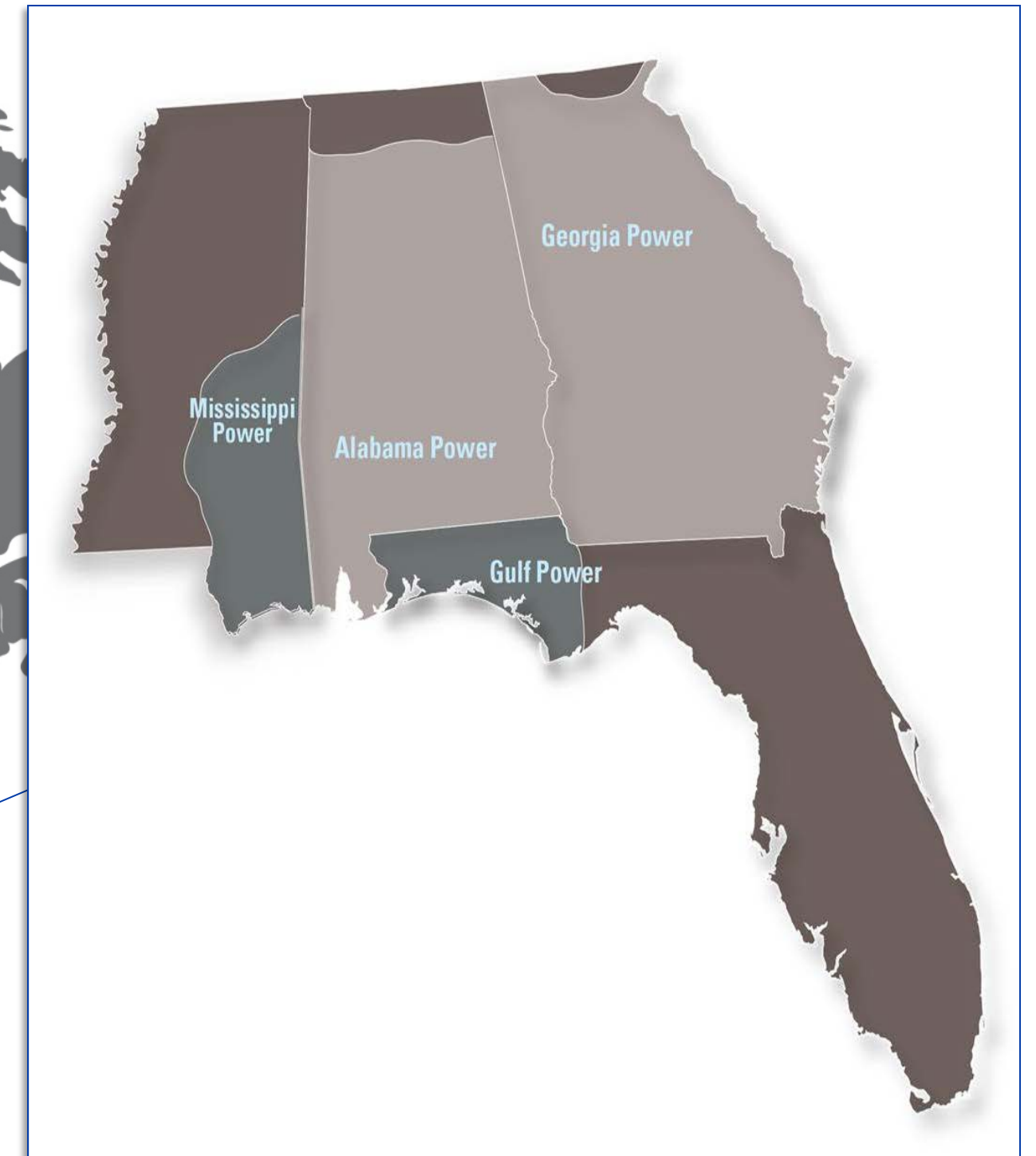
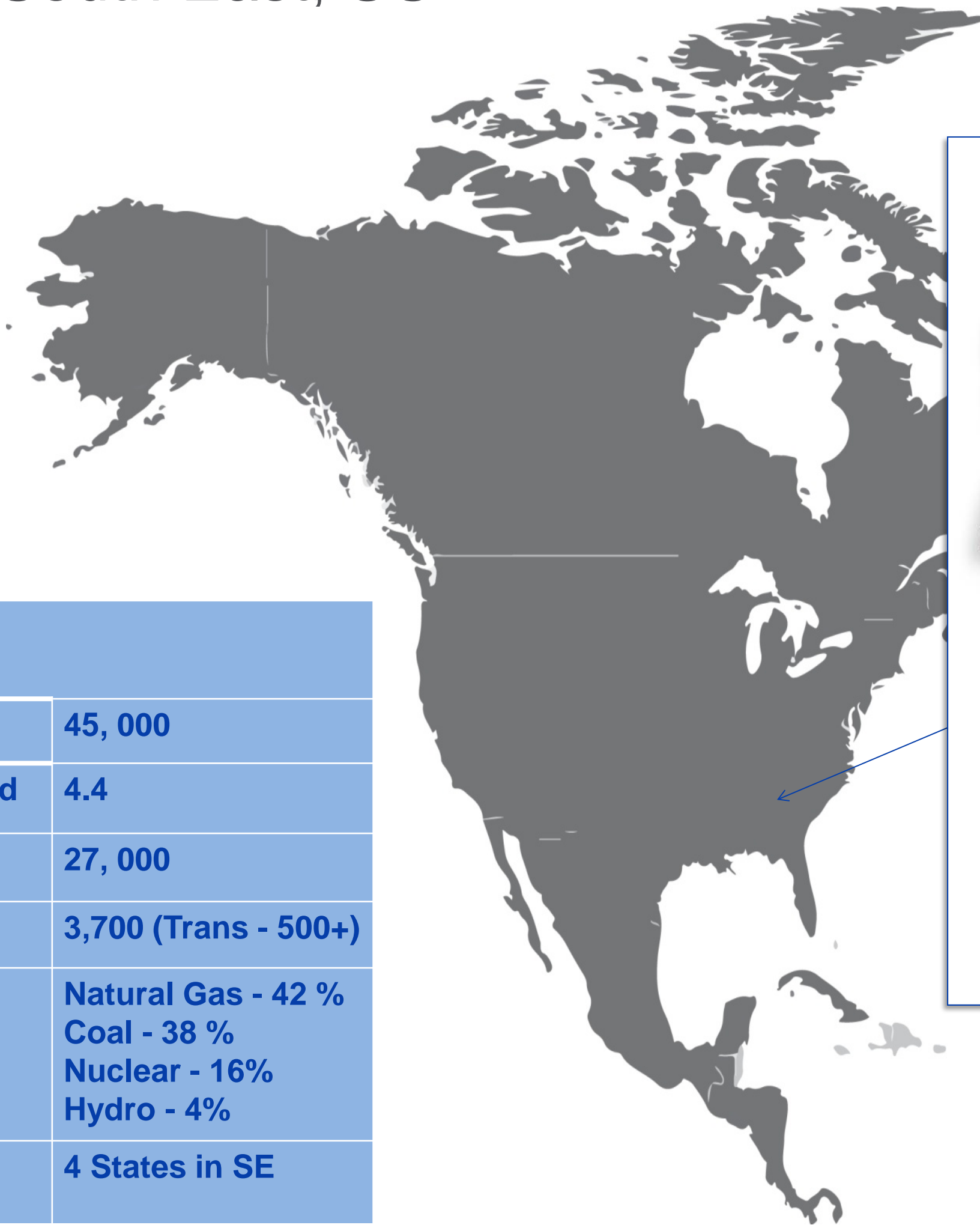
#	Tasks
Task 1	Project Management & Planning
Task 2	Define Software Suite Roadmap and Plans for Development, Deployment & Evaluation of Performance
Task 3	Develop and Refine Analytical Tools (Engines)
Task 4	Software Suite Development
Task 5	Software Suite Deployment
Task 6	Develop Training Materials and Operating Guidelines

► Progress (as of March, 2015)

Milestones	Estimated Completion
Project Kick-off meeting at Southern Company	Complete
An on-site interview meeting at Southern Company	Complete
Draft software requirement specifications	Complete
Define software suite roadmap and plans for development, deployment & evaluation of performance	80% Complete
Develop and refine analytical tools (engines)	On Going

Southern Company – An Overview

- ▶ Located in South East, US



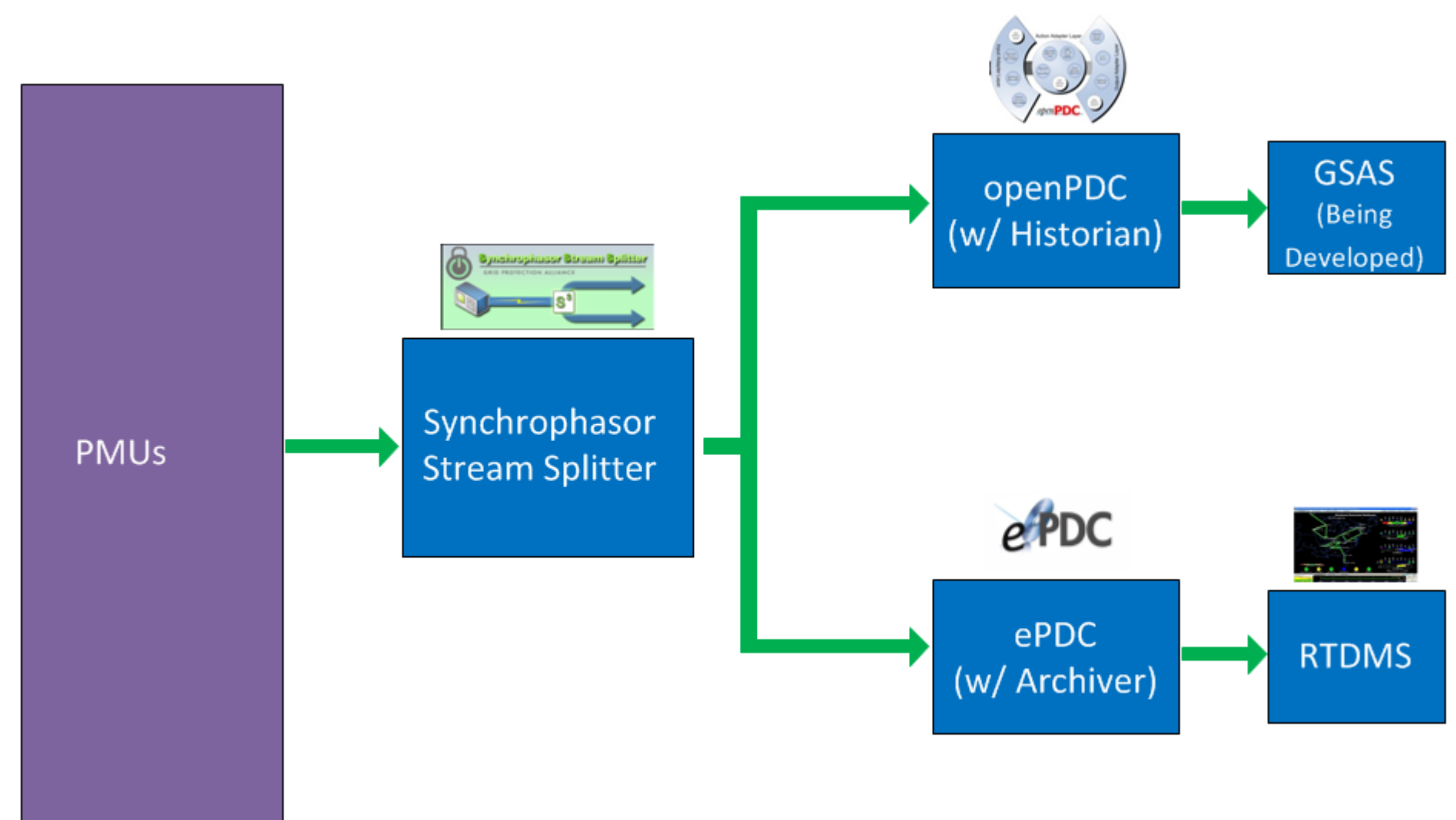
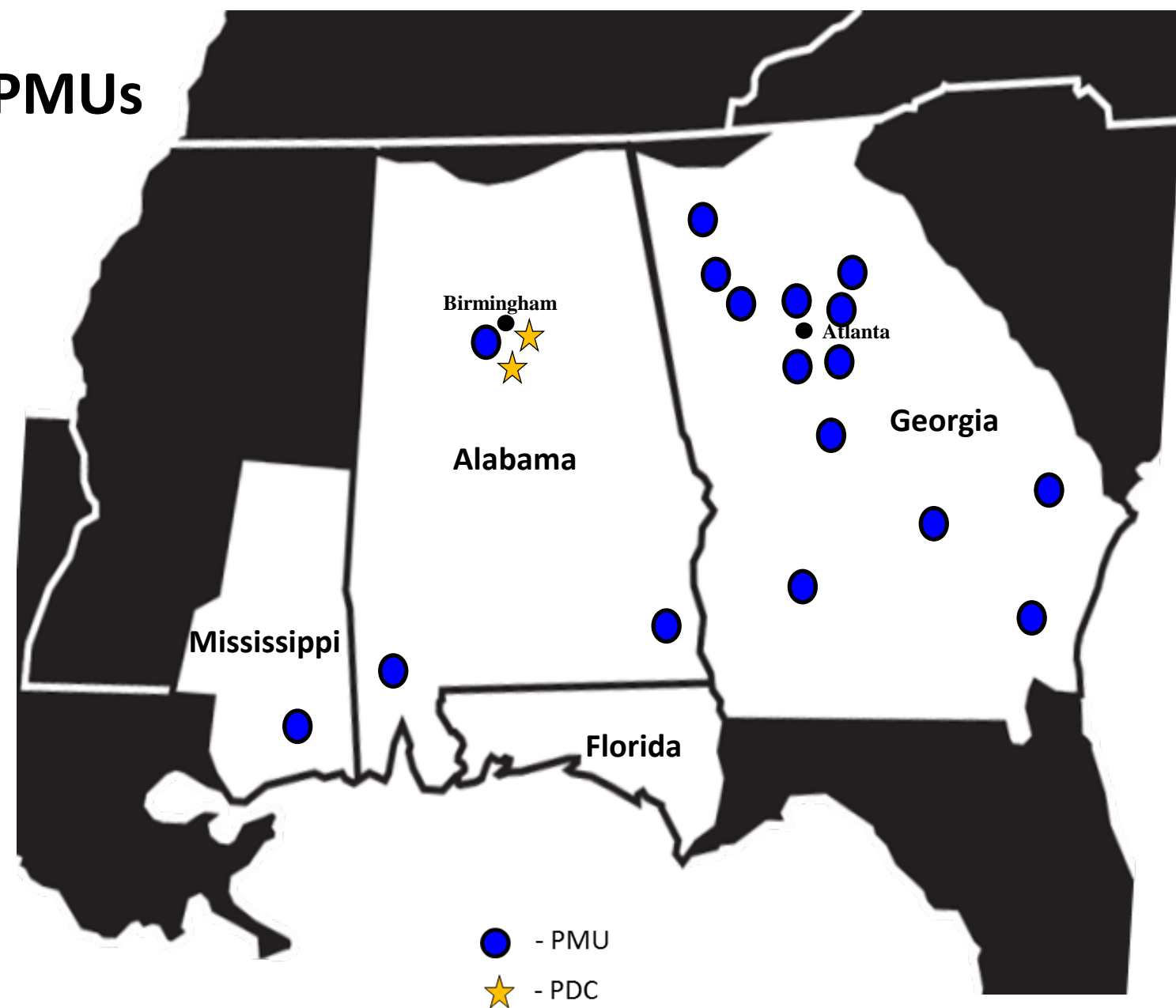
KEY STATISTICS

Generating Capacity in MW	45, 000
Millions of Customers served	4.4
Miles of Transmission lines	27, 000
Number of Substations	3,700 (Trans - 500+)
Generation Mix	Natural Gas - 42 % Coal - 38 % Nuclear - 16% Hydro - 4%
Area served	4 States in SE

Southern Company's Architecture

► PMUs, PDCs and Data Archiving

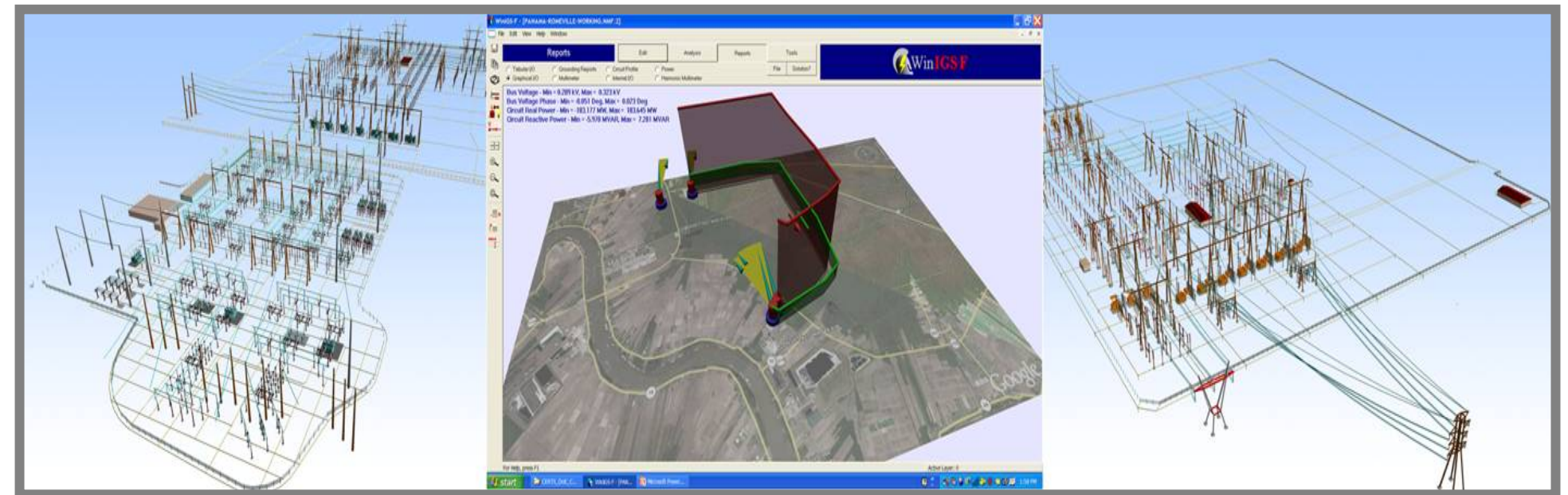
17 PMUs



Sample Synchrophasor Activities



Post Event Analysis & Model Validation



Distributed State Estimator, Generator Parameter Estimation & Stability Monitoring

SMALL SIGNAL STABILITY MONITORING
For low frequency oscillatory modes, tracking damping and oscillatory behavior.
Detect dangerous oscillations which could result in grid separation (e.g. 1996 WECC breakup).

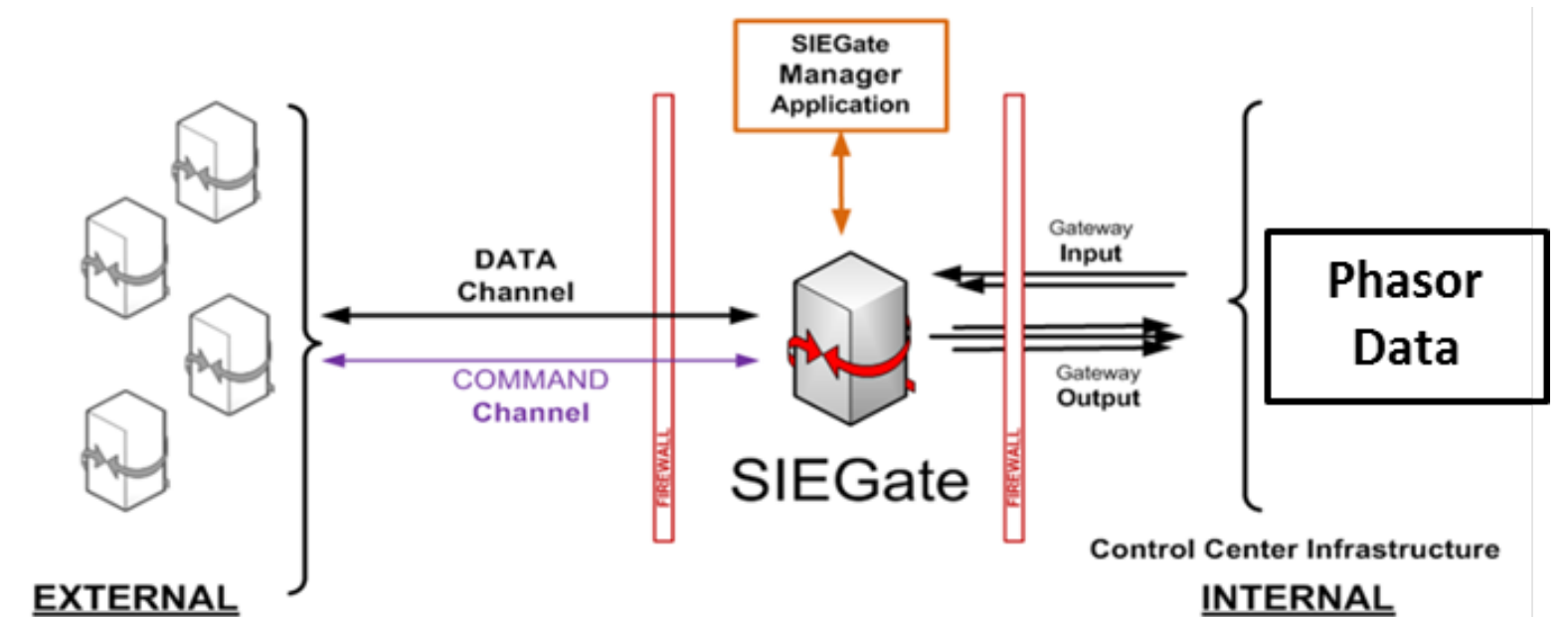
VOLTAGE STABILITY MONITORING
Measurement based dynamics provide voltage sensitivities; monitoring of key corridors or load pockets; Scatter plots for Power-Voltage and Power-Angle monitoring.
Assess proximity to voltage collapse conditions.

DASHBOARD DISPLAY
Situational Awareness— visualization of the overall grid health; attention grabbing traffic lights signal alarms. Gauges quantify the metrics and identify the problem locations.

DETECTION OF GRID STRESS
Real Time tracking of Angular Separations provide an accurate pulse of the stresses on the grid.
Assess high stressed conditions across major interfaces which can lead to cascading blackouts (e.g. 2003 Northeast Blackout).

CONFIGURABLE ALARMS
Triggered by threshold and rate of change violations. Integrates external alarms (FNET). System logs all alarms, events are automatically recorded into event files for offline analysis. Alarm parameters can be set for individual signals, centrally at the RTDMS Server.

Assessment of RTDMS – Wide-Area Situational Awareness Tool



A Security Hardened application for the exchange of Synchrophasor data with other utilities – Pilot Assessment

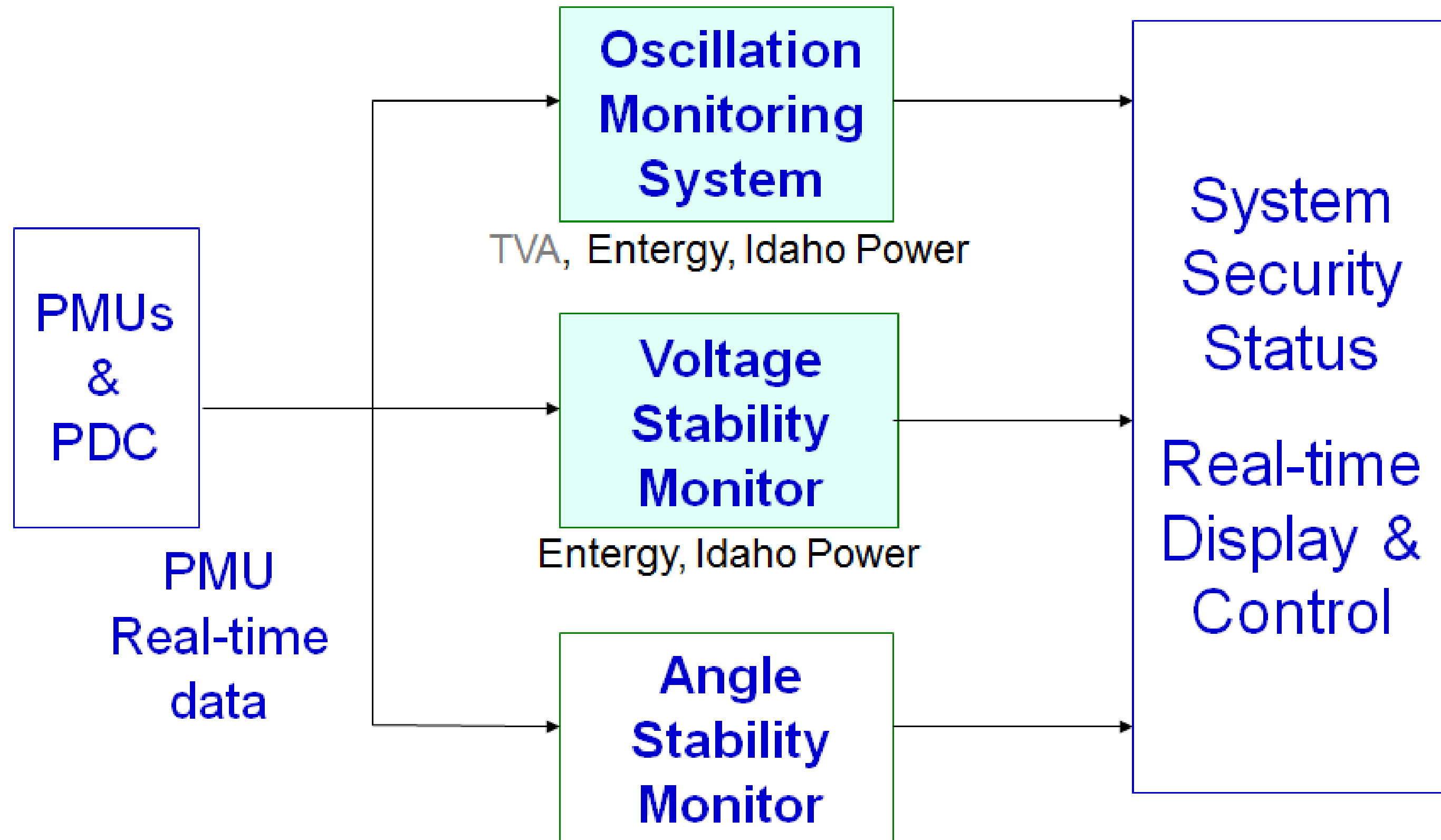
► Support ongoing research with other project partners like EPRI & CEATI

Utility Project Member

- ▶ Software Demonstration Host
- ▶ Cross Functional Project Team: Research, Transmission Planning, Grid Operations, Energy Management Systems (EMS) & Information Technology
- ▶ Work with software development & deployment teams on integration requirements & operator feedback
- ▶ Work with project team on relevant operating guidelines and training materials



Real-Time Security Monitors @ WSU



Oscillation Monitors

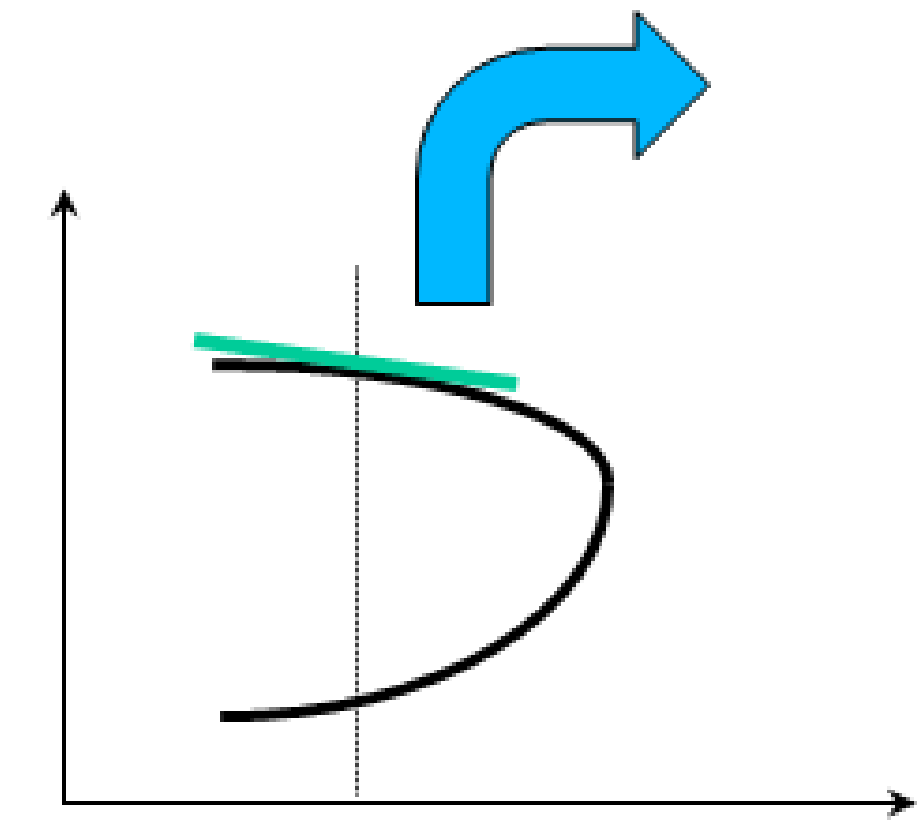
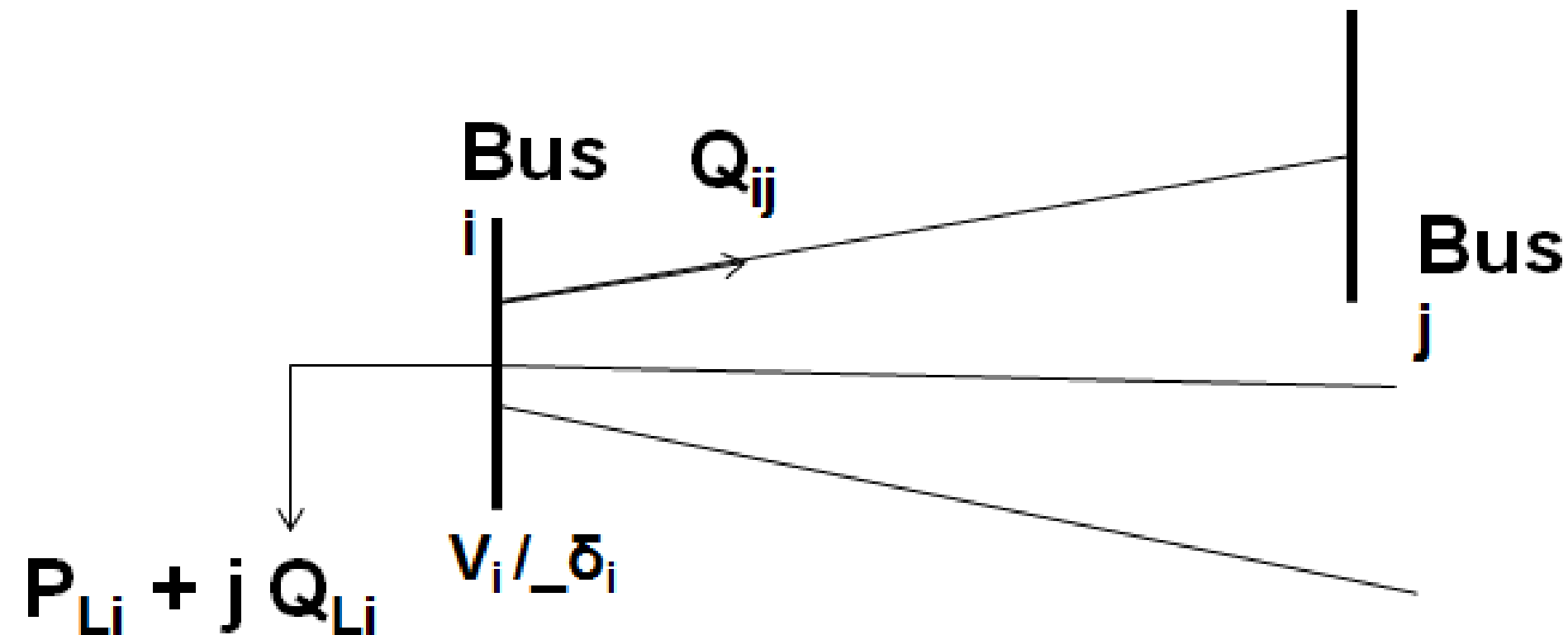
▶ Event Analysis Engine (EAE)

- Multiple algorithms and rule base
- Prony, Matrix Pencil, HTLS, and ERA
- Aimed at events resulting in sudden changes in damping

▶ Damping Monitor Engine (DME)

- Ambient noise based. Continuous. Provides early warning on poorly damped modes.
- Frequency Domain Decomposition (FDD)

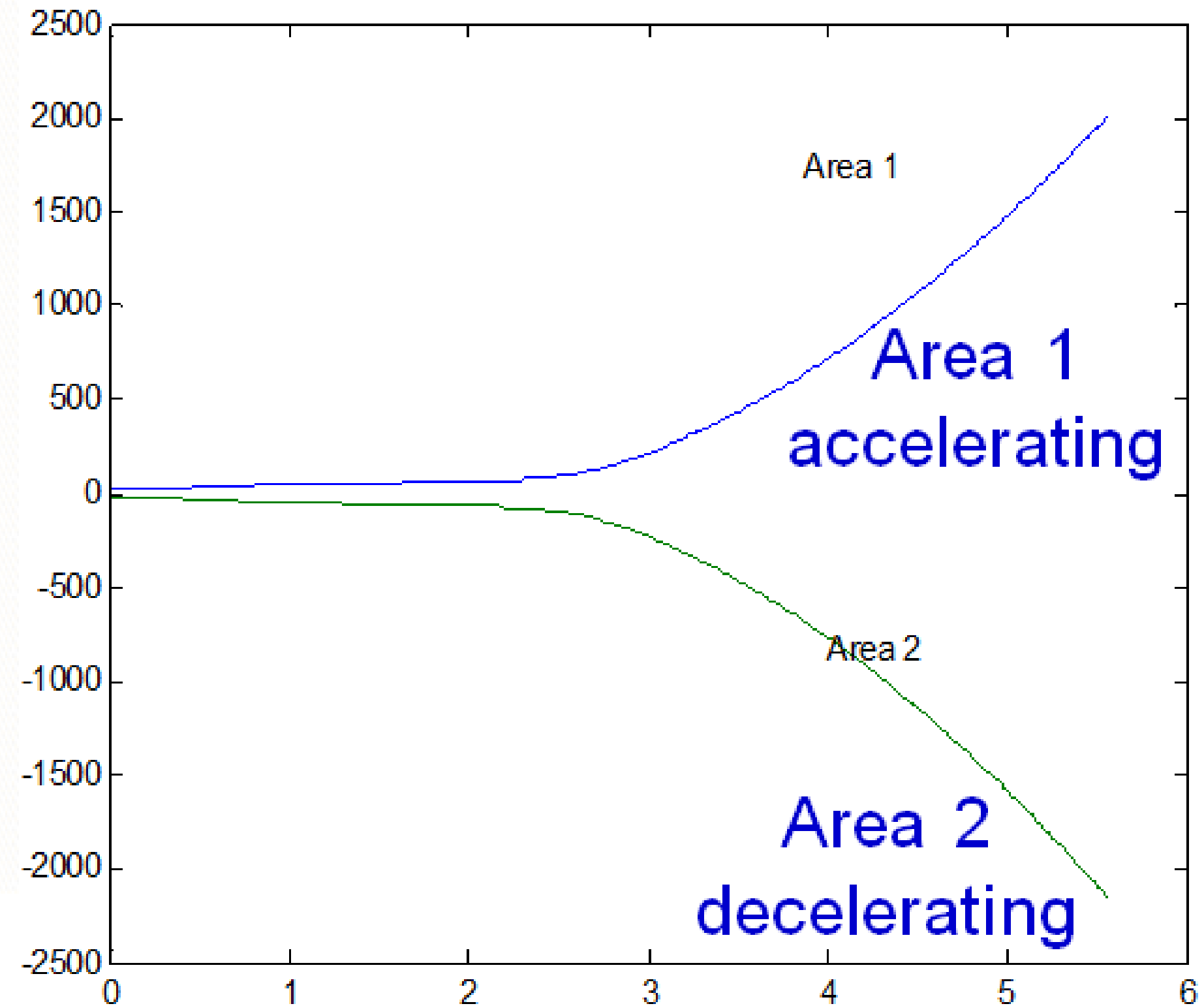
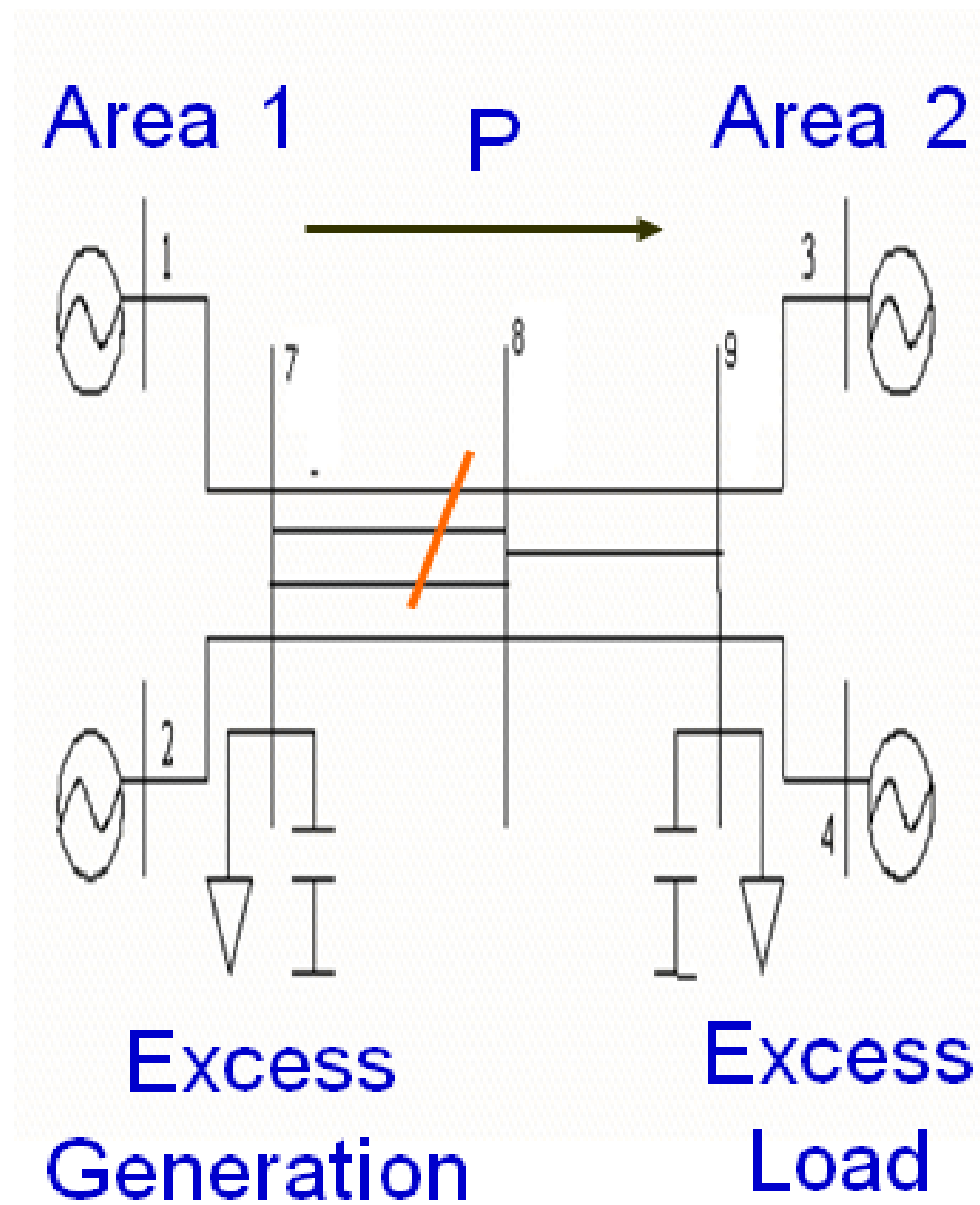
Voltage Stability Monitor



$$\Gamma_i = \partial Q_i / \partial V_i = \sum \partial Q_{ij} / \partial V_i$$

- Γ_i is the slope of QV curve at Bus i
- Γ_i small near static voltage stability limit
- Γ_i directly estimated from ambient PMU data

Angle Stability Monitor



Monitor the phase angles
with respect to system center

