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
## Project Progress

### Project Tasks

<table>
<thead>
<tr>
<th>#</th>
<th>Tasks</th>
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<tbody>
<tr>
<td>Task 1</td>
<td>Project Management &amp; Planning</td>
</tr>
<tr>
<td>Task 2</td>
<td>Define Software Suite Roadmap and Plans for Development, Deployment &amp; Evaluation of Performance</td>
</tr>
<tr>
<td>Task 3</td>
<td>Develop and Refine Analytical Tools (Engines)</td>
</tr>
<tr>
<td>Task 4</td>
<td>Software Suite Development</td>
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<td>Task 5</td>
<td>Software Suite Deployment</td>
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<td>Task 6</td>
<td>Develop Training Materials and Operating Guidelines</td>
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### Progress (as of March, 2015)

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Estimated Completion</th>
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<tbody>
<tr>
<td>Project Kick-off meeting at Southern Company</td>
<td>Complete</td>
</tr>
<tr>
<td>An on-site interview meeting at Southern Company</td>
<td>Complete</td>
</tr>
<tr>
<td>Draft software requirement specifications</td>
<td>Complete</td>
</tr>
<tr>
<td>Define software suite roadmap and plans for development, deployment &amp; evaluation of performance</td>
<td>80% Complete</td>
</tr>
<tr>
<td>Develop and refine analytical tools (engines)</td>
<td>On Going</td>
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Southern Company – An Overview

- Located in South East, US

<table>
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<tr>
<th>KEY STATISTICS</th>
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<tbody>
<tr>
<td>Generating Capacity in MW</td>
<td>45,000</td>
</tr>
<tr>
<td>Millions of Customers served</td>
<td>4.4</td>
</tr>
<tr>
<td>Miles of Transmission lines</td>
<td>27,000</td>
</tr>
<tr>
<td>Number of Substations</td>
<td>3,700 (Trans - 500+)</td>
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| 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

- PMU
- PDC

Locations:
- Birmingham
- Alabama
- Mississippi
- Georgia
- Florida
Sample Synchrophasor Activities

- Post Event Analysis & Model Validation

- Distributed State Estimator, Generator Parameter Estimation & Stability Monitoring

- Assessment of RTDMS – Wide-Area Situational Awareness Tool

- 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

PMUs & PDC

Oscillation Monitoring System

TVA, Entergy, Idaho Power

Voltage Stability Monitor

Entergy, Idaho Power

Angle Stability Monitor

System Security Status

Real-time Display & Control

PMU Real-time data
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

\[ \Gamma_i = \frac{\partial Q_i}{\partial V_i} = \Sigma \frac{\partial Q_{ij}}{\partial V_i} \]

- \( \Gamma_i \) is the slope of QV curve at Bus i
- \( \Gamma_i \) is small near static voltage stability limit
- \( \Gamma_i \) directly estimated from ambient PMU data
Angle Stability Monitor

Monitor the phase angles with respect to system center.

Area 1 accelerating
Area 2 decelerating

Excess Generation
Excess Load

Area 1  p  Area 2