Pre-Commercial Demonstration of DNSE+

Project with Quanta, NYPA & EPG

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Project Objective:
Demonstrate functionality and performance of a production-grade Direct Non-iterative State Estimator (DNSE) integrated with NYPA’s Energy Management System (EMS) and with an enhanced Real Time Dynamic Monitoring System (RTDMS) synchrophasor platform from Electric Power Group (EPG);

Background:
• DNSE started as an idea by Bruce Fardanesh at NYPA several years ago; also patented
• It was further researched as PhD thesis by Tony Jiang
• DNSE+ (+ added to designate SE with additional components around the estimation “engine”)

DNSE+ vs Other State Estimators

Traditional State Estimator:
- runs every 30 sec to several minutes,
- takes latest RTU/ICCP analog measurements and breaker status;
- solved iteratively (potential convergence issue)

Linear State Estimator:
- uses PMU data, can run at phasor frame rate;
- direct method (no iteration or convergence issues);
- needs large number of PMUs (larger than currently available) to estimate the complete state of the system

Why DNSE+?
- combines both SCADA and PMU data to obtain the complete state of system; on output can provide synchrophasors not available through PMUs
- mechanism to provide functionality to identify “bad” PMU data
- non-iterative;
- fast (executed at nearly phasor data rate); Challenge: huge equations to be solved
Advantage of DNSE+

Overcomes a major obstacle of operational use of Synchrophasor Management System (SPMS) by providing to SPMS applications a consistent and complete synchrophasor data foundation in the same manner that traditional SE provides foundation for EMS applications.
Degree of Innovation

1. First SE to use available phasors and provide estimates of the entire operation model at near-phasor rate
2. First SE that does not use iterations (provides increased robustness when compared to traditional SE)**
3. First SPMS in industry to provide (within a commercial product) comprehensive data quality management functionality based on the state estimates of the entire grid
   • This will overcome some barriers standing in the way of active use of SPMS in control room of any utility, not only NYPA

Portability: DNSE will be developed as an application with input/output adapters mostly based on IEC 37.118 standard, ICCP for SCADA and models as an ASCII export of the host utility’s EMS source data base

** A patent has been awarded on this basis to B. Fardanesh, a member of the project team
Project Participants

Key team members

Executive Sponsor: Damir Novosel

Quanta DNSE+ Principal Investigator Dino Lelic

Department of Energy: Brian Mollohan

EPG Project Team: Wayne Schmus Ashley Wang Prashant Palayam Simon Mo

Quanta Project Team: Boza Avramovic Yi Hu Tony Jiang Vasudev Gharpure

NYPA Project Team: George Stefopoulos Bruce Fardanesh Alan Ettlinger

NYISO – Project Observer & Advisor
Project team Roles

- **Quanta Technology**
  - Overall project management
  - Overall technical lead; overall system design
  - System integration and FAT lead; Site Acceptance Test support

- **NYPA**
  - End user of developed system
  - System design support
  - Field installation & SAT test lead

- **Electric Power Group**
  - EPG product supplier
  - RTDMS enhancement development
  - System integration & FAT support
  - Field installation & SAT support

- **NYISO**
  - Technical advisor and historical PMU data provider
Project Budget & Timeline

- Pre-Commercial Demonstration of Direct Non-Iterative State Estimator for Operational Use of Synchrophasor Management Systems
- Award number: DE-OE0000704
- $998,890 DOE share
- $1,052,978 Cost share
- $2,051,868 Total project value
## Project Tasks & Progress

<table>
<thead>
<tr>
<th>Milestone #</th>
<th>Milestone Name</th>
<th>Completion Date</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Project Management Planning</td>
<td>Aug 30, 2014</td>
</tr>
<tr>
<td>2</td>
<td>System Design Completion</td>
<td>Jan 30, 2015</td>
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<tr>
<td>3</td>
<td>DNSE+ implemented</td>
<td>Jul 30, 2015</td>
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<tr>
<td>4</td>
<td>RTDMS Platform Enhancement completed</td>
<td>Jul 30, 2015</td>
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<tr>
<td>5</td>
<td>Integration and FAT completion</td>
<td>Dec 30, 2015</td>
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<tr>
<td>6</td>
<td>Field Installation, User training, and SAT completion</td>
<td>Jun 30, 2016</td>
</tr>
<tr>
<td>7</td>
<td>Project completion</td>
<td>Jul 29, 2016</td>
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## Success Criteria

<table>
<thead>
<tr>
<th>Decision point</th>
<th>Performance test environment</th>
<th>Success criteria</th>
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<tbody>
<tr>
<td>End of Task 3</td>
<td>A mid-range server at QT</td>
<td>&lt; 5s</td>
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<tr>
<td></td>
<td></td>
<td>&lt; 4s</td>
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<tr>
<td>Mid-point of Task 5</td>
<td>A mid-range server at QT</td>
<td>&lt; 2s</td>
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<tr>
<td></td>
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<td>&lt; 1s</td>
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<tr>
<td>End of Task 6</td>
<td>NYPA acquired DNSE+ server</td>
<td>&lt; 1s</td>
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<tr>
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<td>&lt; 0.1s</td>
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System Architecture – Functional View

Component Diagram of Proposed Project

Legend
- Phasor Rate
- SCADA rate or slower
- Within project scope
- Existing component
Direct Non-Iterative State Estimation

• Originally proposed by Bruce Fardanesh of the New York Power Authority. Initial implementation developed by NYPA and RPI
• Based on Kipnis-Shamir re-linearization technique used for solving over-defined sets of polynomial equations
• For power systems, measurement equations (in terms of the states) are 2\textsuperscript{nd} order polynomials.
• The technique first identifies all quadratic terms, replaces them with new variables, and solves resulting linear equations in terms of new variables.
  ➢ There are many more quadratic terms (new variables) than the original state variables
  ➢ The technique fundamentally relies on having many more starting equations than the number of original states
  ➢ The original state variables are computed from the new variables as a follow up activity
• No starting guess required, no issues with convergence
DNSE Algorithm

- **Start**
  - Read in Measurement Data and System Topology/Parameters
  - A) Formulate Measurement Equations
  - B) Partition Coefficients Matrix and First Transformation
  - C) Find Variable Pair Combinations using System Topology
  - D) Second Transformation into Linear System
  - E) Extracting the State Solution

In rectangular coordinates, e.g.

$$V_{iR}^2 + V_{iI}^2 = V_{iM}^2$$

Put into matrix form

$$A_\xi \xi = C$$

Express $Y$ in terms of the rest of the system

$$Y = d + DZ$$

Generate constraints using the relationships between quadratic variables, e.g.

$$(V_{iR}^2)(V_{jI}^2) = (V_{iR}V_{jI})(V_{iR}V_{jI})$$

$$A_t t = k$$

$t$ is the linear and quadratic combinations of the $Z$ variables. Solve for $t$ and then $Z$ and $Y$. 
References


Questions/Comments