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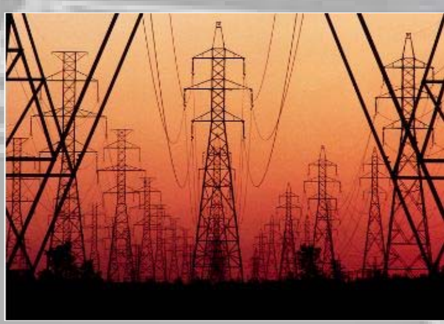
New York Power Authority

Electric Power Group



Pre-Commercial Demonstration of DNSE+

Project with Quanta, NYPA & EPG

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Problem Statement & Background

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:

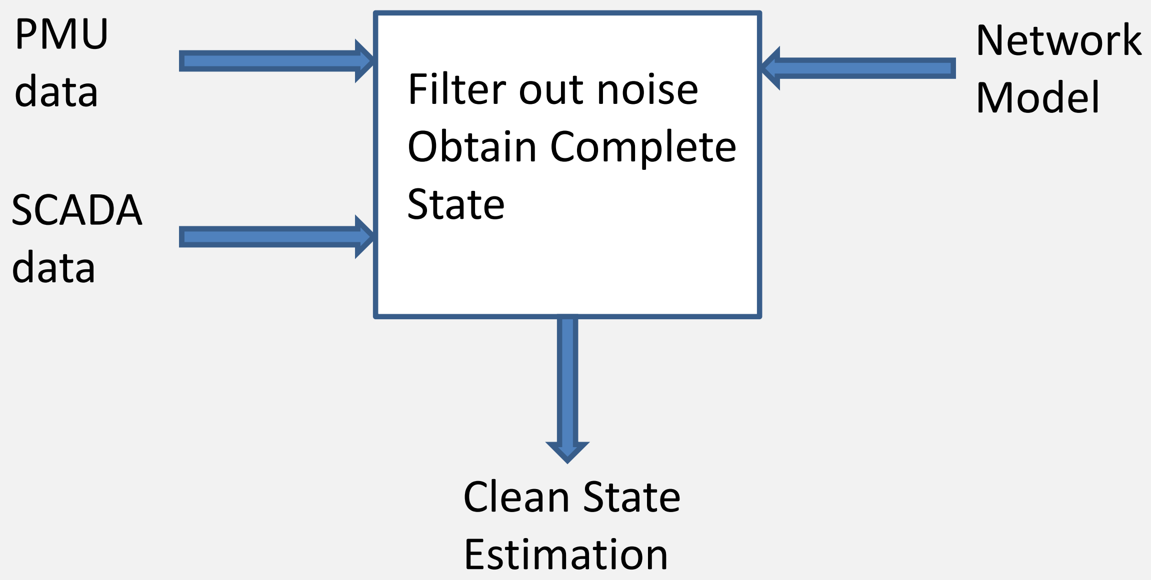
– uses PMU data, can run at phasor frame rate;
– direct method (no iteration or convergence issues);
– needs large number of PMUs (larger than currently available) to estimate the complete state of the system

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 od 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

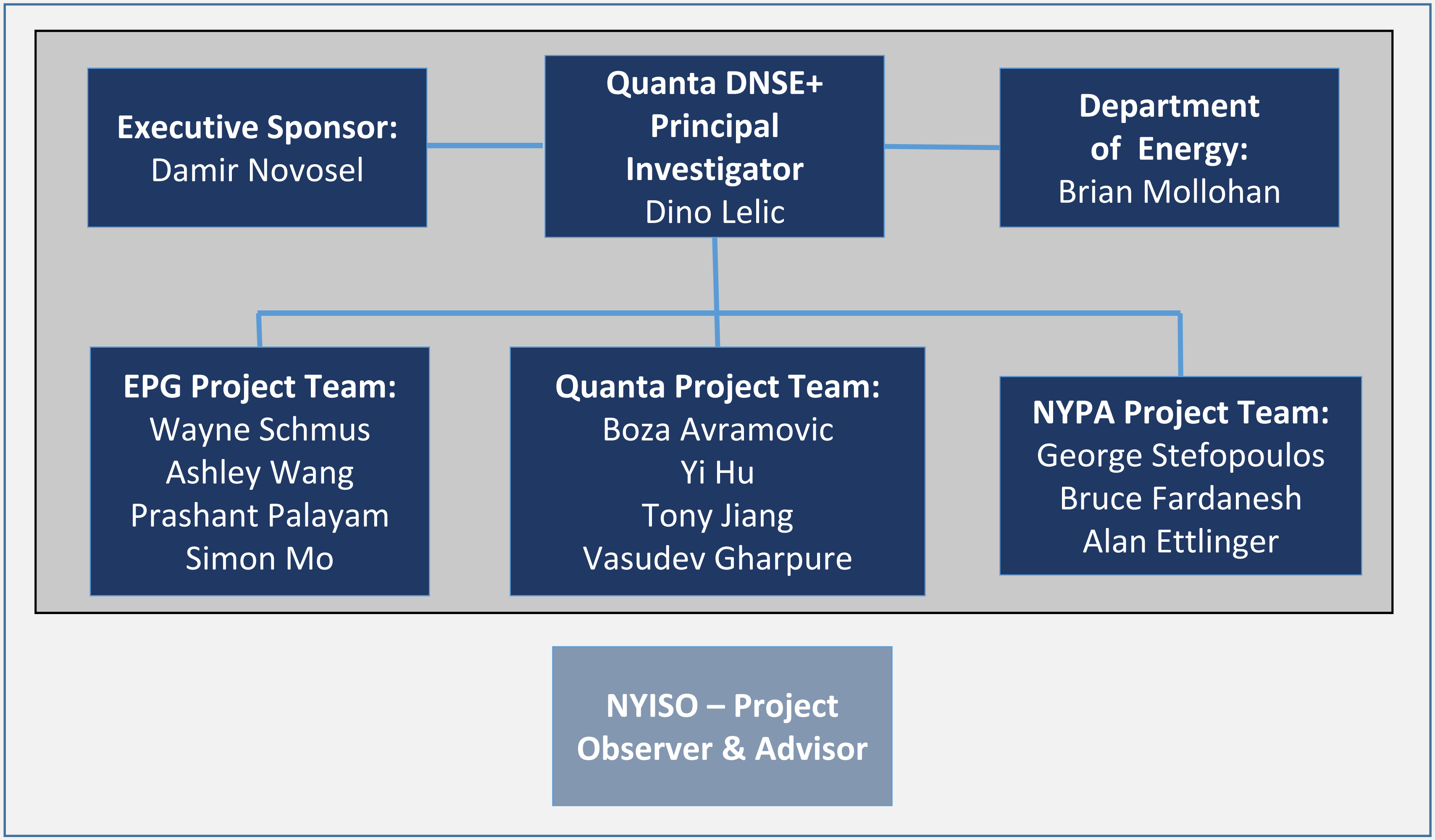
1. First SE to use available phasors and provide estimates of the entire operation model at near-phasor rate
2. First SE that does not use iterations (provides increased robustness when compared to traditional SE)**
3. First SPMS in industry to provide (within a commercial product) comprehensive data 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



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
- Period of Performance – July 30, 2014 – July 29, 2016

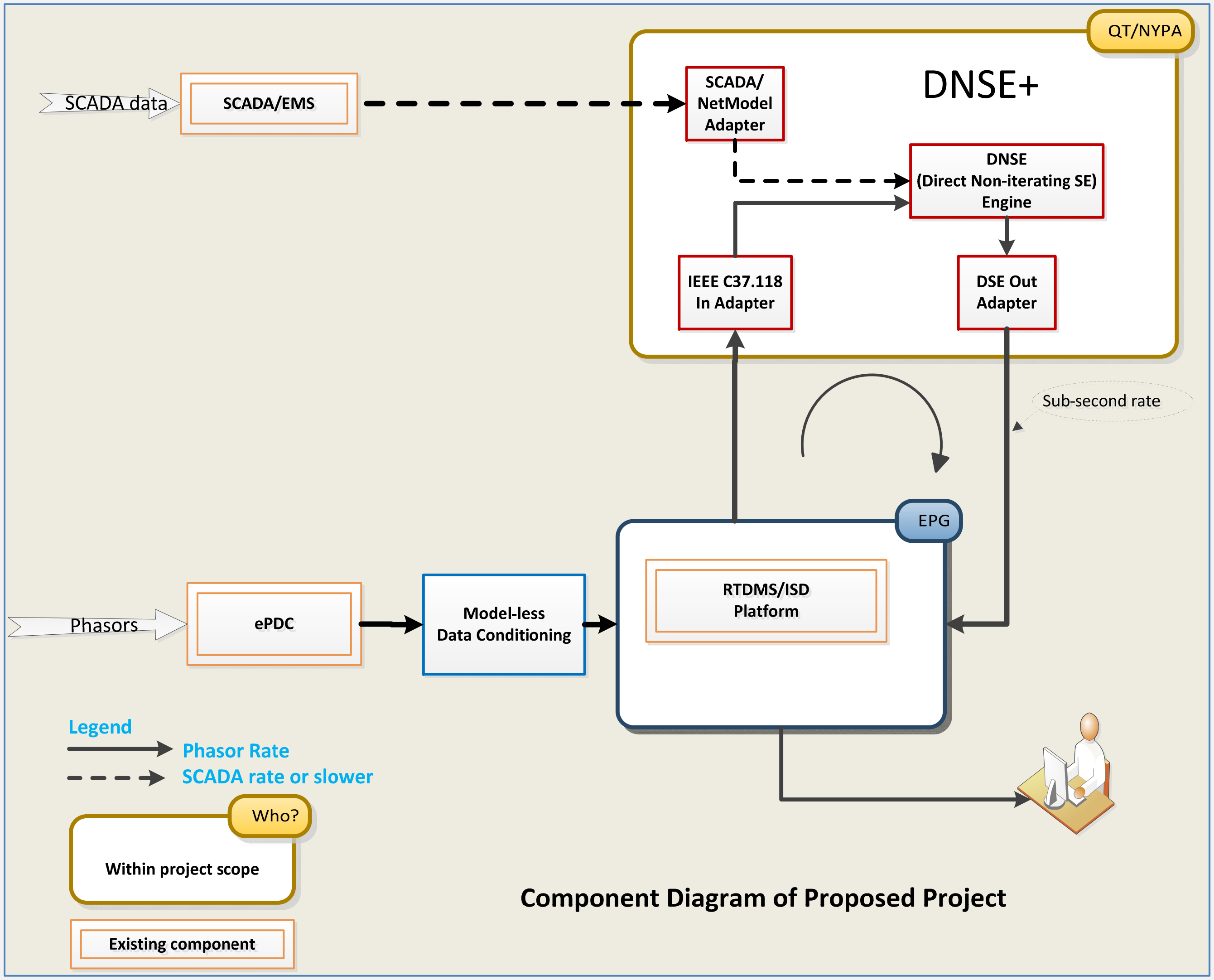
Project Tasks & Progress

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

Success Criteria

Decision point	Performance test environment	Success criteria	
		Minimum	Desired
End of Task 3	A mid-range server at QT	< 5s	< 4s
Mid-point of Task 5	A mid-range server at QT	< 2s	< 1s
End of Task 6	NYPA acquired DNSE+ server	< 1s	< 0.1s

System Architecture – Functional View

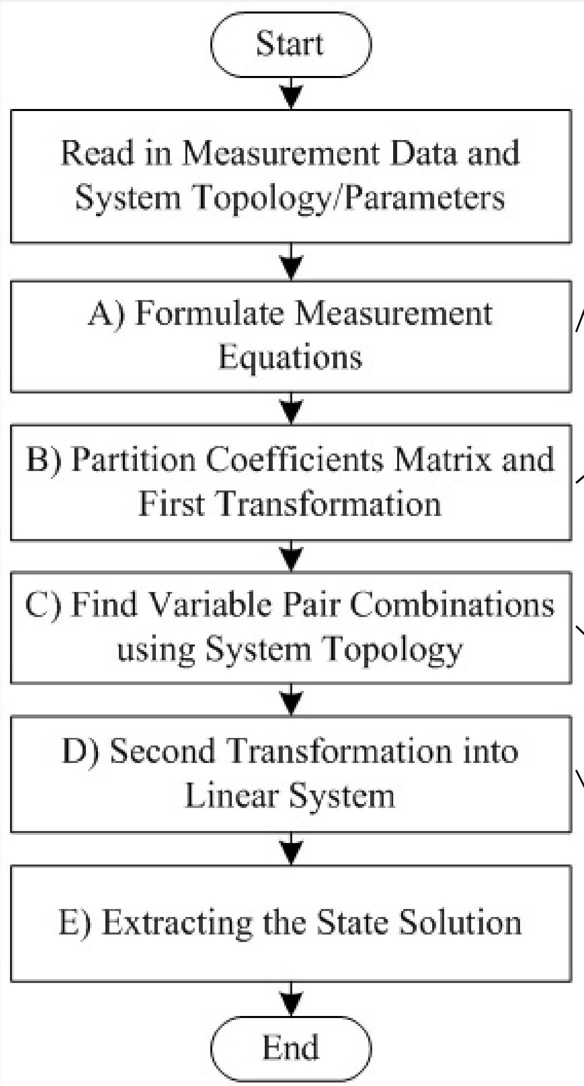


Component Diagram of Proposed Project

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^{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



In rectangular coordinates, e.g. $V_{iR}^2 + V_{iI}^2 = V_{iM}^2$

Put into matrix form $A_\xi \xi = C$

$$[A|B]\begin{bmatrix} Y \\ Z \end{bmatrix} = C$$

Express $\boldsymbol{Y}$ in terms of the rest of the system

$$Y = d + DZ$$

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

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

$$A_t t = k$$

$\boldsymbol{t}$ is the linear and quadratic combinations of the $\boldsymbol{Z}$ variables. Solve for $\boldsymbol{t}$ and then $\boldsymbol{Z}$ and $\boldsymbol{Y}$

References

1. B. Fardanesh, “Methods and systems for power systems analysis: a non-iterative state solver/estimator for power system operation and control”, US patent no. US 8,108,184. Jan. 2012
2. X. T. Jiang, “Non-iterative Method for Power System State Estimation and a PMU-Based Method for Assessing Generator Damping Contributions”, Ph.D. Dissertation, Rensselaer Polytechnic Institute, May 2014.
3. Real Time Dynamics Monitoring System® (RTDMS®): Built upon GRID-3P® platform. US Patent 7,233,843, US Patent 8,060,259, and US Patent 8,401,710. ©2014 Electric Power Group

Questions/Comments