U.S. DEPARTMENT OF ENERGY

Virginia Tech

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

NETL

Synchrophasor Based Tracking Three Phase State Estimator and Its Applications

NASPI Working Group Meeting

October 18, 2012
Atlanta, GA

QUANTA TECHNOLOGY

Dominion

Project Objectives

Develop and Implement a novel Synchrophasor-based tracking state estimator

Develop Transducer Calibration Techniques

Develop Tools for the characterization and analysis of unbalanced conditions

Develop tools for detecting and monitoring islanding

Develop visualization tools for the 3-phase tracking state estimator

Phase 1 Analytical Studies Tasks

- ✓ Task 2: Establishment of study system database
- ✓ Task 3: Tracking Three Phase State Estimator
  Development and implementation of tracking estimator algorithm
- ✓ Task 4: Tracking Three Phase State Estimator Applications
  Monitoring and tracking generator unbalance currents
  Transducer Calibration, Islanding Application

Phase 2: Prototype Demonstration Tasks

- ✓ Task 6 PDC/Server System Integration, specification and selection
  PDC and Application Server configuration, selection and acquisition
- ✓ Task 7 Tracking Three Phase state estimator Lab testing and demonstration
  Simulation of system data in daily load cycle, Performance verification

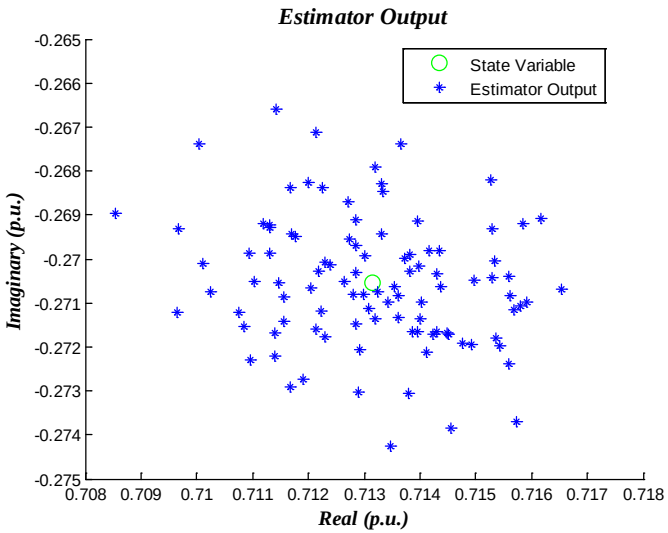
Task 3 Development of Tracking Estimator Algorithm

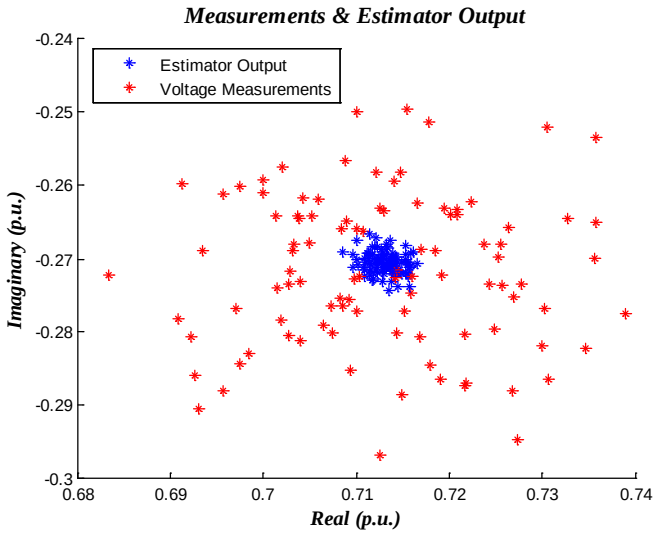
Three-Phase Linear State Estimator algorithm was implemented and tested in Matlab ✓

- Used close to 600 voltage and current phasor measurements to determine the system state

A topology processor was implemented and tested ✓

- Uses current phasors magnitude and breaker statuses from PMUs and other devices to determine network topology





Task 4 Application: Instrument Transformer Calibration

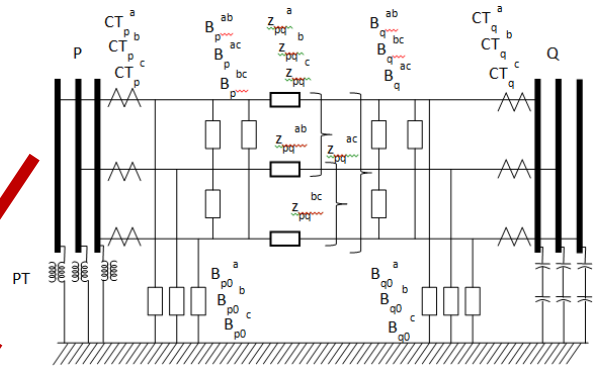
Procedure:

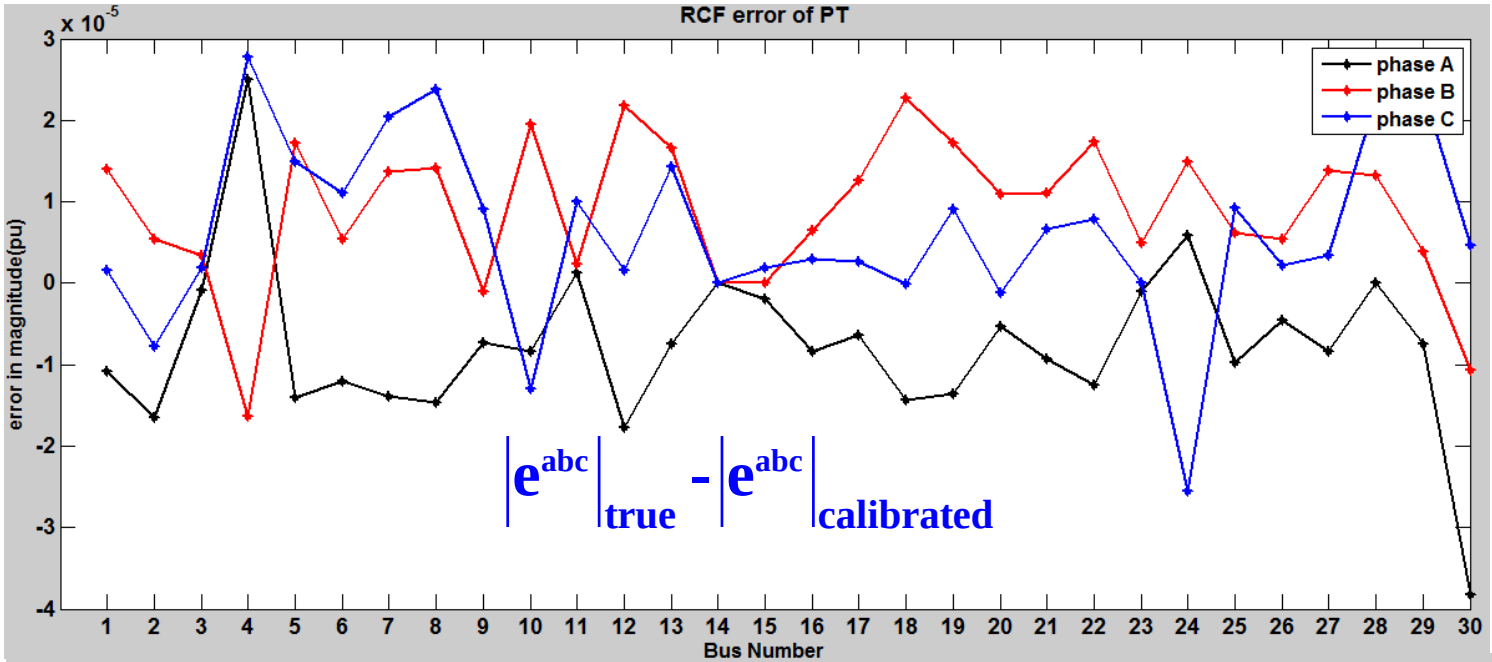
1) Three phase error base model was created ✓
   - Derive a three phase system model
   - Assume ratio correction factors for all CTs and CVTs

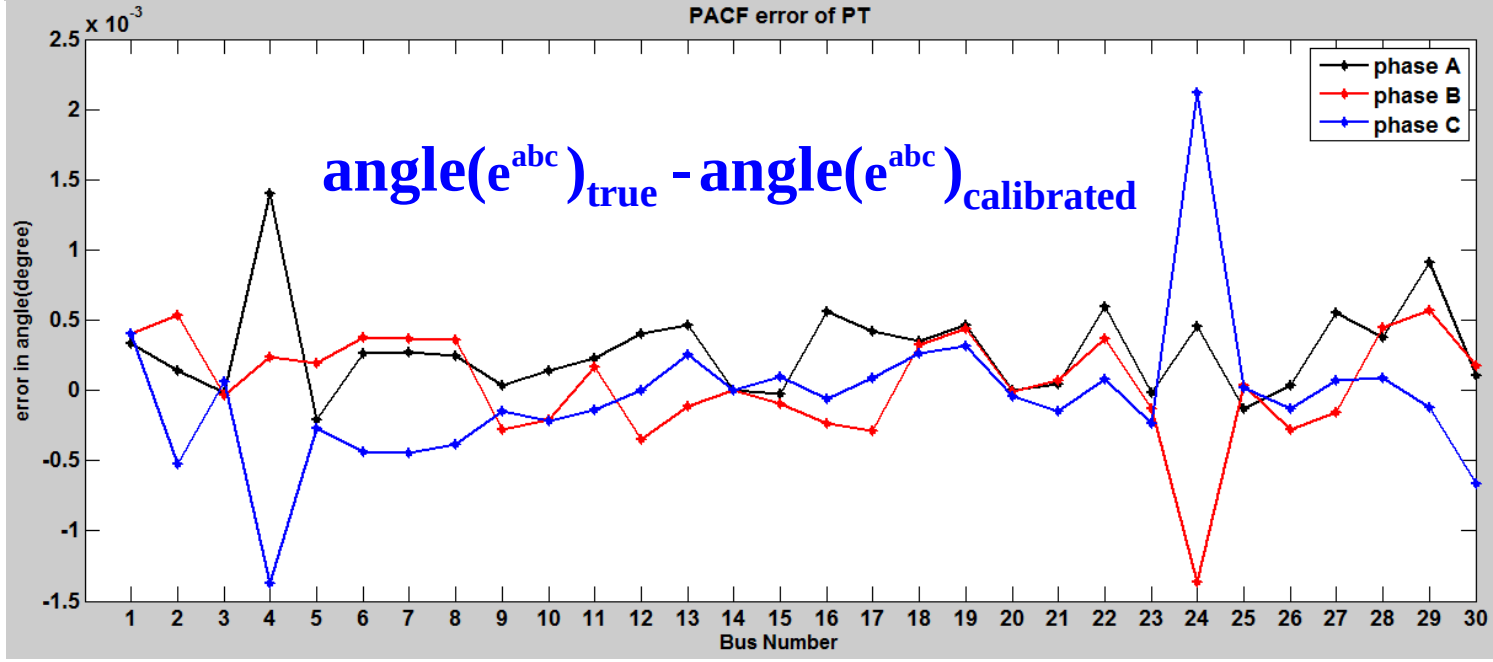
2) Three phase error data base was generated ✓
   - Load flow analysis used daily load curves
   - Converted data to secondary values

3) Developed an error estimation algorithm ✓
   - Derived Error model
   - Used different load conditions to obtain redundant data
   - Used least square techniques to estimate CT and CVT errors

4) Used known model to determine estimation error ✓




RCF error of PT
x 10^-5
error in magnitude(pu)
Bus Number
phase A
phase B
phase C
|e^abc|_true - |e^abc|_calibrated


PACF error of PT
x 10^-3
error in angle(degree)
Bus Number
phase A
phase B
phase C
angle(e^abc)_true - angle(e^abc)_calibrated

Task 4 Application:
Islanding Detection

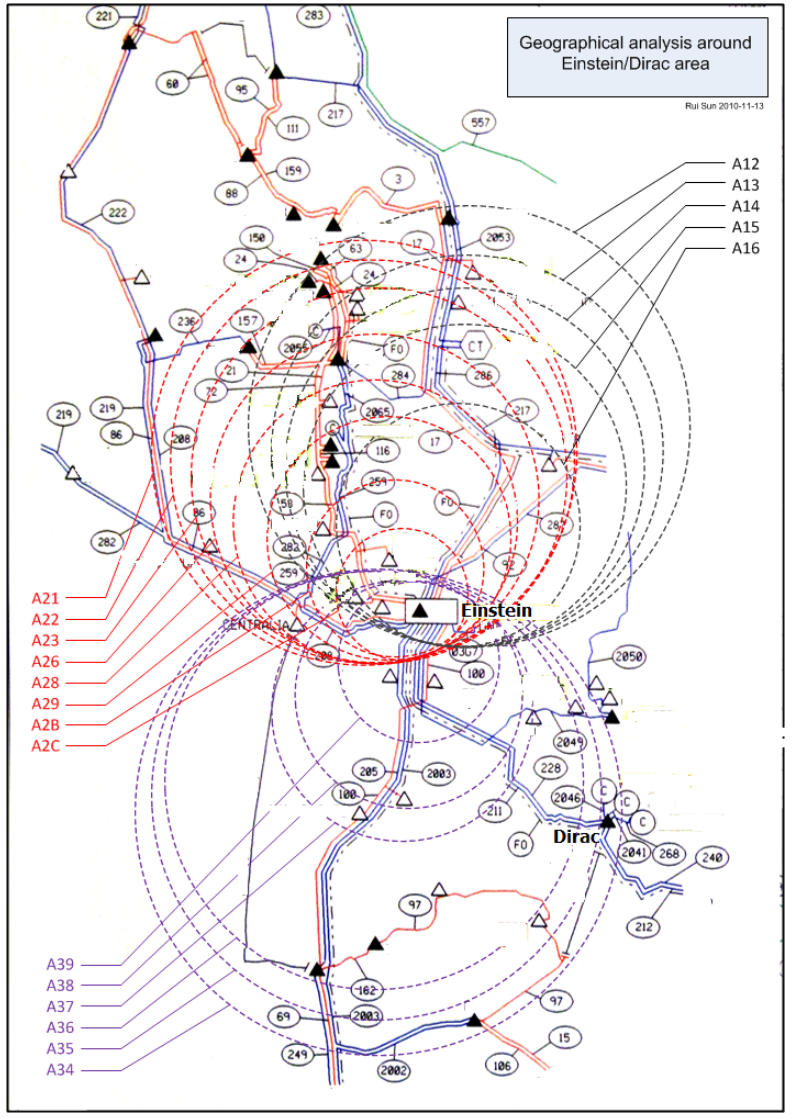
Three locations in the Dominion's system were identified for possible islanding contingencies

Analysis of all possible islanding scenarios has been performed on the selected locations under load variation

Number of islanding cases derived for each location

- Location 1, 396 cases
- Location 2, 130 cases
- Location 3, 159 cases

Three Decision Trees implemented and tested



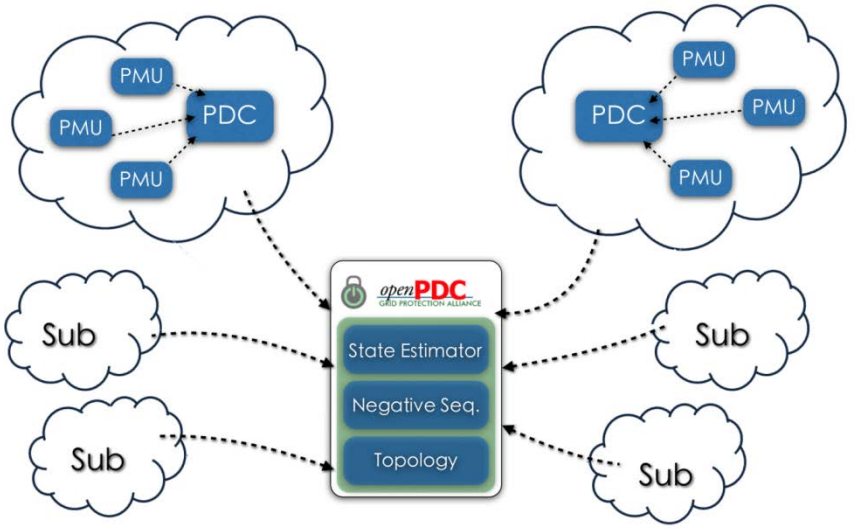
Islanding scenarios for one of the locations

Task 4 Application: Monitoring and tracking generator unbalance currents

1) Created a three-phase unbalance base case
2) Used the base case to calculate all negative sequence currents in the network
3) Determined negative sequence currents at generators and compare with generator limits
4) Set alarms for negative sequence currents that approach limits at generators

Task 6: PDC Selection (OpenPDC) and integration

- OpenPDC offered best solution for all known requirements
- RTO requirements: name translations & phase angle rotation
- Offered Platform to create the custom Synchrophasor applications



Task 7 Implementation of tracking estimator software

Matlab code was converted to C# for used in selected platform OpenPDC

1) Custom adapters (class libraries) in C# were developed

2) State Estimator and Topology processor were implemented and tested

3) Completed troubleshooting of State Estimator/Topology Processor application as adapter in OpenPDC

4) Used simulators and lab equipment to test software with simulated system data

Phase 3: Full Scale Demonstration Tasks

Task 8 PMU and PDC field installation

8.1 Phased installation of PMUs ✓

8.2 PDC installation and Synchrophasor unit network formation ✓

Task 9 Tracking estimator field installation and verification

9.1 Field installation of estimator ✓

9.2 Verification of the system performance ✓

Task 8.1 Phased Installation of PMUs and PDC

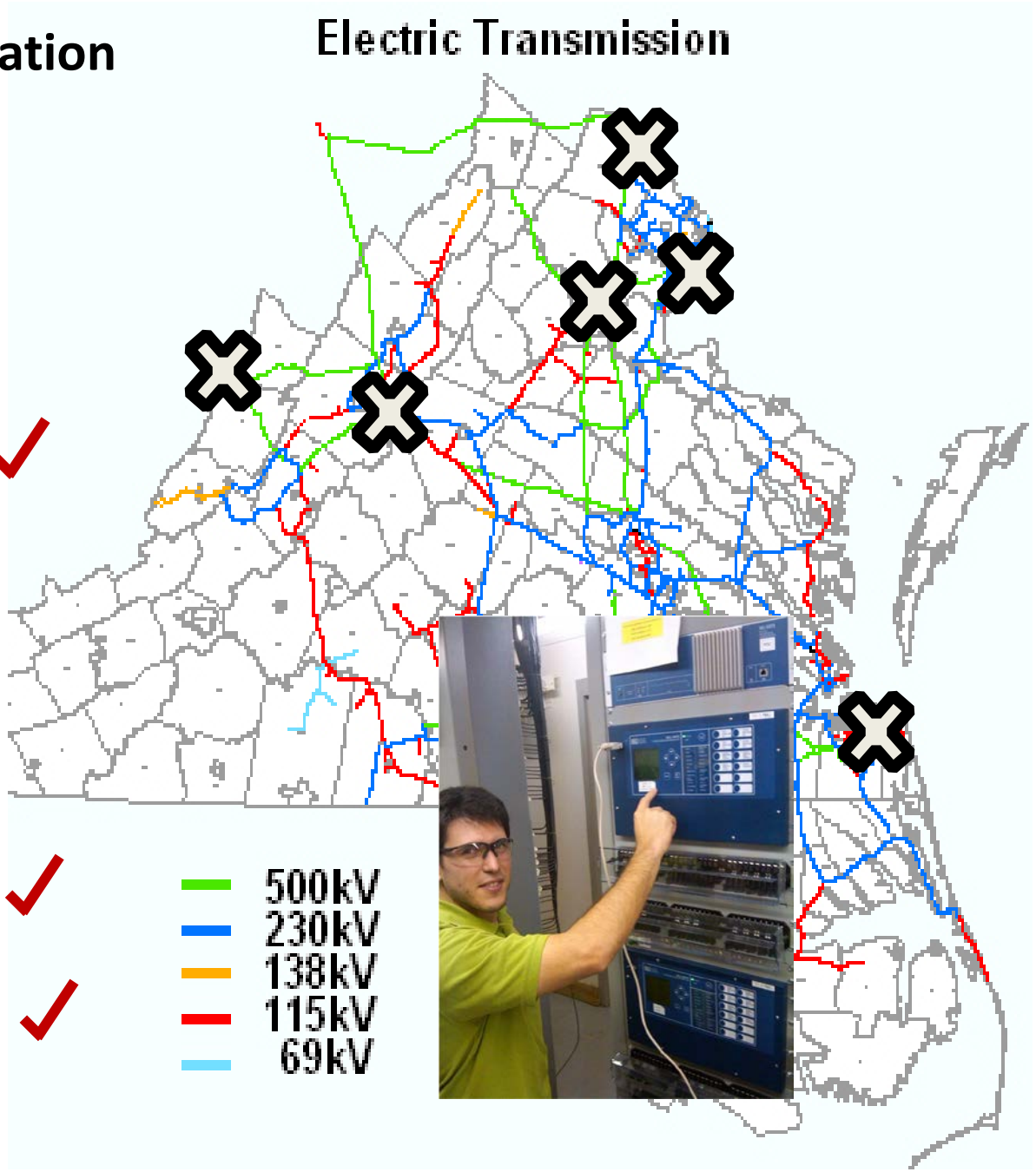
Phase A

PMU Installed at:

1. North Anna Generating Station ✓
2. Surry Generating Station ✓

Operations Center Activities:

1. Data concentration and calculation architecture developed ✓
2. PDC hardware procured ✓



Synchrophasors units are from SEL digital relays:

- Relays are either stand-alone PMUs or dual-use devices

  Scalability from dual-use relays

  Simple to include in existing & future construction projects

- Each synchrophasor substation has a local PDC:
  - Stores highest res. data (60 frames/sec) for short term (one month)
  - Output down-sampled (30 frames/sec) data to SOC

Task 8.1 Phased Installation of PMUs and PDC

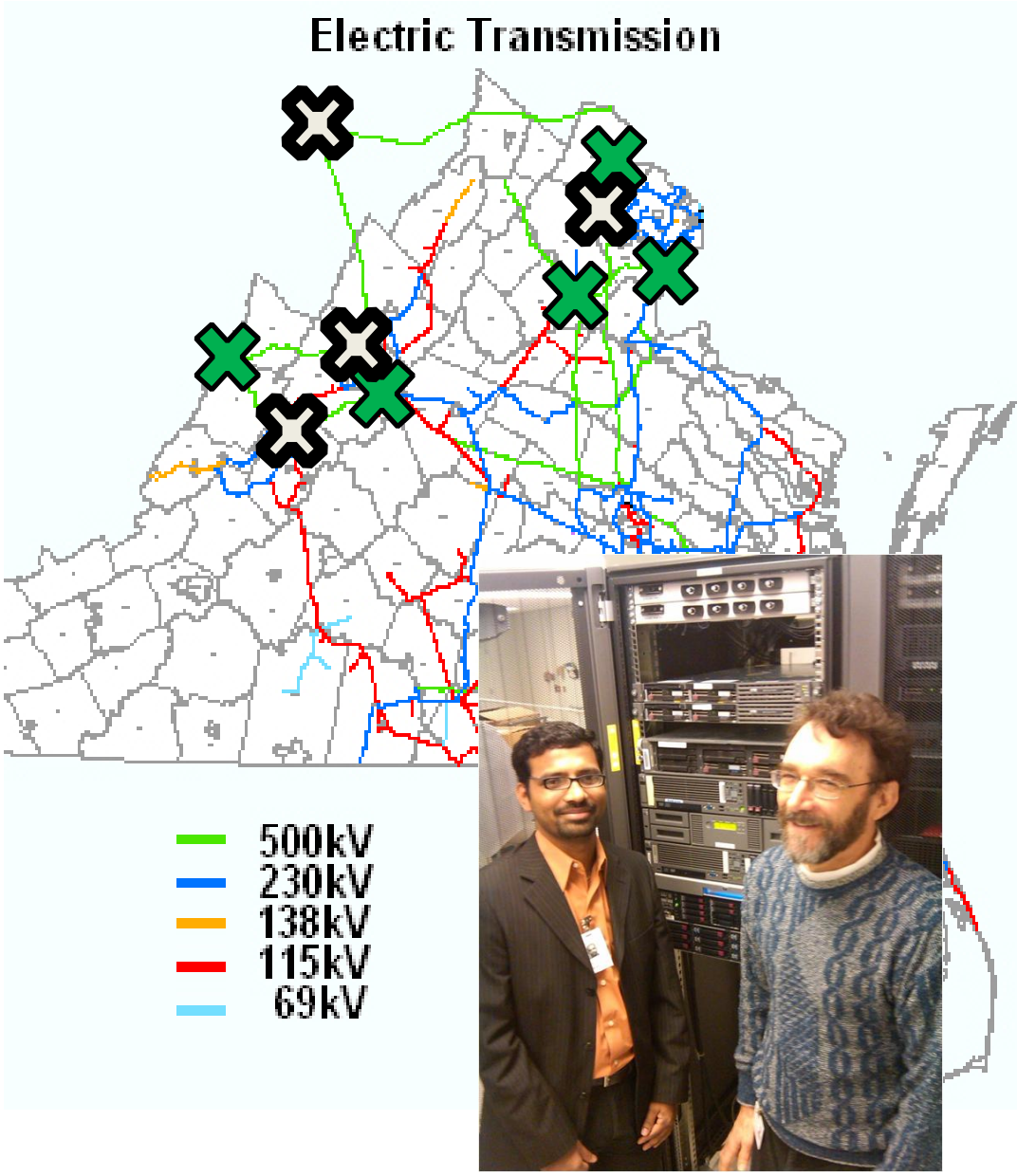
Phase B PMU

Installations:

1. Chesapeake Substation
2. Suffolk Substation
3. Valley Substation

Operations Center Activities (under way):

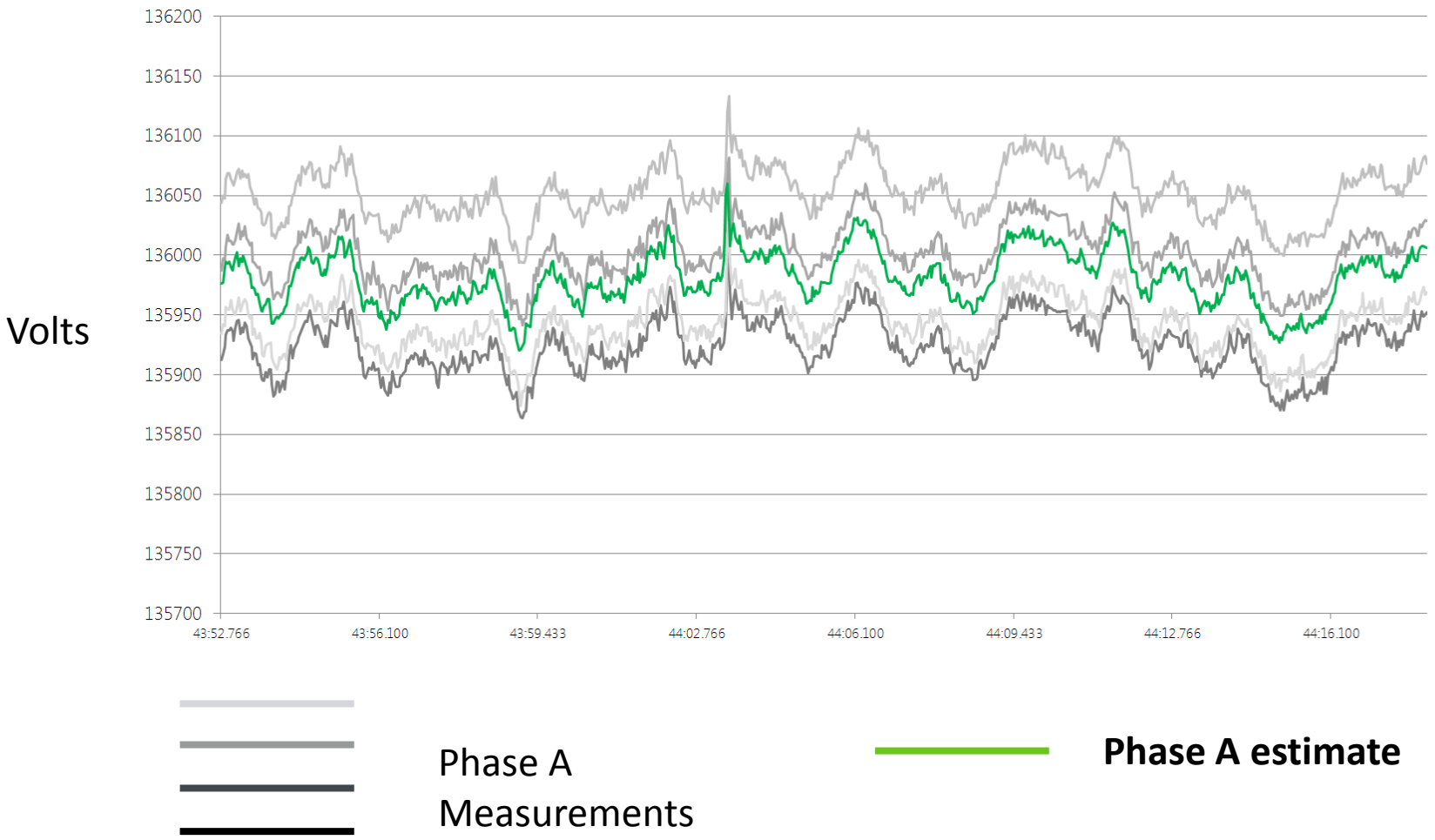
1. PDC Architecture Refinement
2. OpenPDC deployment
3. Basic Visualization mock-ups



Project Status

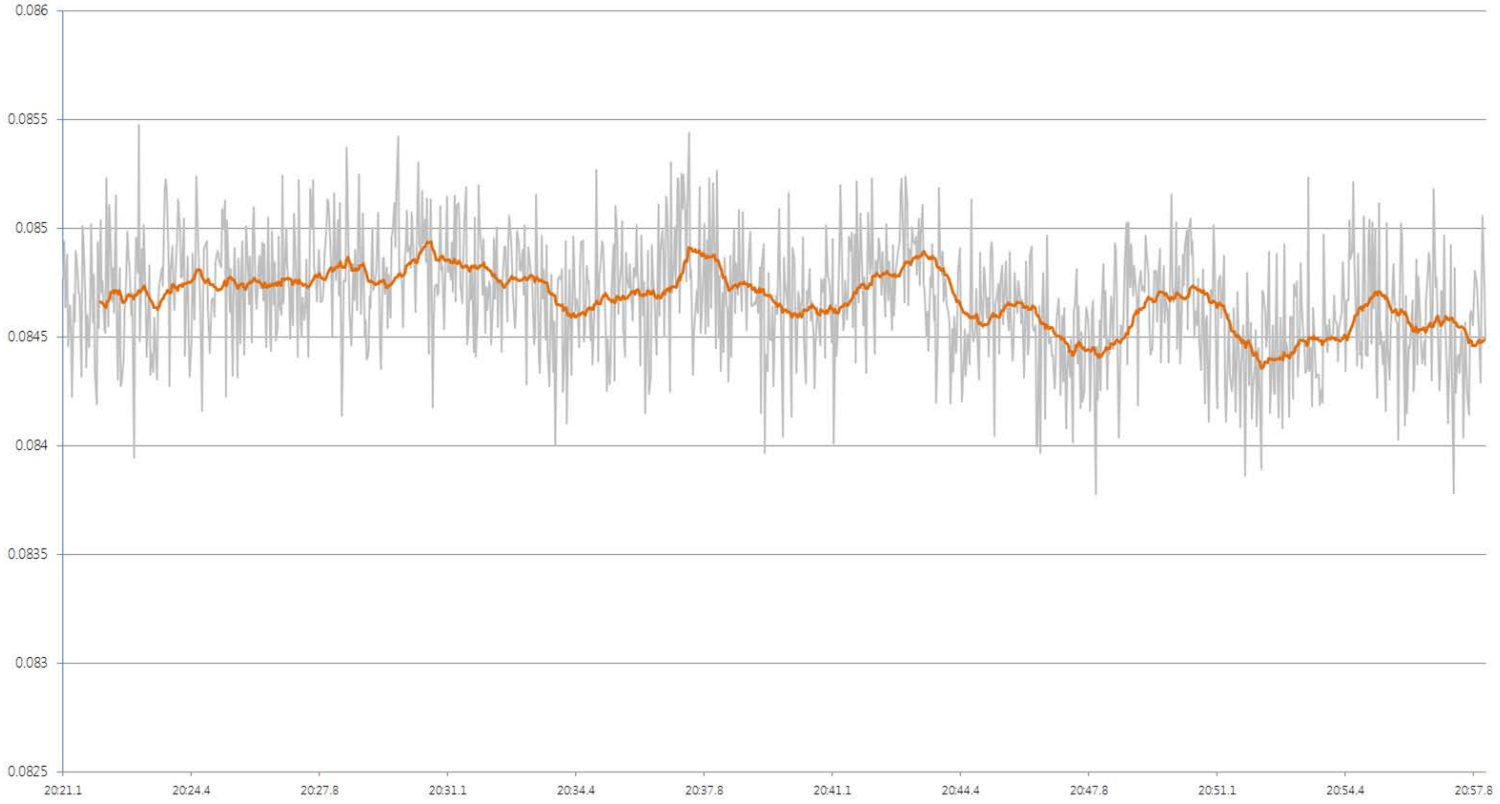
- Data streaming to operations center/central PDC architecture
- Three Phase Estimator, Topology Processor, Negative Sequence Monitor installed and running on central PDC
- Almost all substation installations complete. Last installation scheduled for December
- Many other applications were developed in conjunction as need aroused: naming convention, phase angle rotation, and breaker status mapping to PJM, signal-to-noise ratio, zero sequence, status flag parsing

Phase A Voltage Magnitude 230 kV Bus



Ratio of Negative Sequence to Positive Sequence of 230 kV line

%



1 second moving average

Remaining Work

Substation installations are almost complete, but many still need connected to operations center

Islanding & Calibration applications will come online once enough data is streaming to central PDC

Visualization Applications interface to OpenPDC real time data is being implemented

Questions?