ENERGISE Program Kickoff

DOE Award #: 8005

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Robust Distributed State Estimator for Interconnected Transmission and Distribution Networks

Northeastern University

October 11, 2017

Project Team

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Name	Role	Main Responsibilities (High level tasks/sub-tasks)
Ali Abur (NEU) plus 2 GRAs	PI	Management of the overall project Coordination of tasks among NEU and PJM Mentoring/advising graduate research associates Project reporting, documentation and deliverables Development and implementation of all methods and algorithms Organization of project workshop at NEU
Jianzhong Tong (PJM)	Subcontractor	Coordination of data/information exchange between NEU and PJM Facilitating acquisition of network data and measurements from member utilities Enabling implementation and testing of project software at PJM Providing technical advice and participation in project review meetings Organization of project workshop at PJM

Project Goals

Develop a combined *transmission – distribution state estimator* which:

- can account for **very large system size and model complexity** (by way of distributing the computations) and **large number of solar PV units** connected to the distribution system on multiple feeders,
- will not only provide a **robust formulation and solution** to this problem but also **test** the solution by **implementing** it on a well-established large utility system.

Major Innovations

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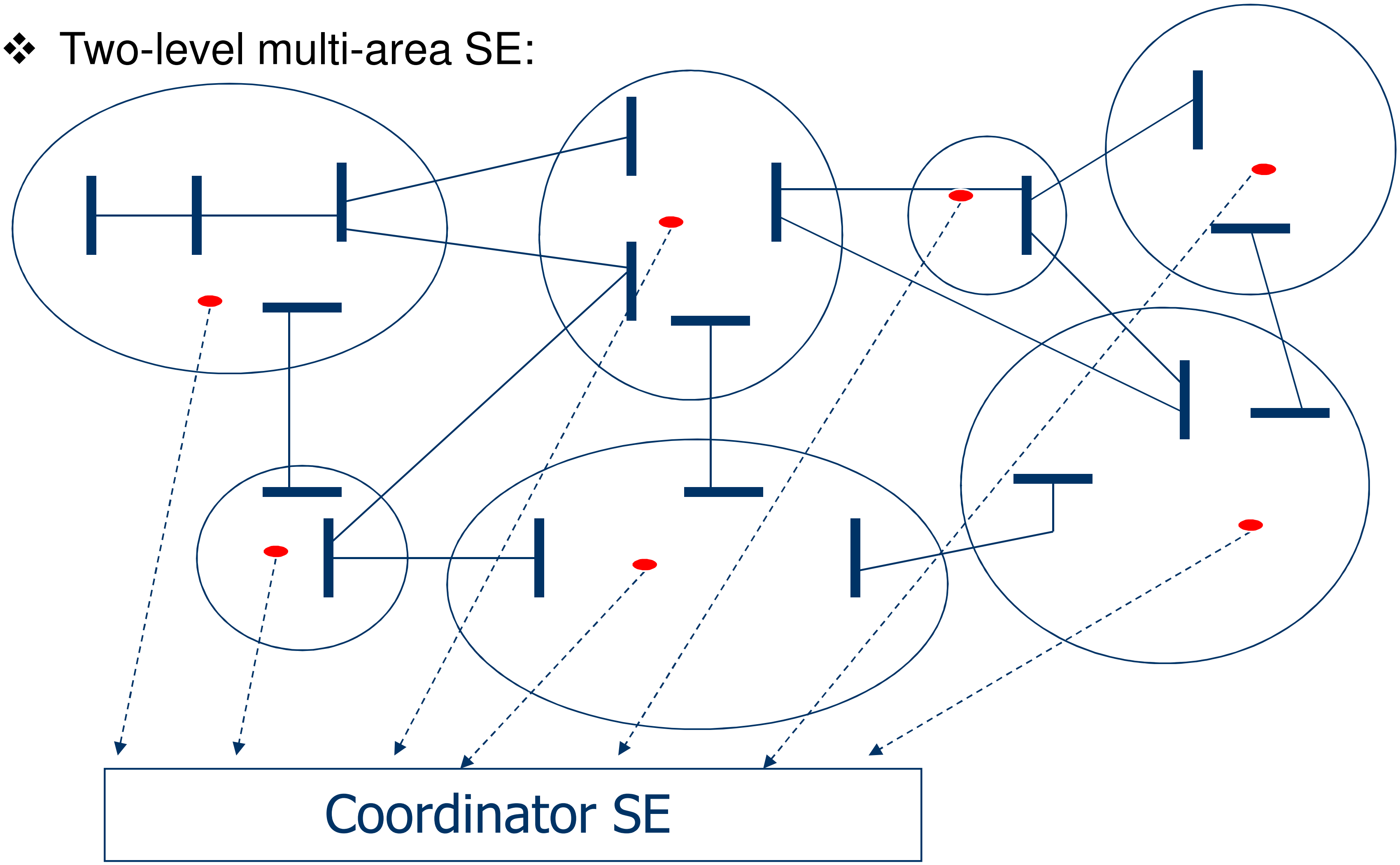
Innovations are proposed to address the following issues:

- Computational burden: finding a scalable solution which will remain viable as the network size increases.
- Robustness: maintain the ability to detect and remove bad data, thus provide an unbiased state estimate both for the distribution and transmission system states.
- Stitching the transmission and distribution system real-time models, by estimating the zero sequence component of the transmission system bus voltages commensurate with the estimated state of the three-phase distribution system.

Computational innovations:

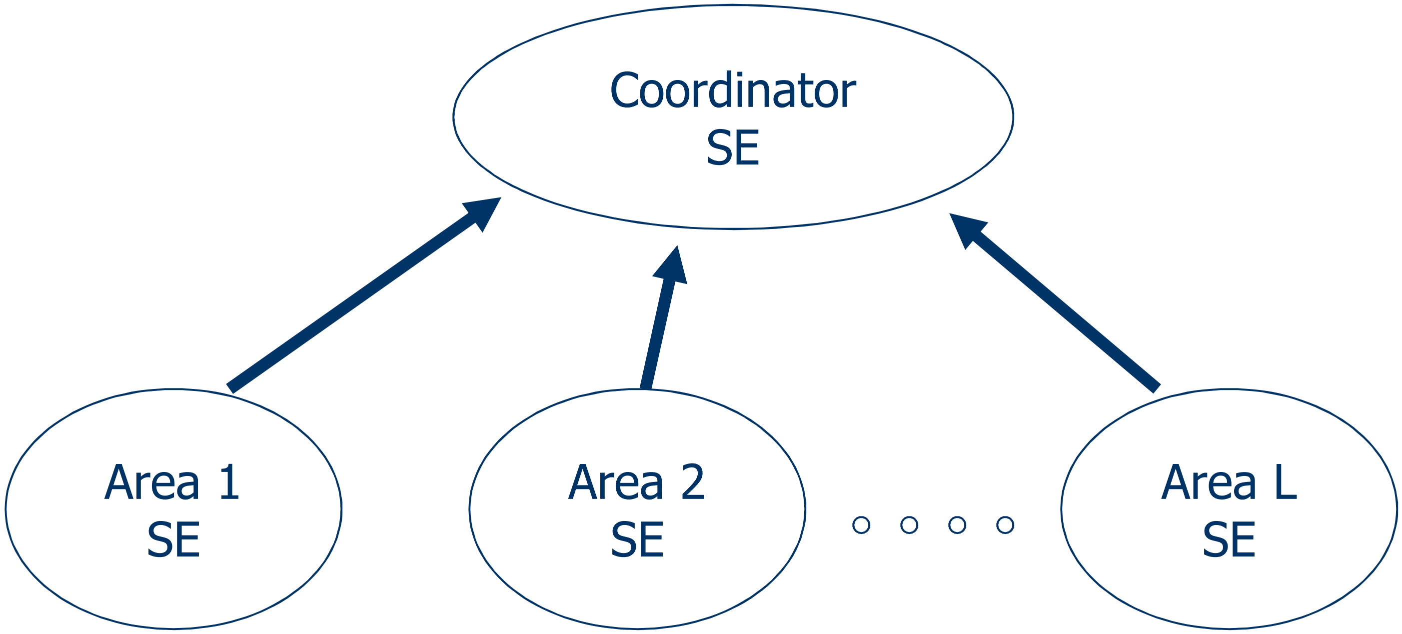
❖ Two-level multi-area SE:



Major Innovations

Computational innovations:

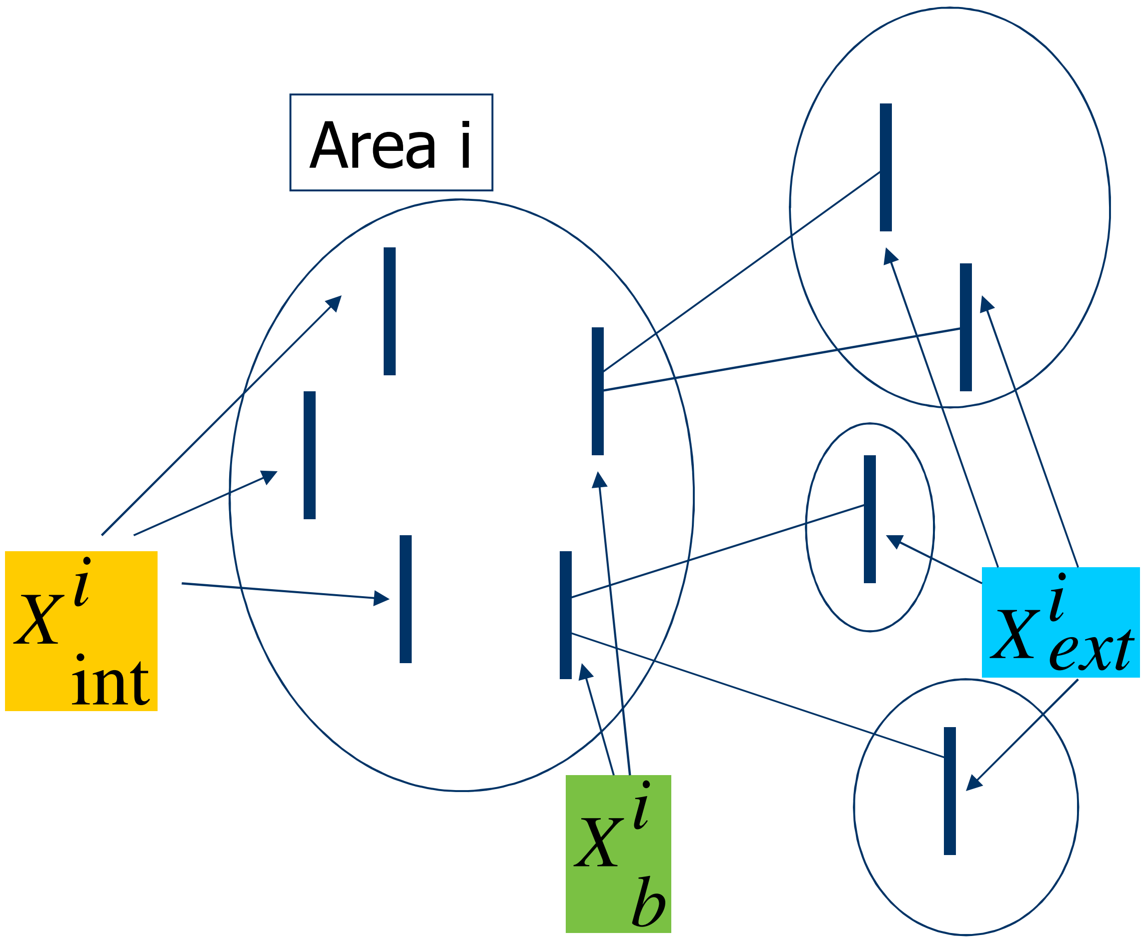
- ❖ Each area SE estimates its own state.
- ❖ Coordinator SE
  - merges the solutions, and
  - processes bad data for boundary measurements.



Major Innovations

Computational innovations:

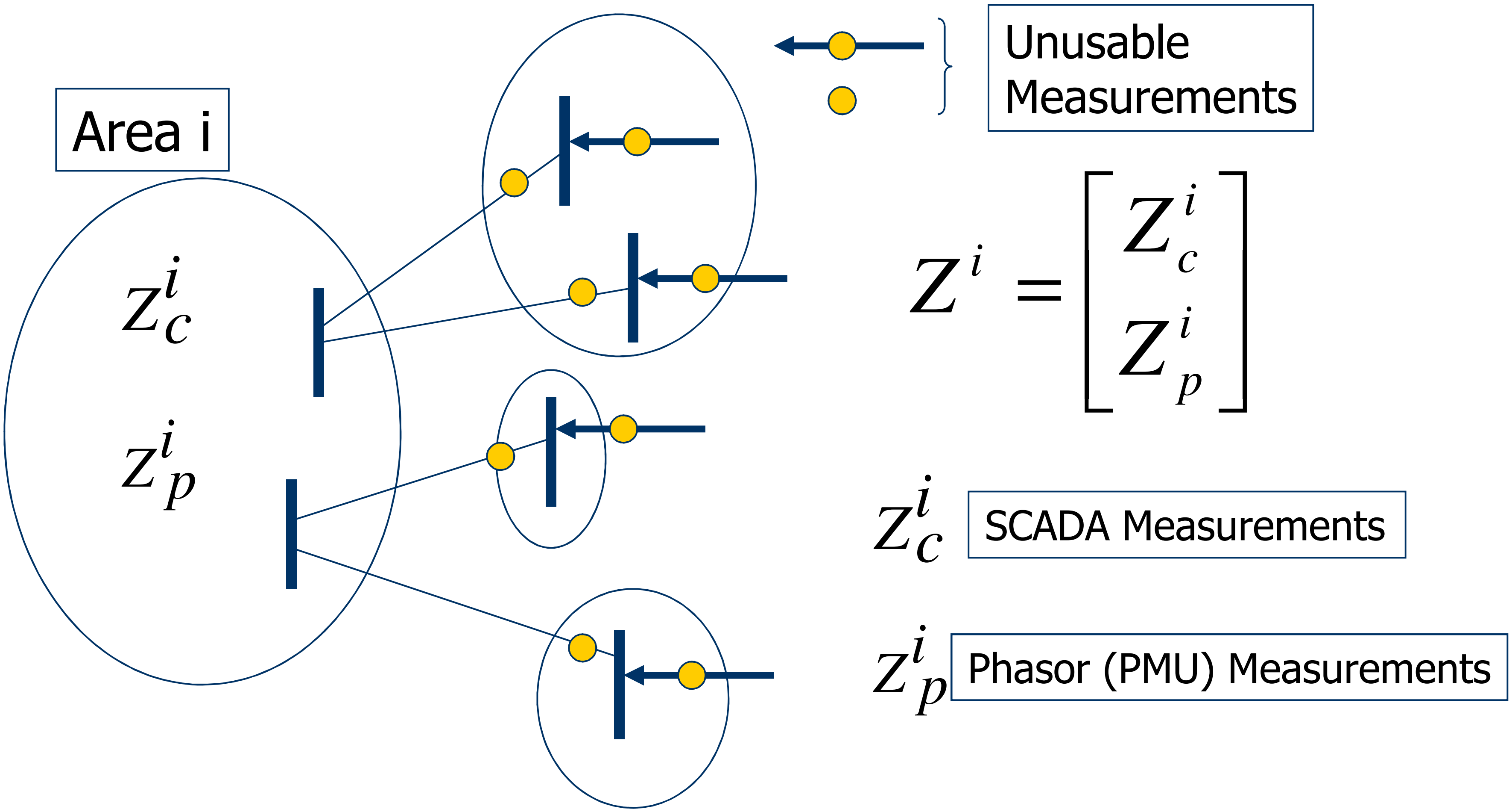
❖ Define the state vector for each area ***i***



$$X^i = \begin{bmatrix} X^i_{int} \\ X^i_b \\ X^i_{ext} \end{bmatrix}$$

Computational innovations:

❖ Measurement vector for each area ***i***



Computational innovations:

- SE problem of each area ***i***

$$\text{Minimize} \sum_{j=1}^{m_i} \frac{1}{\sigma_j^2} (r_j^i)^2$$

$$\text{Subject to } z_j^i = h_j(\hat{x}^i) + r_j^i \quad 1 \le j \le m_i$$

where:

$e_j^i \propto N(0, \sigma_j^2)$

m_i: number of measurements in z^i

$\hat{z}_j^i = h_j(\hat{x}^i)$ estimated measurement

$$\hat{x}^i = \begin{bmatrix} \hat{x}_{int}^i \\ \hat{x}_b^i \\ \hat{x}_{ext}^i \end{bmatrix} \text{ estimated state}$$

- Measurements received and used by the coordinator SE
- Each area state estimates are treated as pseudo-measurements with the following distribution:

$$N(\hat{x}^i, \Lambda^i)$$

where:

$$\Lambda^i = \left[G^i\right]^{-1}$$

$$G^i = \left[H^i\right]^T \left[R^i\right]^{-1} \left[H^i\right]$$

$$\left[H_{jk}^i\right] = \partial h_j / \partial x_k^i$$

$$R^i = \operatorname{cov}(e^i)$$

Computational innovations:

❖ Coordinator SE

$$\text{Minimize} \sum_{j=1}^{k} \frac{1}{R_{jj}} (r_j)^2$$

$$\text{Subject to } z_j = h_j(\hat{x}_b) + r_j \quad 1 \le j \le k$$

$$e_j \propto \begin{cases} N(0,\sigma_j^2) & \text{boundary measurements} \\ N(0,\sigma_{pj}^2) & PMU \text{ measurements} \\ N(0,\Lambda_{jj}) & \text{area state estimates} \end{cases}$$

Computational innovations:

Two-level SE Properties:

- No boundary measurements are discarded.
- All detectable / identifiable bad data are detected and identified.
- PMU measurements are effectively used, but not required for this scheme to work.
- Areas do not share network data (internal system details) or intermediate iteration results. They only provide boundary network model and measurements and their estimated states to the coordinator.
- Applicable to both single phase [positive seq.] and three-phase SE, areas representing either transmission control areas or distribution system feeders which may or may not be configured radially.

Major Innovations

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Robustness innovations:

- ❖ WLS SE followed by the largest normalized residual (LNR) – Plan to use a recently developed technique which drastically increases the computational speed of LNR test for very large scale systems.

Innovative stitching of T&D real-time solutions:

- ❖ Use of D system sequence current injections and T system pseudo-injections to solve for the zero sequence voltages in the T system. Also provide real-time monitoring capability of reverse flows at the seams.

Main Project Tasks/Subtasks

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Task 1: Multi-area Transmission State Estimation (MAT SE)

1.1. Formulation and software design
1.2. Prototype code development
1.3. Testing and validation

Task 2: Multiple Distribution Feeder State Estimation (MDF SE)

2.1. Formulation and software design
2.2. Prototype code development
2.3. Testing and validation

Task 3: T&D Network Data and Measurement Acquisition

3.1. Identifying data sources and gathering data
3.2. Verifying data consistency and sufficiency

Main Project Tasks/Subtasks

Task 4: Technology-Market Transition Plan Preparation

Task 5: BD Processing by MAT SE

5.1. LNR test for individual areas

5.2. LNR test by coordinator

5.3. Testing and validation

Task 6: PV Incorporation and BD Processing by MDF SE

6.1. LNR tests on individual feeders

6.2. Incorporating large number of solar PV units

Task 7: Network Data and Measurement Configuration

7.1. Acquire data and measurement configuration for both T&D

7.2. Test data and synthesized measurements using MAT and MDF estimators.

Main Project Tasks/Subtasks

Task 8: Engagement of PE community / Workshop at NEU

Task 9: Combining MAT and MDF SE

9.1. Code development for pos. seq. combined SE

9.2. Implementing unbalanced estimator

9.3. Testing and validation

Task 10: Testing with Large System Data and Measurements

10.1. Create large scale measurements using save cases

10.2. Test MAT and MDF estimators, then the combined SE

Task 11: Dissemination of Results / Workshop at PJM

Task 12: Documentation

12.1. Final project report

12.2. User's manual for the developed software

Project Milestones/Deliverables

- M:1.0 Validation of MAT SE code [12 mo.]
- M:2.0 Validation of MDF SE code [12 mo.]
- M:3.0 Test data for both transmission and distribution systems [12 mo.]
- M:5.0 Validation of robustness (MAT SE) [24 mo.]
- M:6.1 Validation of robustness and PV incorporation (MDF) [24 mo.]
- M:7.0 Testing w/ actual data, synthesized measurements [24 mo.]
- M:8.1 Workshop at NEU [24 mo.]
- M:9.0 Validation of combined T&D SE code [33 mo.]
- M:10 Testing with utility data and measurements [36 mo.]
- M:11 Workshop at PJM [36 mo.]
- D:1 Combined T&D SE program [36 mo.]
- D:2 Final report and acceptance tests [36 mo.]

Project Architecture

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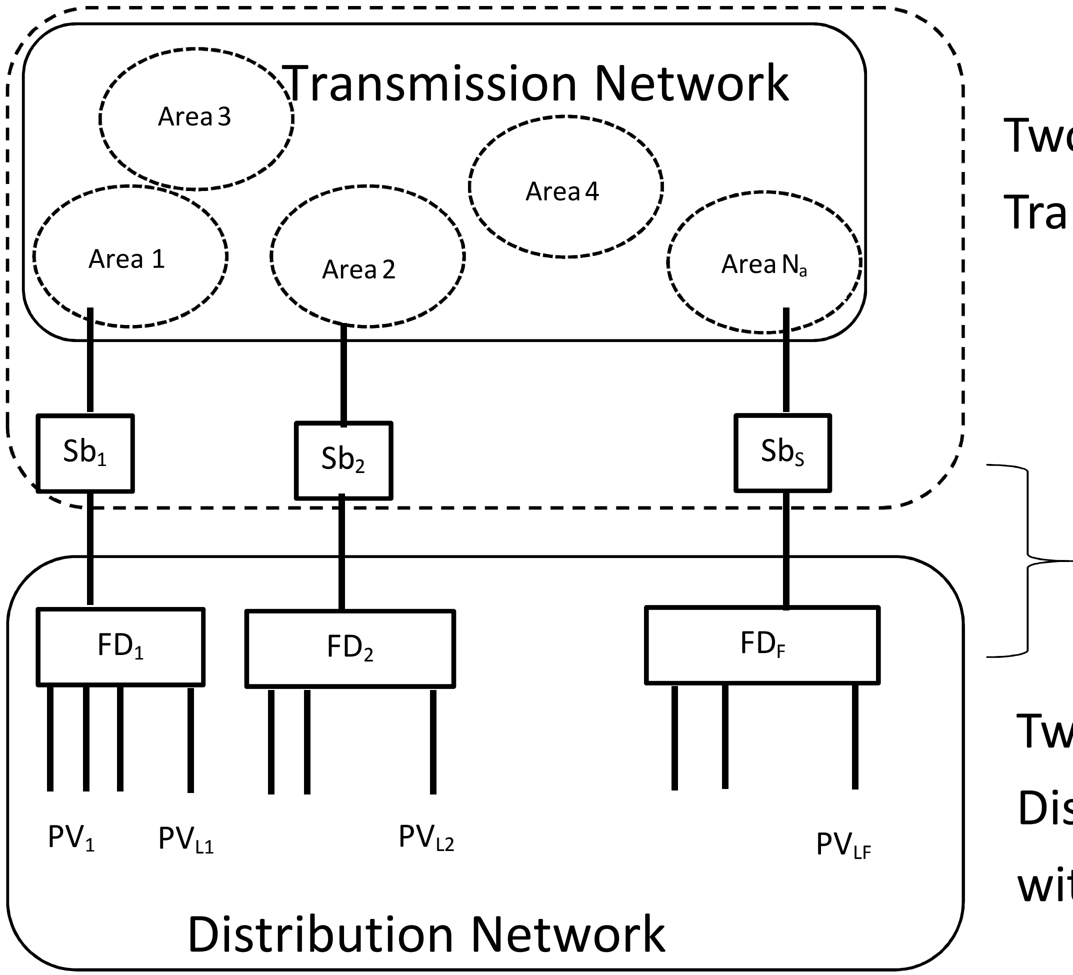

Two-level Multi-Area Transmission SE

Combining T&D SE Solutions

Two-level Multiple Distribution Feeder SE with Solar PV

High Risks & Mitigation

1. Premature termination of graduate research associate contracts due to students failing QE, unsatisfactory performance, etc.
   - Engage multiple students via project group meetings to keep them familiar with the project tasks, developed software and methods.
2. Difficulty to acquire large scale distribution system network data and measurement configurations. This task will be facilitated by project subcontractor PJM.
   - Contact multiple distribution companies to increase chances of acquiring typical data / measurements from at least one.