Integrating Synchrophasor Technology with the Oregon State University Campus Smart Grid Project

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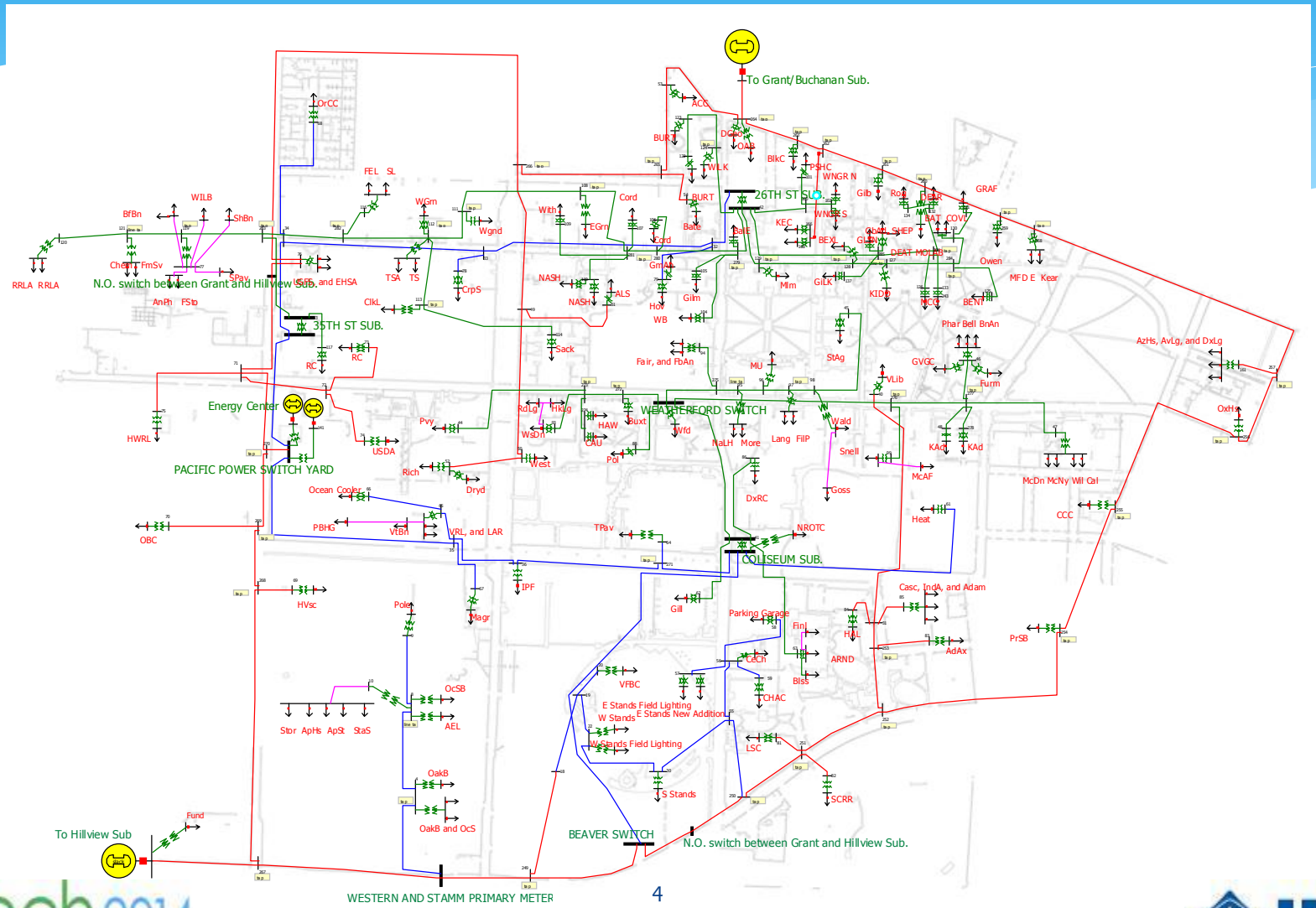
Overview

- Background
  - synchrophasor fundamentals
  - OSU campus data
  - goals
- Methodology
- Results
- Conclusions and Future Work
- Questions

Synchrophasor Fundamentals

- Features
  - value recorded in phasor format: magnitude and angle
  - high fidelity (60,120 Hz)
  - synchronized data by Global Positioning System (GPS) timestamps
- Applications
  - wide-area control
  - determining stability margins
  - islanding detection
  - …
- Synchrophasor technology system elements
  - GPS clock
  - Phasor Measurement Unit (could be standalone or inside some other devices)
  - Phasor Data Concentrator (PDC)
  - communications equipment
  - visualization software

OSU-Corvallis Campus Grid



Goals

- Find the best locations to place synchrophasors.
- Discuss whether the synchrophasor placement methods work well at distribution level or not.

Methodology

- Integer Linear Programing (ILP)
  - topological structure
  - electrical structure
- Sensitivity analysis

ILP based on Topological Structure

$$x_i = \begin{cases} 1 & \text{if a synchrophasor is installed at bus i} \\ 0 & \text{otherwise} \end{cases}$$

We want

$$\min \sum_{i=1}^{N} x_i$$

such that

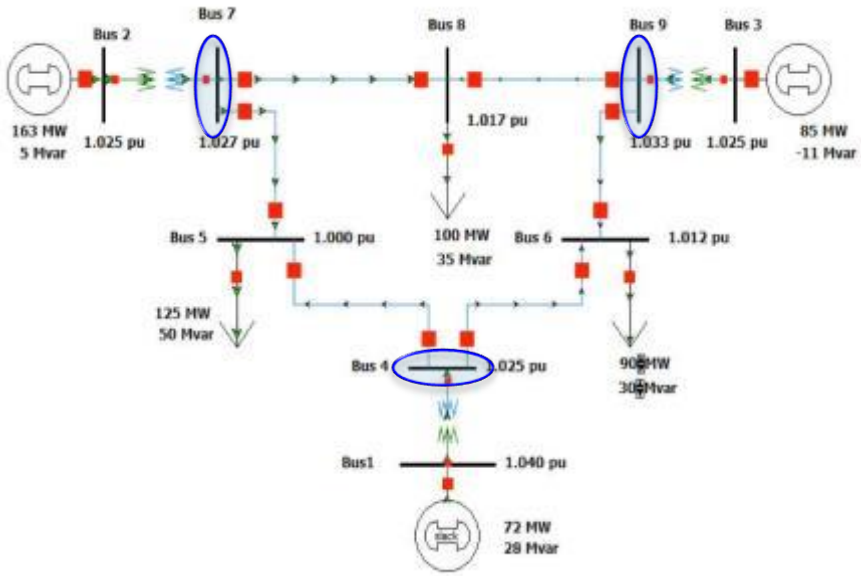
$$Ax \geq b$$

- N is the total number of buses.
- A is an N*N connectivity matrix with binary valued elements.
- b is an N*1 unit vector.

K. Nagananda, "Electrical structure-based pmu placement in electric power systems," arXiv preprint arXiv:1309.1300, 2013.

Example: IEEE Case 9

Case 9



A-matrix

$$
\begin{matrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}
\quad
\begin{matrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix}
\quad
\begin{matrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{matrix}
$$

$$
\begin{matrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{matrix}
\quad
\begin{matrix} 1 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \end{matrix}
\quad
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\begin{matrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{matrix}
\quad
\begin{matrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{matrix}
\quad
\begin{matrix} 1 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \end{matrix}
$$

ILP based on Electrical Structure

- Every element in A-matrix represents the electrical distance.
- Obtain binary elements by applying a threshold.

Sensitivity Analysis

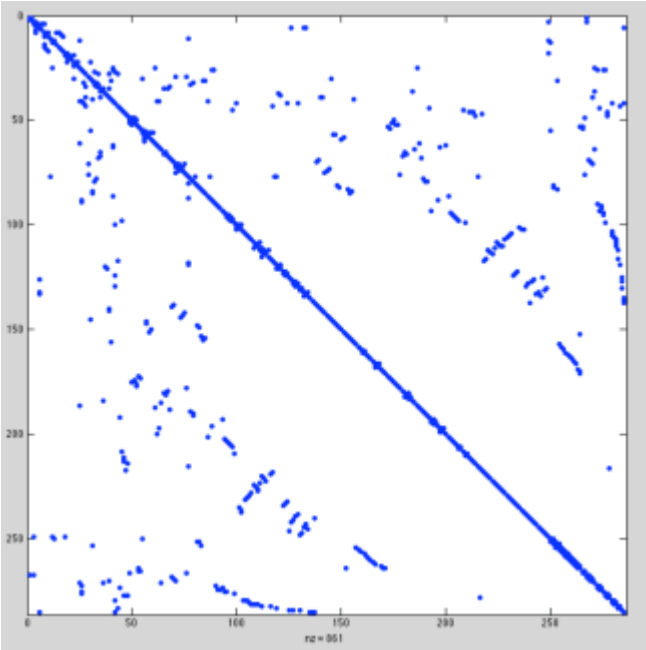
$$\mathrm{D}P = \left[\frac{\partial P}{\partial q}\right]\mathrm{D}q + \left[\frac{\partial P}{\partial |V|}\right]\mathrm{D}|V|$$

$$\mathrm{D}Q = \left[\frac{\partial Q}{\partial q}\right]\mathrm{D}q + \left[\frac{\partial Q}{\partial |V|}\right]\mathrm{D}|V|$$

J. Song, T. K. A. Brekken, E. Cotilla-Sanchez, A. von Jouanne, and J. D. Davidson, "Optimal placement of energy storage and demand response in the pacific northwest," in Power and Energy Society General Meeting (PES), 2013 IEEE, July 2013, pp. 1–5.

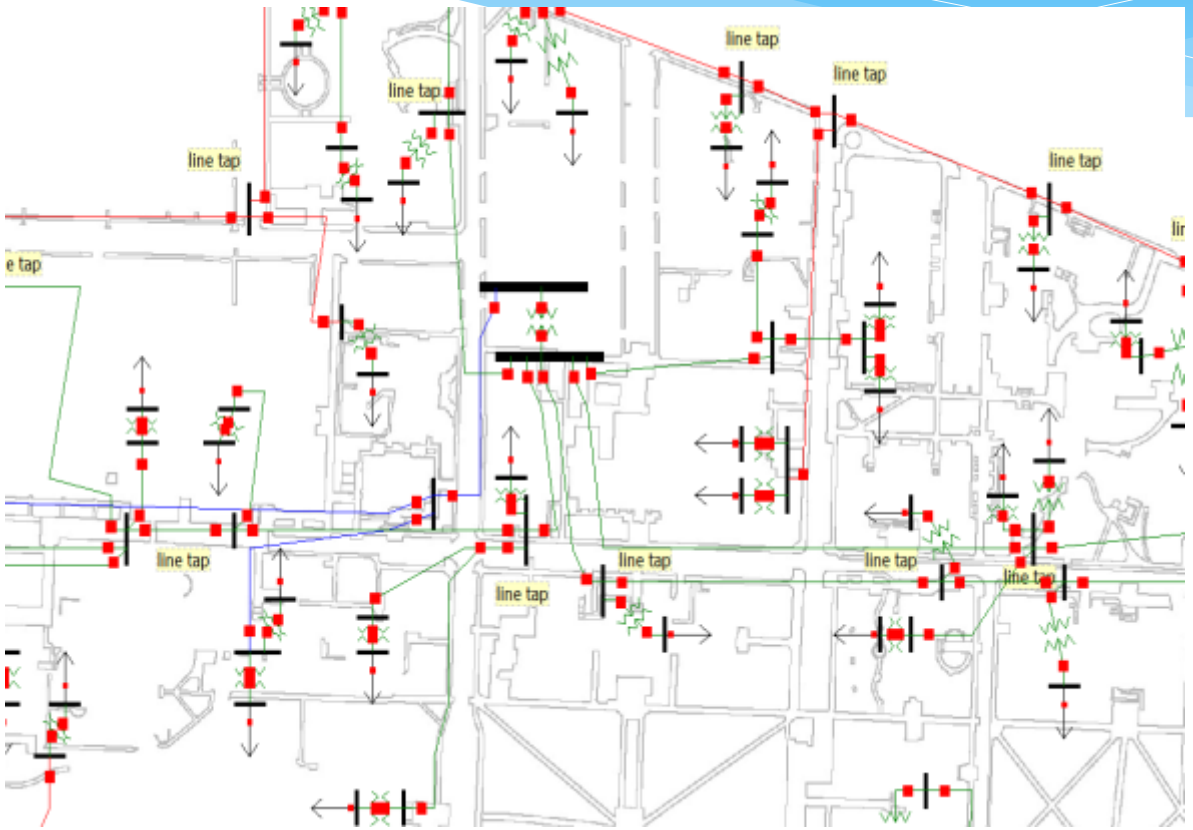
Results for ILP based on Topological Structure

A-matrix



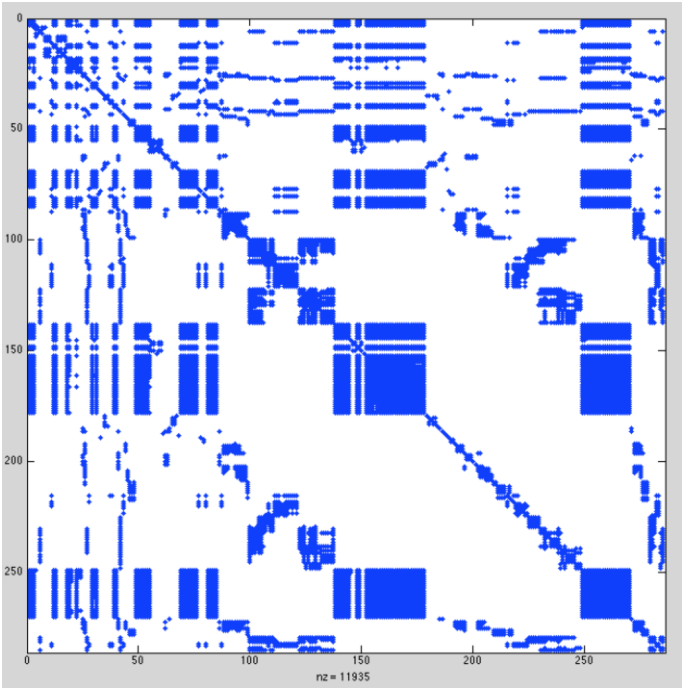
Synchrophasor locations

Discussion about Topological Structure

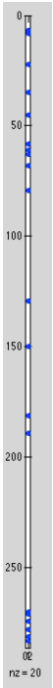


Results for ILP based on Electrical Structure

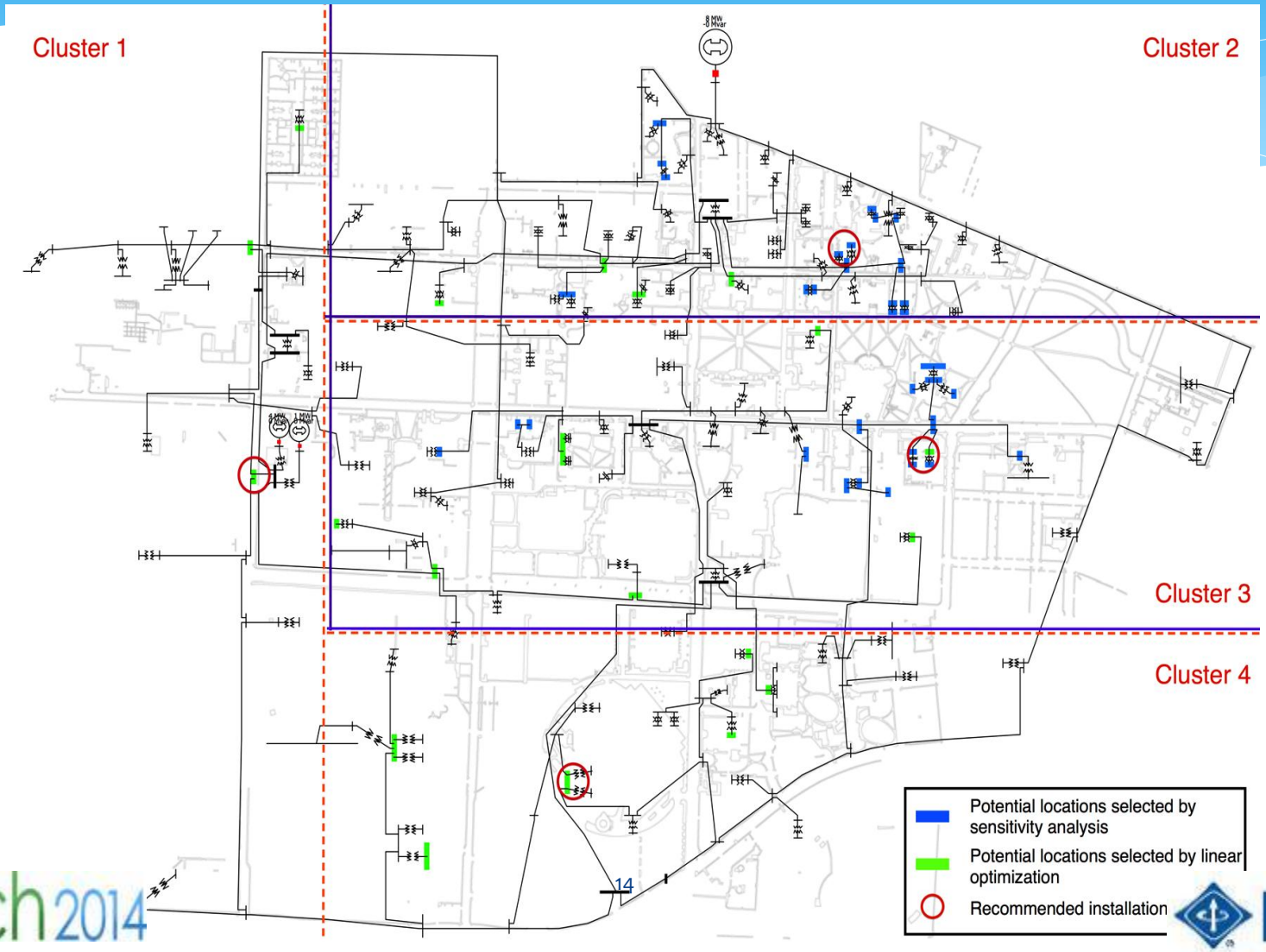
A-matrix



Synchrophasor locations



Results for Electrical Structure and Sensitivity Analysis



Conclusions

- Four suggested synchrophasor locations.
- Topological structure doesn't work well for distribution level, especially for a radial power grid.
- Electrical structure and sensitivity analysis need a proper threshold.

Future Work

- Testing and deploying synchrophasors based on the results.
- Analyzing how those synchrophasors could facilitate our campus grid operation.

Thank you!

QUESTIONS?