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Strategic PMU Placement for Secure and Resilient Power Grids

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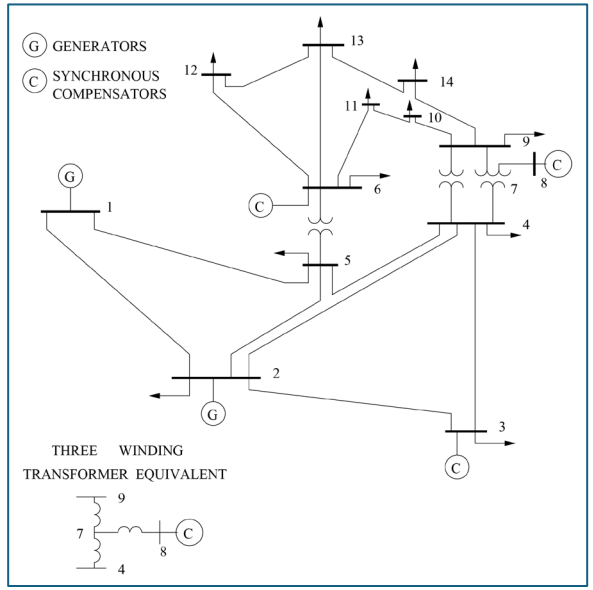
Introduction

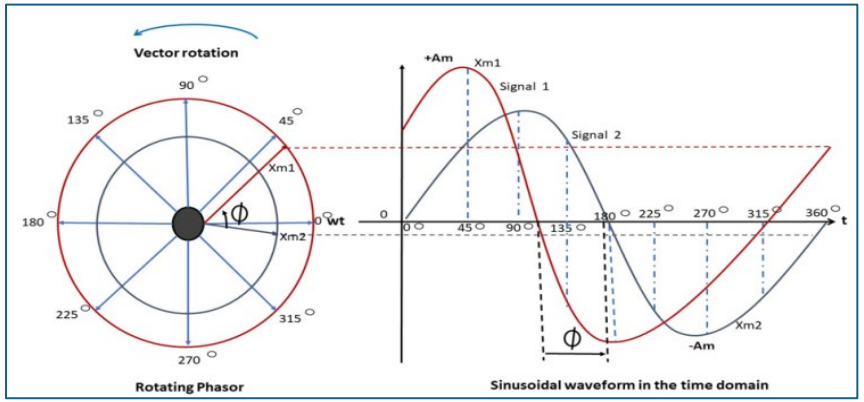
- **Power Grid:** electrical network that delivers power from generators to loads
- **Network**: a bus topology where every element is connected through a line (bus)
- **Phasor Measurement Unit (PMU):** a device used to measure voltage and current in phase and amplitude

It is capable to deliver measurement by using Global Positioning System GPS, taking up to 60 measurements per second

Cost per PMU: roughly **$40,000**



Img src: Ali R. Al-Roomi (2015). Power Flow Test Systems Repository [https://al-roomi.org/power-flow]. Halifax, Nova Scotia, Canada: Dalhousie University, Electrical and Computer Engineering



Img src: Maveeya BABA, BABA. "A Review of the Importance of Synchrophasor Technology, Smart Grid, and Applications." PAN Journals , PAN, 2022, journals.pan.pl/Content/125560/PDF/BPASTS_2022_70_6_2991.pdf

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Motivation

- Power grids are the backbone of modern societies
- Power grid networks are designed to transfer power

An efficient network **requires observability** of the whole system

- PMUs with their synchronized phasor measurements can monitor grid operations
- PMUs' high costs limits how many units can be deployed in a network

OBJECTIVE

Designing a strategy to optimize the allocation of PMUs to ensure observability while considering:

- Cost per PMU
- Network topology
- Types of nodes/buses

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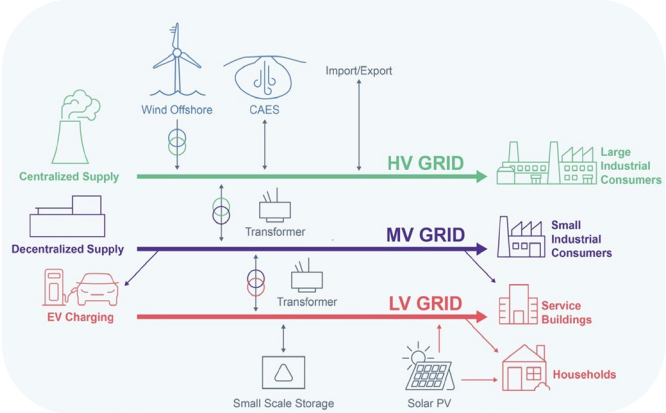
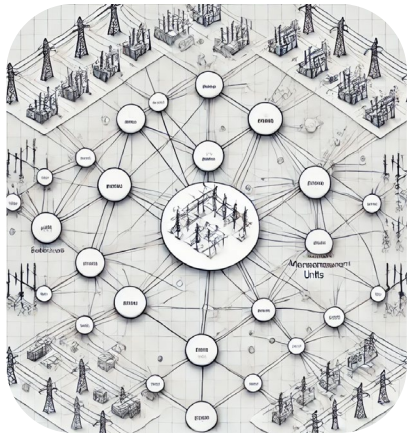
Research Overview





GAMS + MATLAB®

Modern Power Grid Observability Issues due to insufficient Monitoring Devices

Phasor Measurement Units (PMUs) Collecting Data

Optimal Placement of PMUs for Grid Control

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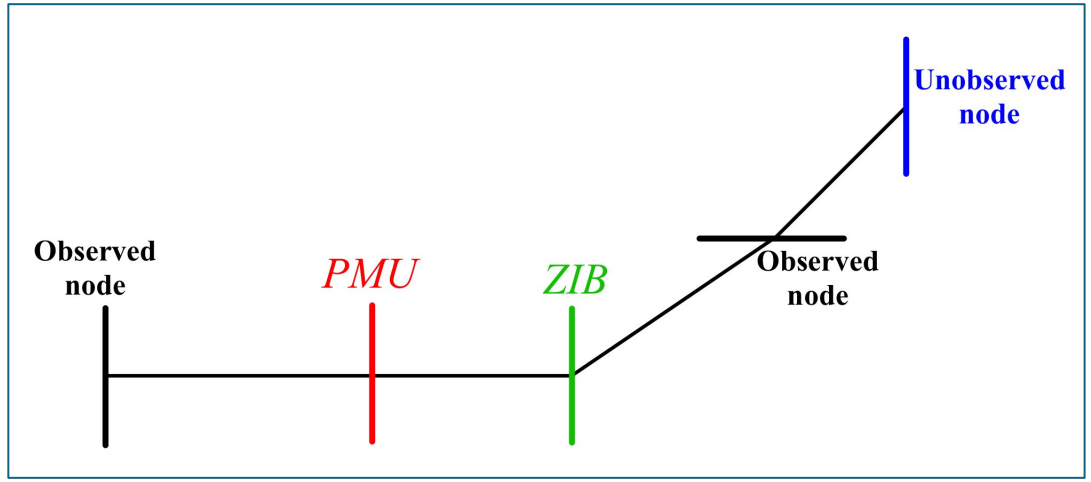
Preliminary Definitions

- **Observability**: the ability to measure a system's inputs and output data
- PMU facilitates observability for the node it resides and adjacent nodes
- Power grids will require at **least** 100% observability on any network
- Cost per PMU will depend on the number of channels
- **Zero injection Bus (ZIB):** buses that don't consume nor produce power
- **Critical Node (CN):** node that is directly connected to a generator

Observability System Depth



Improved observability will:

- Increase the number of PMU needed
- Increase monitoring around CN
- Increase the total cost

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Notation

- Bus-Node connection and constrains

$i, j \rightarrow bus\ index$

$\Omega_B \rightarrow Set\ of\ all\ busses$

$\Omega_{ij} \rightarrow Set\ of\ bus\ i\ connected\ to\ j$

$\gamma_i \rightarrow Observability, integer\ variable$

$$a_i = \begin{cases} 1 & node\ contains\ a\ PMU \\ 0 & else \end{cases}$$

$c \rightarrow cost\ per\ PMU$

$n \rightarrow number\ of\ PMU\ channels\ used$

$C_i \rightarrow total\ PMU\ cost\ based\ on\ n$

- Consideration of ZIBs:

$\Omega_Z \rightarrow Set\ of\ ZIBs$

$\Omega_{Za} \rightarrow Set\ of\ adjecent\ buses\ to\ ZIBs$

$\Omega_n \rightarrow Set\ of\ normal\ Buses\ (Not\ ZIBs\ or\ CN)$

- Consideration of critical nodes:

$\Omega_C \rightarrow Set\ of\ critical\ nodes$

Methodology

Objective Functions

Minimization of PMU's based on cost

$$C_i = (1 + 0.1 * n)c$$

$$min\ OF = \sum_{i \in \Omega_B} C_i * a_i$$

Maximizing Observability

$$\gamma_i \geq 1$$

$$max\ OBS = \sum_{i \in \Omega_B} \gamma_i$$

Critical nodes

$$a_i + \sum_{j \in \Omega_{ij}^l} a_j \geq 1 + \gamma_i \qquad \forall i \in \Omega_c$$

Normal Buses

$$a_i + \sum_{j \in \Omega_{ij}^l} a_j \geq 1 \qquad \forall i \in \Omega_n$$

Abnormal buses (not in normal set, not CN)

$$\sum_{j \in \Omega_{ia}^l} \left\langle a_a + \sum_{j \in \Omega_{aj}^l} a_j \right\rangle \geq |\Omega_{za}| - 1 \qquad \forall i \in \Omega_{za}$$

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Optimal PMU placement in IEEE-30

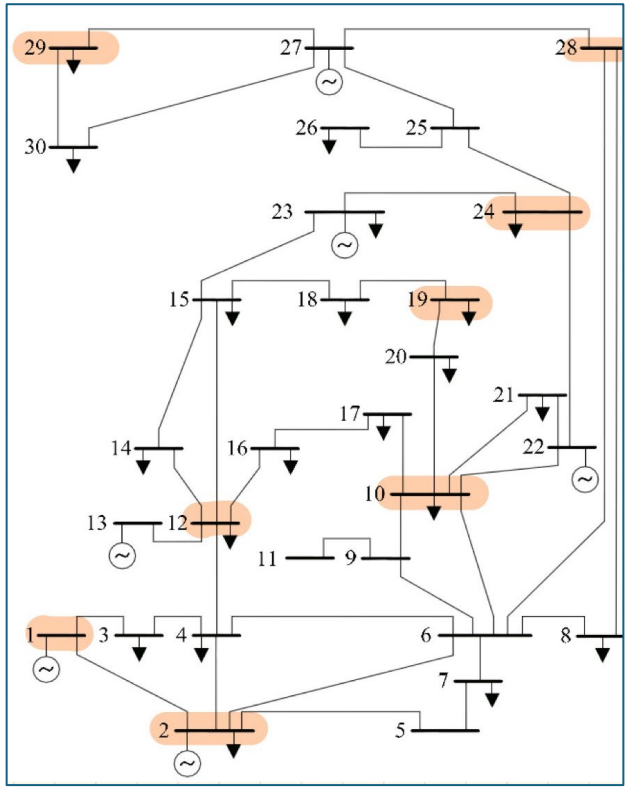
IEEE – 30 bus

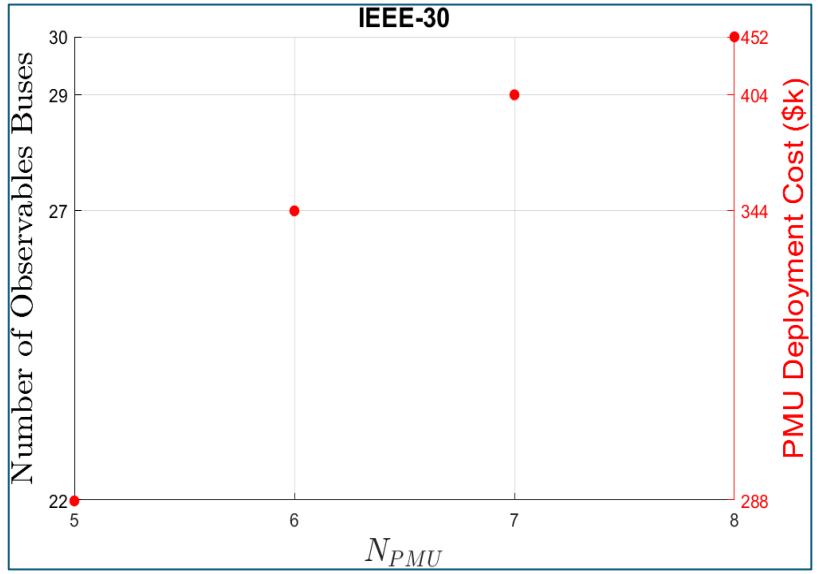
- ZIBs: 6
- CNs: 6
- 100%

  Observability:

  $$N_{PMU} = 8$$

- Cost: $452k





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Optimal PMU placement in IEEE-57

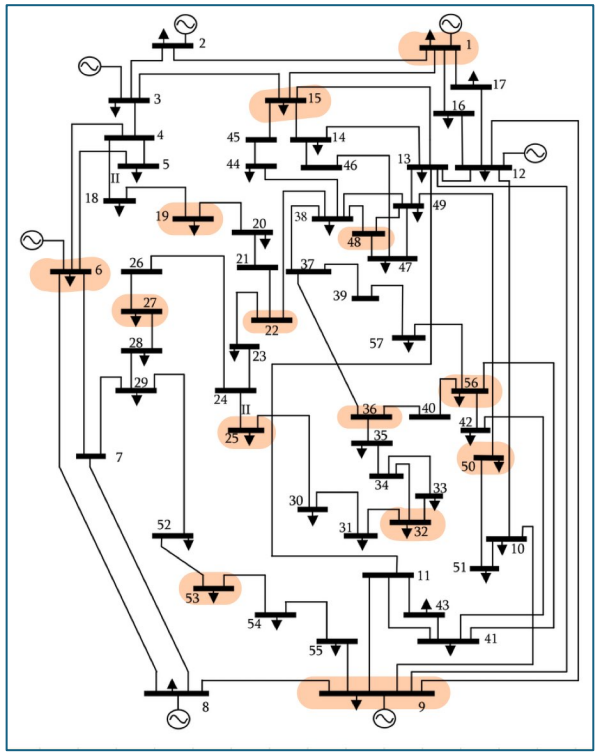
IEEE – 50 bus

- ZIBs: 15
- CNs: 7
- 100%

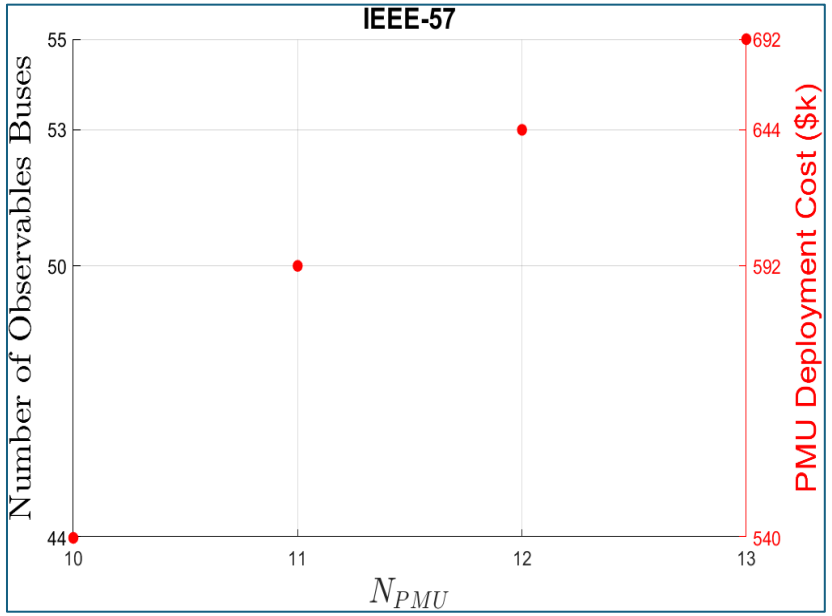
  Observability:

  $$N_{PMU} = 13$$

- Cost: $692k



PMU location



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Optimal PMU placement in IEEE-118

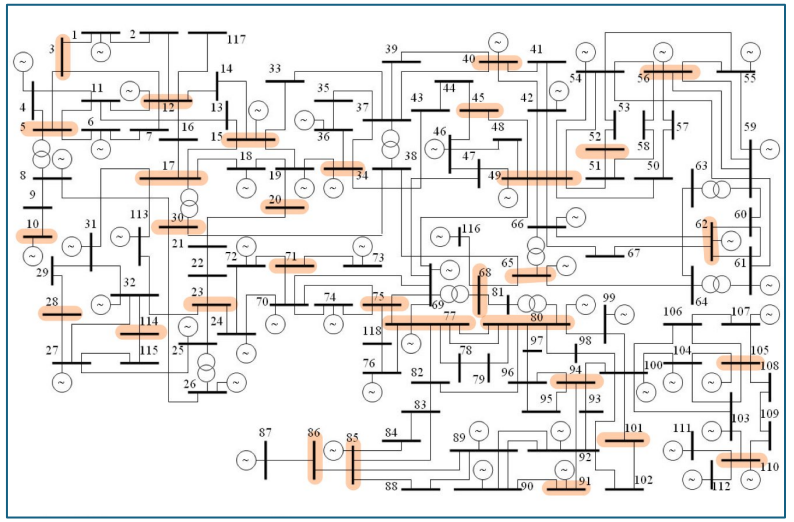
IEEE – 118bus

- ZIBs: 10
- CNs: 52
- 100%

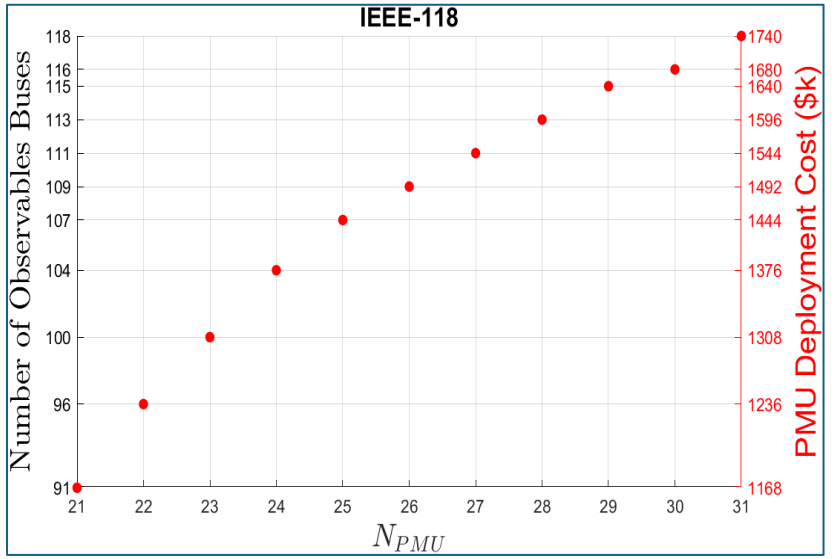
  Observability:

  $$N_{PMU} = 31$$

- Cost: $1740k



PMU location



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Conclusions

- PMUs are essential for grid observability
- Improved observability → more PMUs → higher deployment cost
- IEEE bus networks are used to assess our approach
- Our optimization strategy **prioritized** observability around CN
- ZIBs and their adjacent buses were used for improved observability and to minimize the number of PMUs

Contact us!

SCAN ME

Ioannis (Yannis) Zografopoulos