Machine learning algorithms to improve electrical power grids for a carbon free energy supply

Eberhard Waffenschmidt

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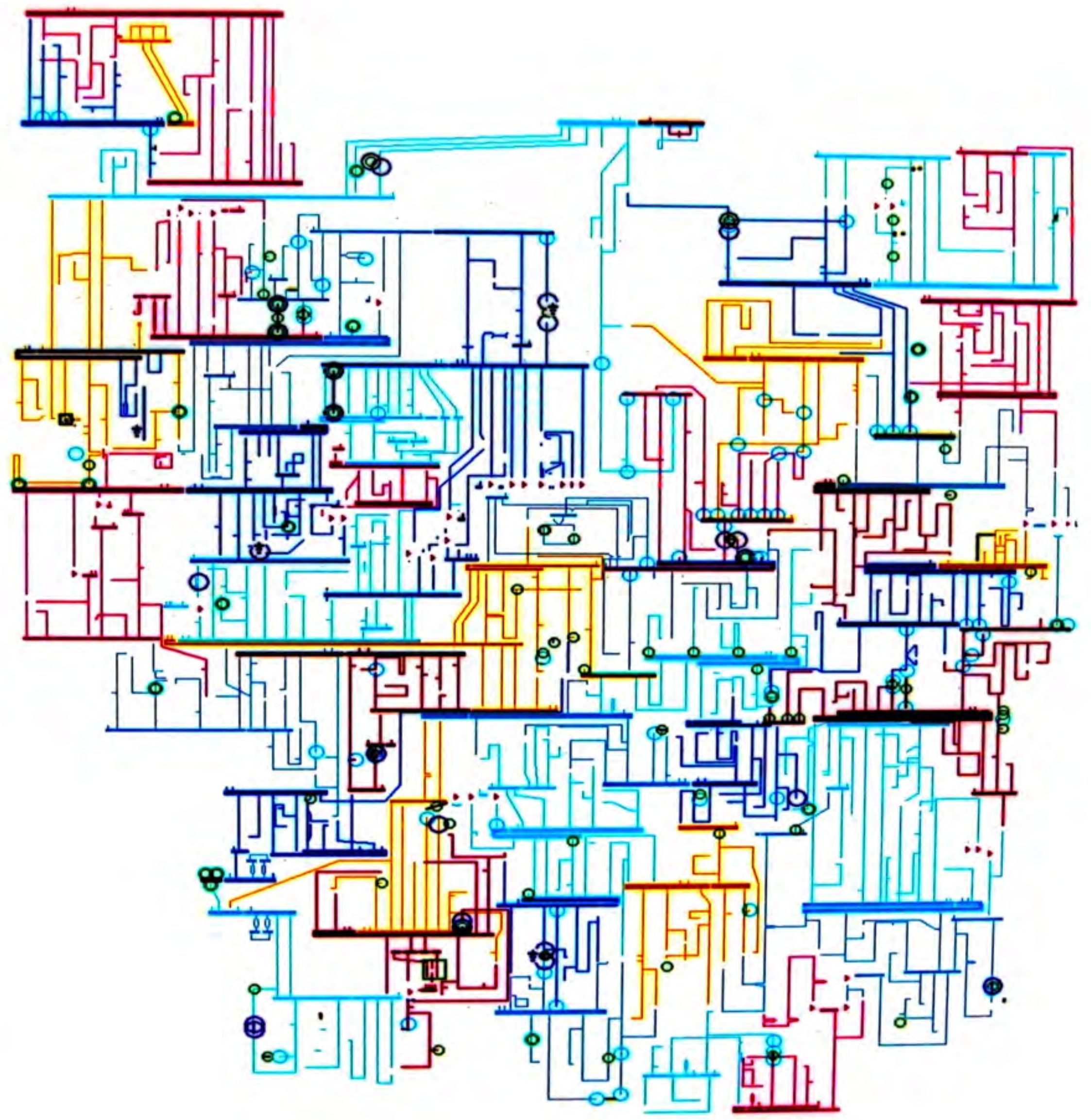
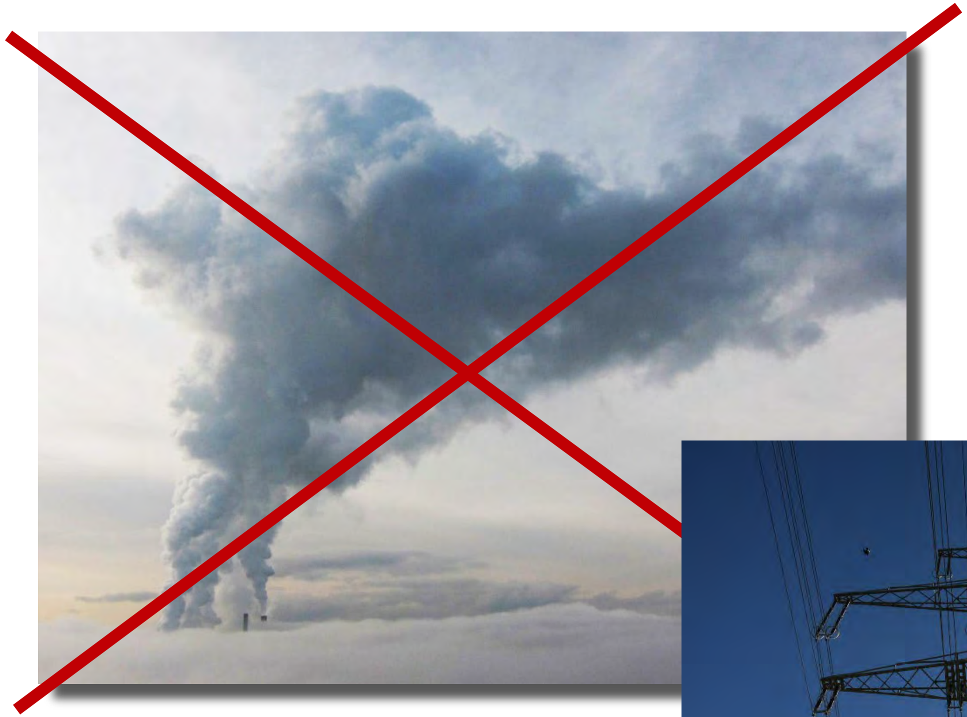
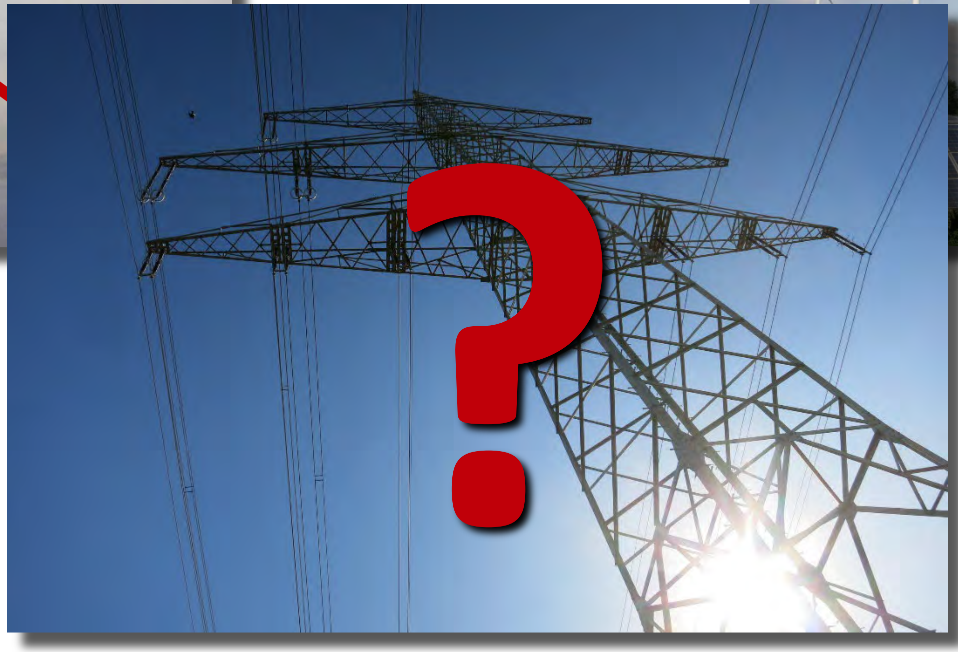
IRENEC 2025, Istanbul, Online Presentation

14. May 2025

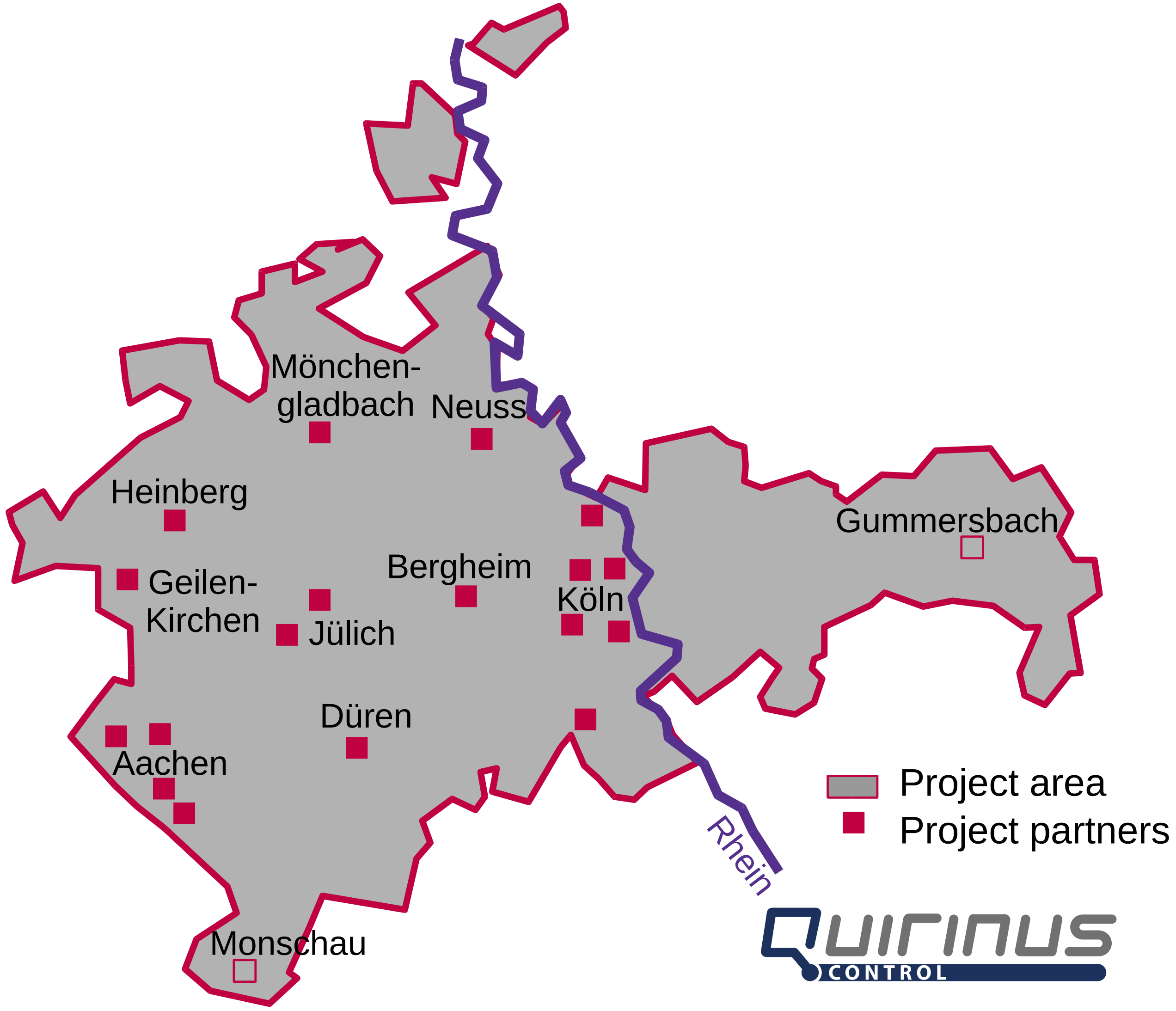


Our Task





Research project Quirinus Contol



- *Background:*
  Phase out of coal and lignite
- *Aim:*
  Supervise quality
  of grid voltage
- *Project area*:
  “Rheinisches Revier”
- *Partners*:
  - Grid operators
  - Universities
  - Research institutions
  - Companies

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Problems

- Hugh amount of data:
  - > 1000 nodes
  - Measurement frequency every 1 sec.
- Not enough measurement devices
  - State estimation of non-equipped nodes
- Multiple origins of disturbance

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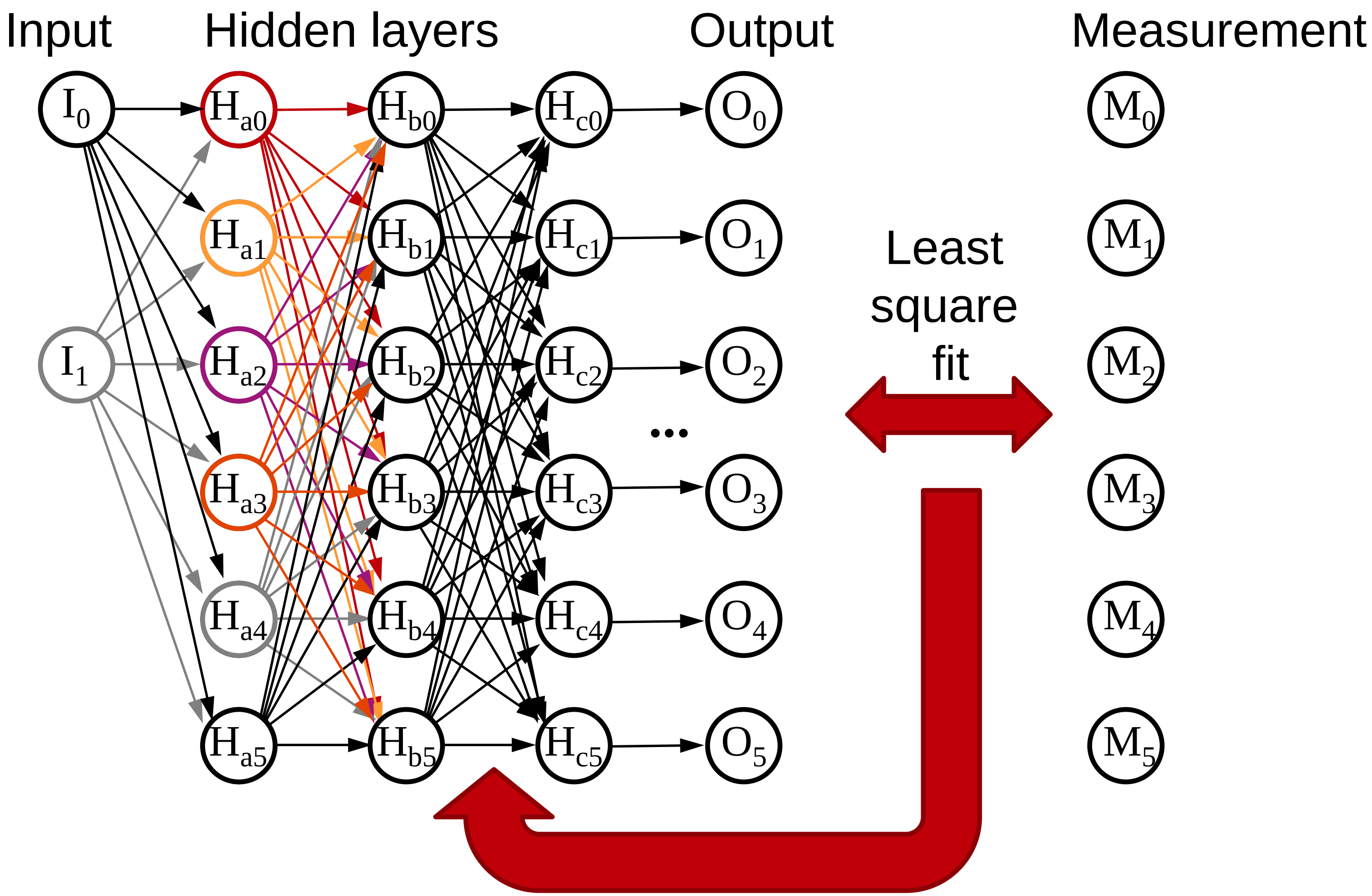
Principle of neural networks

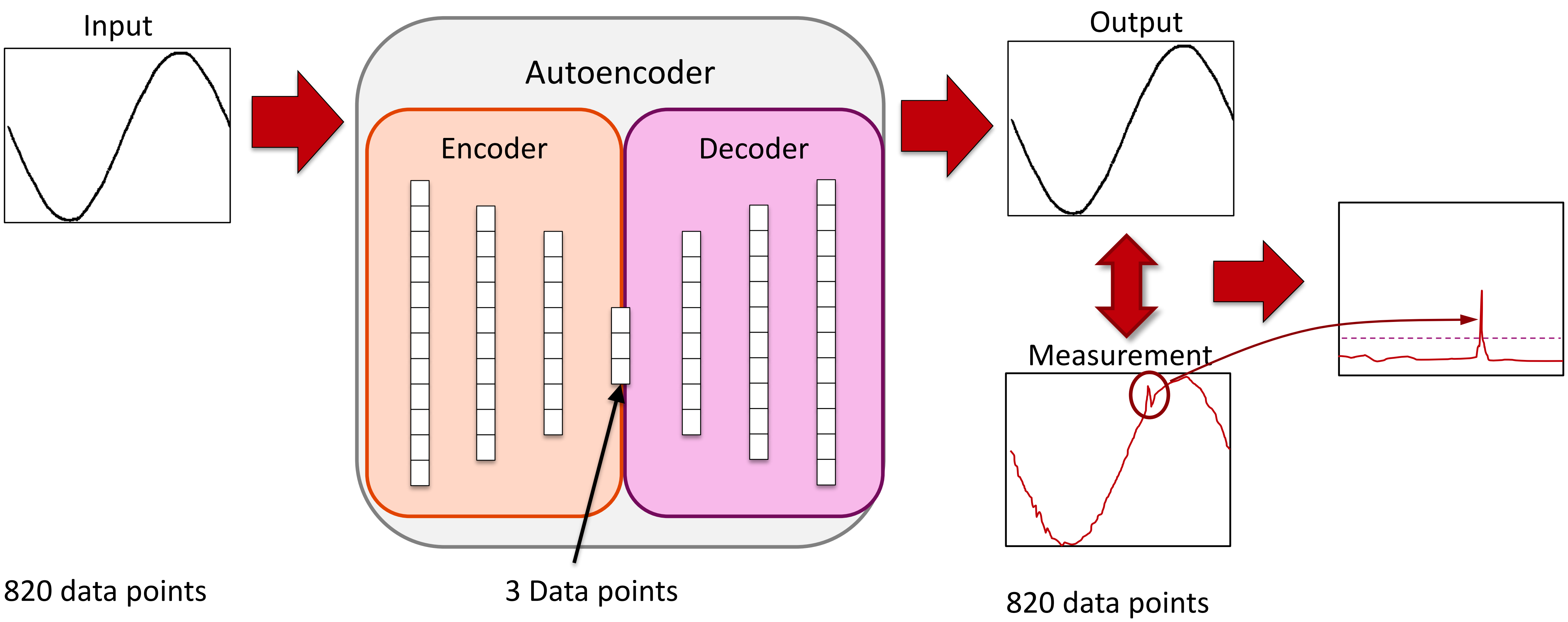


Stages using neural networks

- Training
  - Determines weights in neural network
  - As many different realistic states as possible
- Validation
  - Monitors process
  - Can be used to optimize model parameters
- Test set
  - Test model with previously un-seen data
  - To check performance

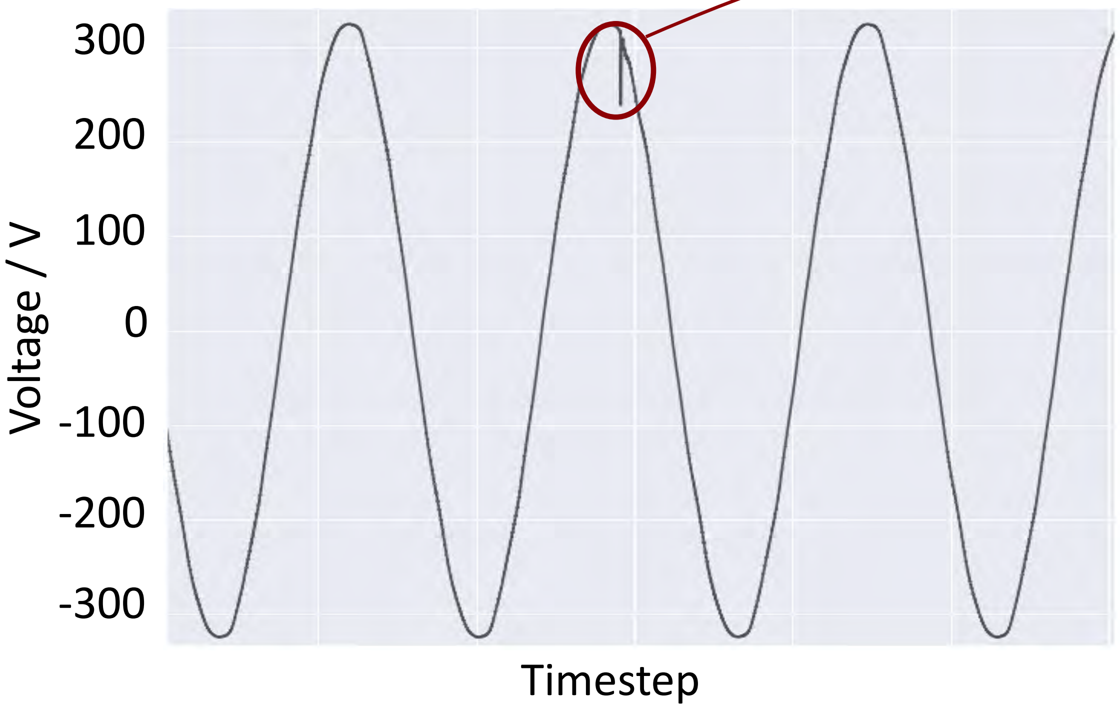
Fault detection

Compression and decrompession

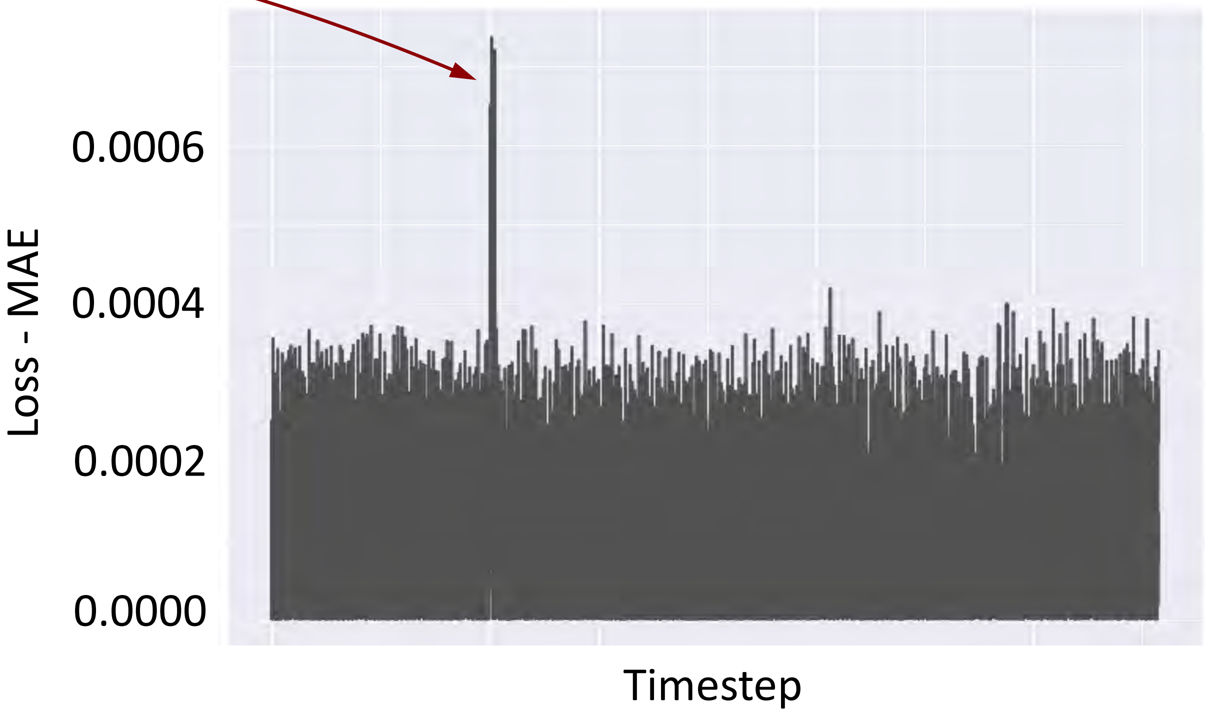


Results for fault detection

Measurement



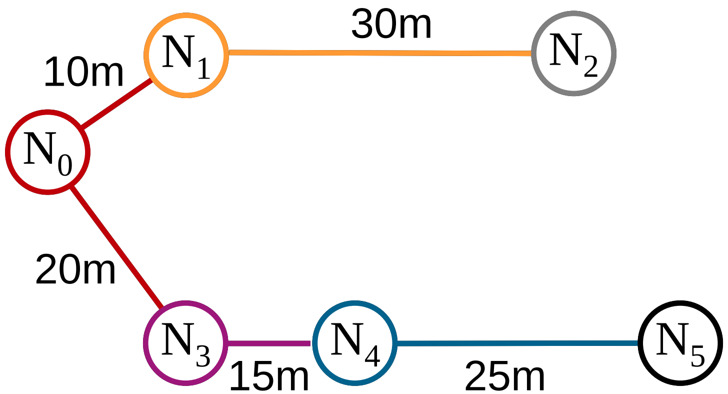
Fault detection



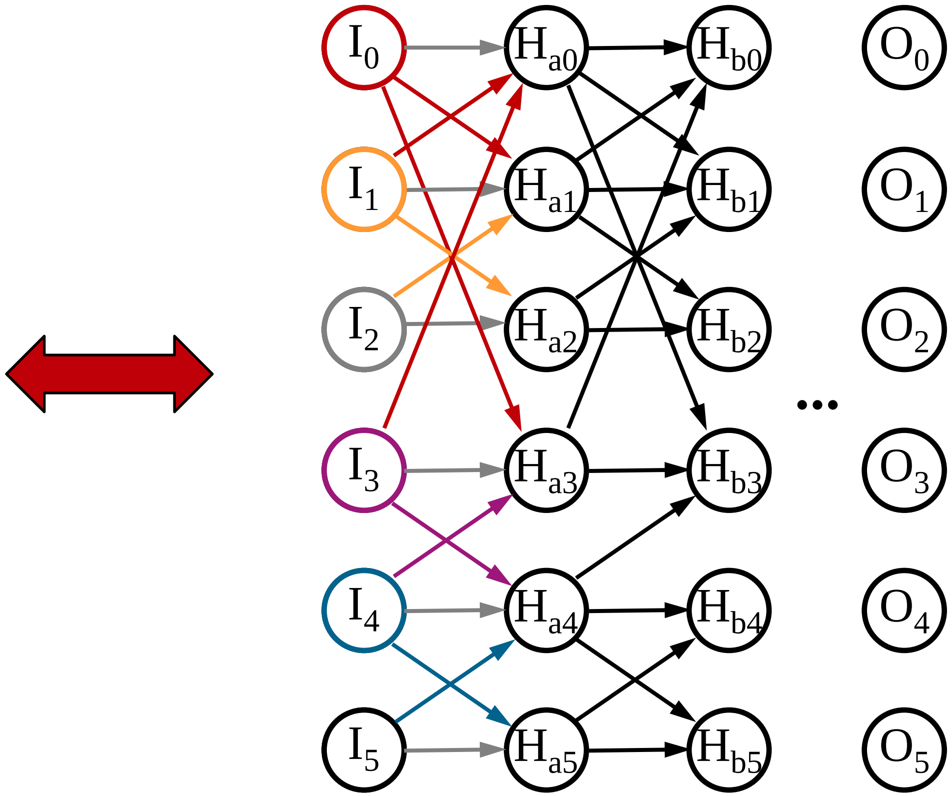
Grid state estimation

Physics aware network

Power grid

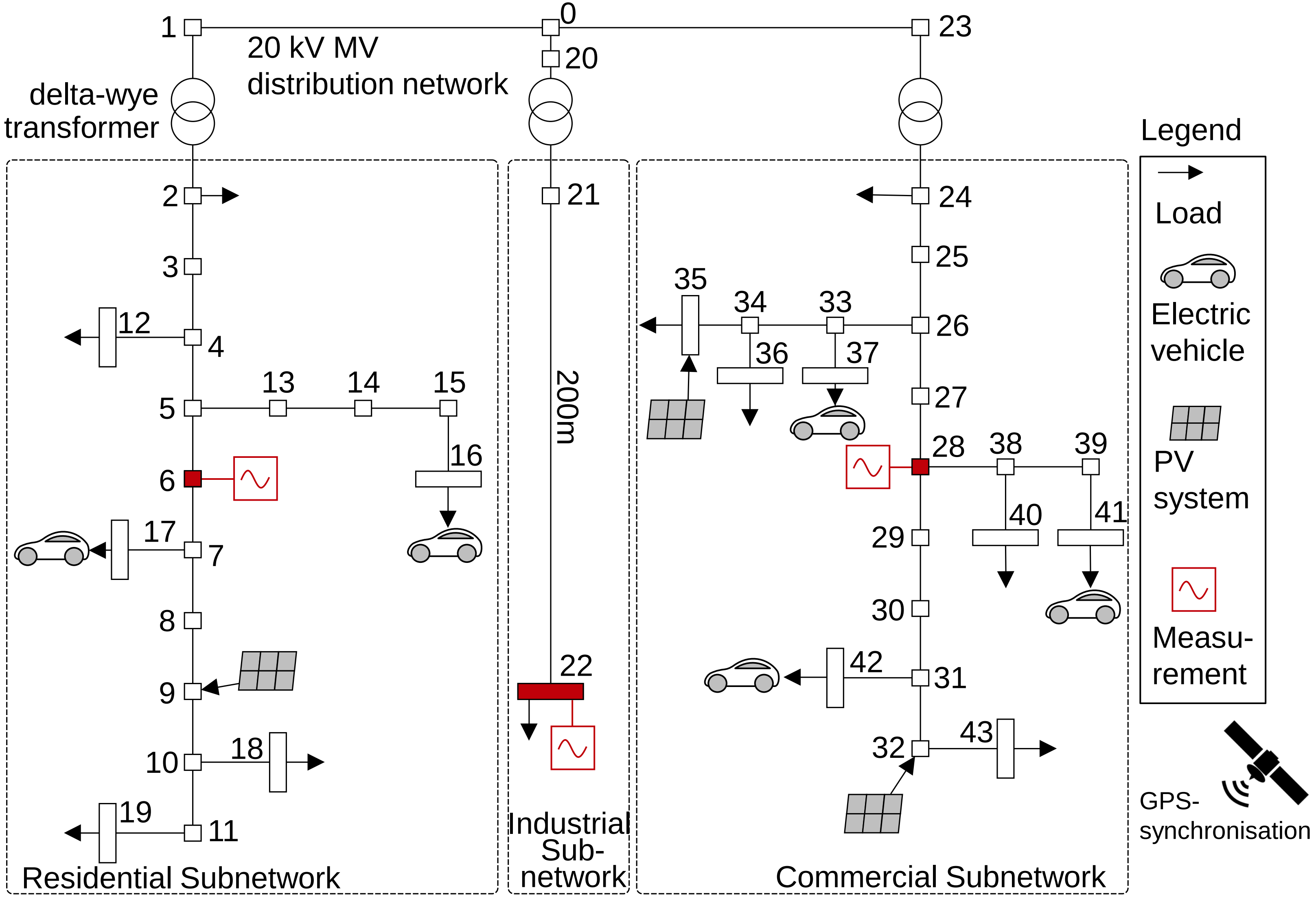


Physics aware neural network (PANN)



Citation: Mack, P.; de Koster, M.; Lehnen, P.; Waffenschmidt, E.; Stadler, I. Power Quality State Estimation for Distribution Grids Based on Physics-Aware Neural Networks—Harmonic State Estimation. Energies 2024, 1, 0. https://doi.org/

Exemplary power grid



- CIGRE benchmark grid
- Three parts
  - Residential
  - Industrial
  - Commercial
- Including
  - Photovoltaic
  - Electric vehicles
- Only three nodes with measurements

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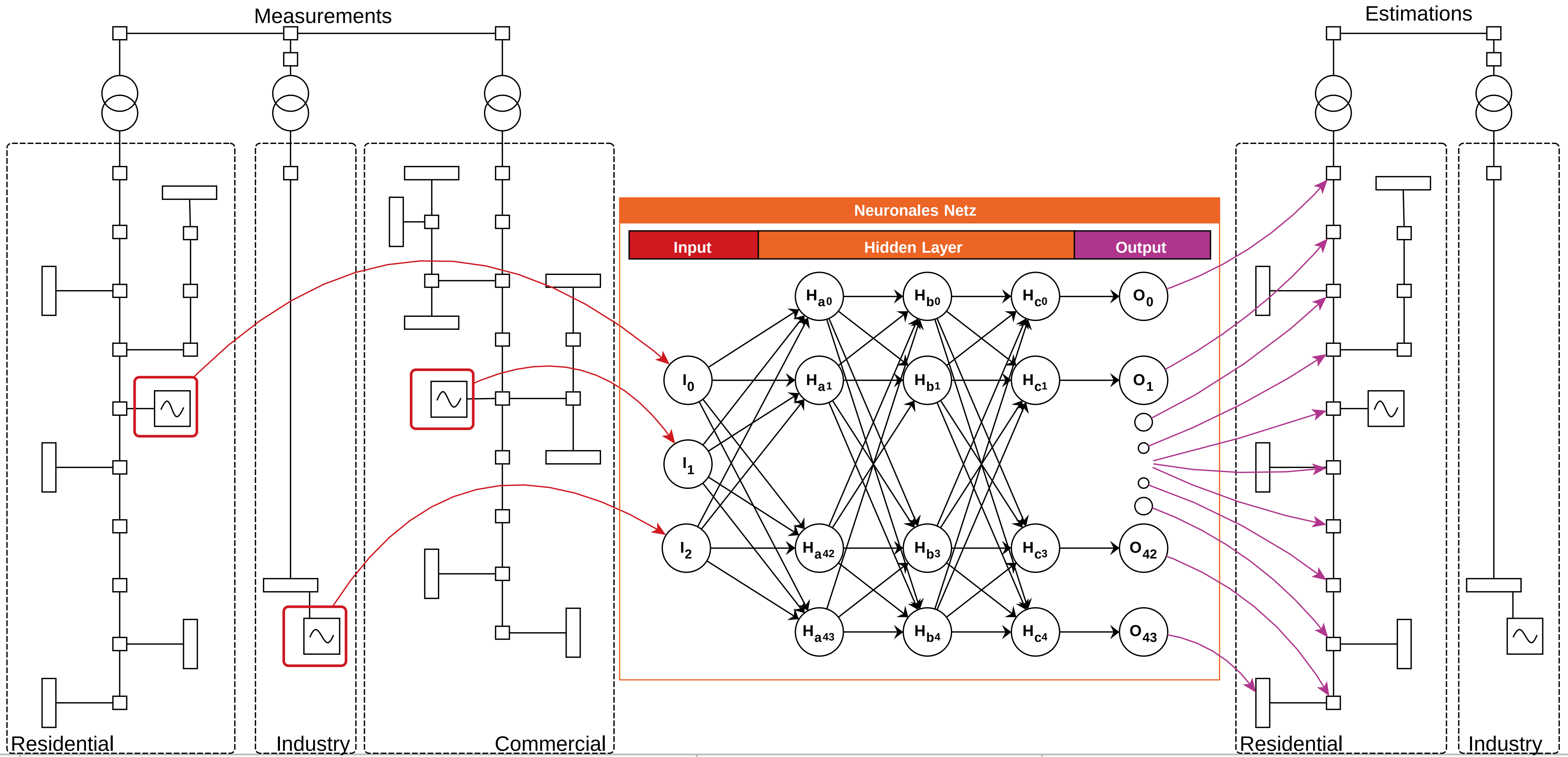
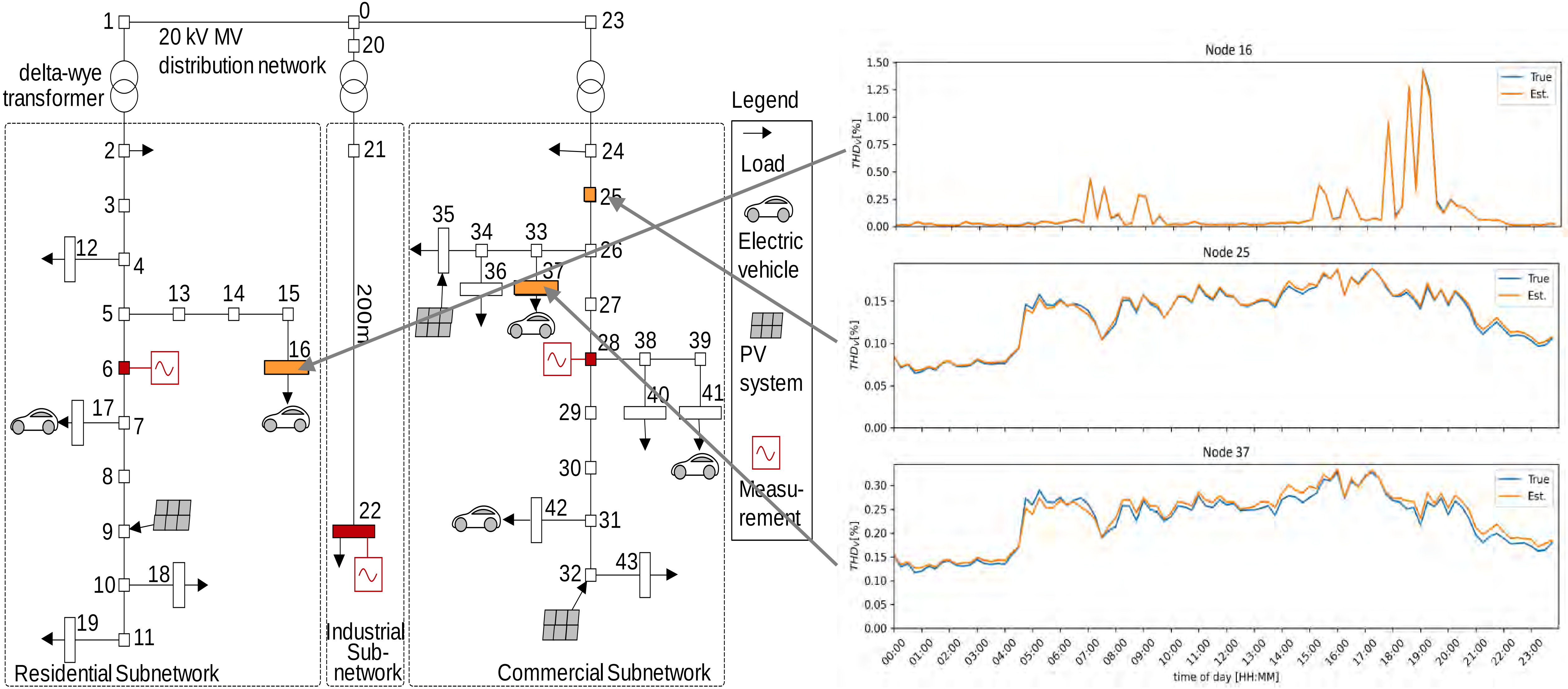
Power grid state estimation



Training

- Training with digital twin: All nodes are simulated
- Grid parameters as reality, not varied.
- Training:
  - Load parameter random variation, quasi-monte-carlo simulation.
  - Harmonics random variation, various distribution profiles.
- Validation:
  - Realistic simulated load profiles (behavioural generation model)
  - Harmonics: measured values from lab and literature
- Test set:
  - Realistic simulated load profiles (behavioural generation model)
  - Harmonics: measured values from lab and literature

Results state estimation



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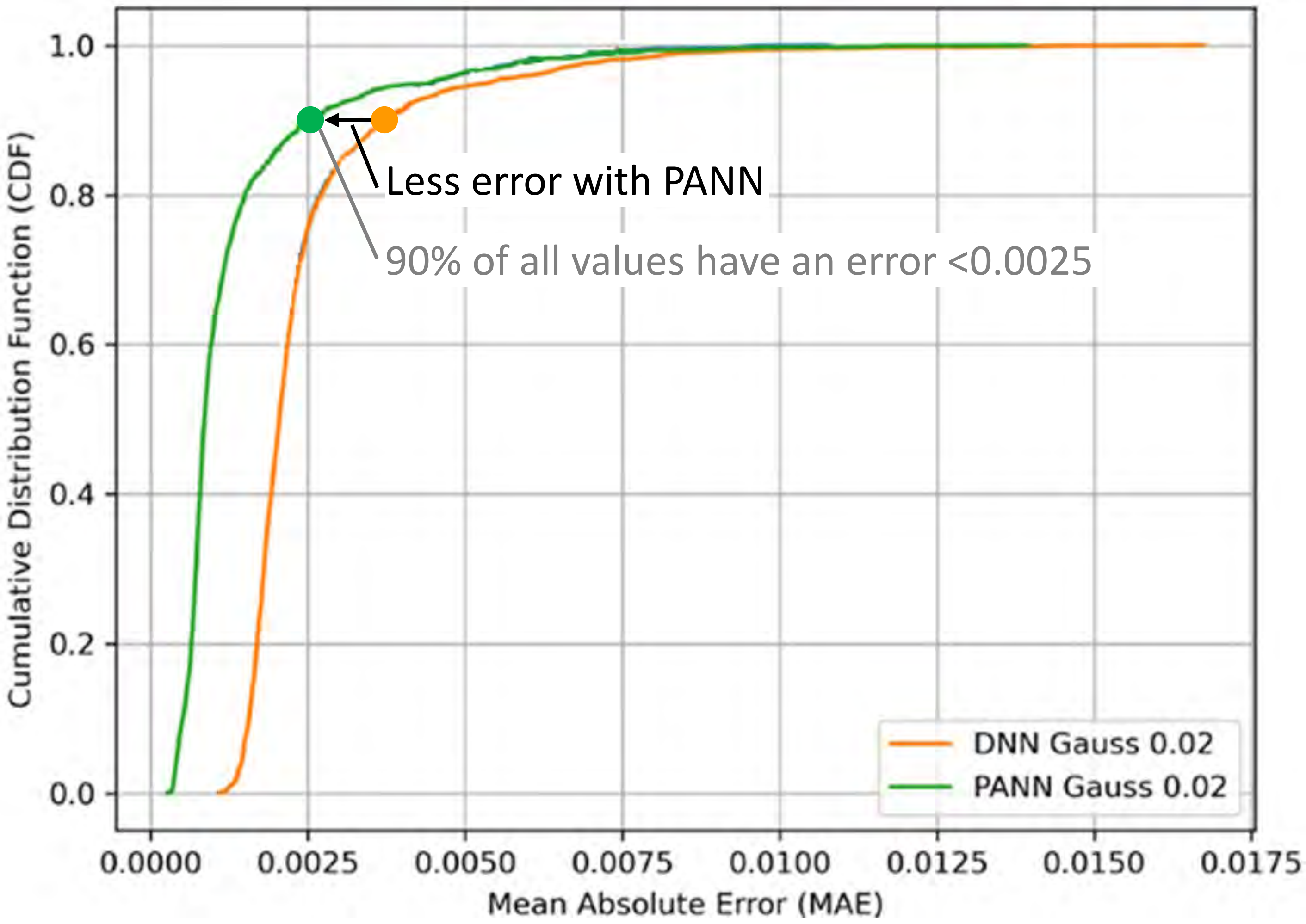
Results state estimation



- Less error with physics aware neural network (PANN)

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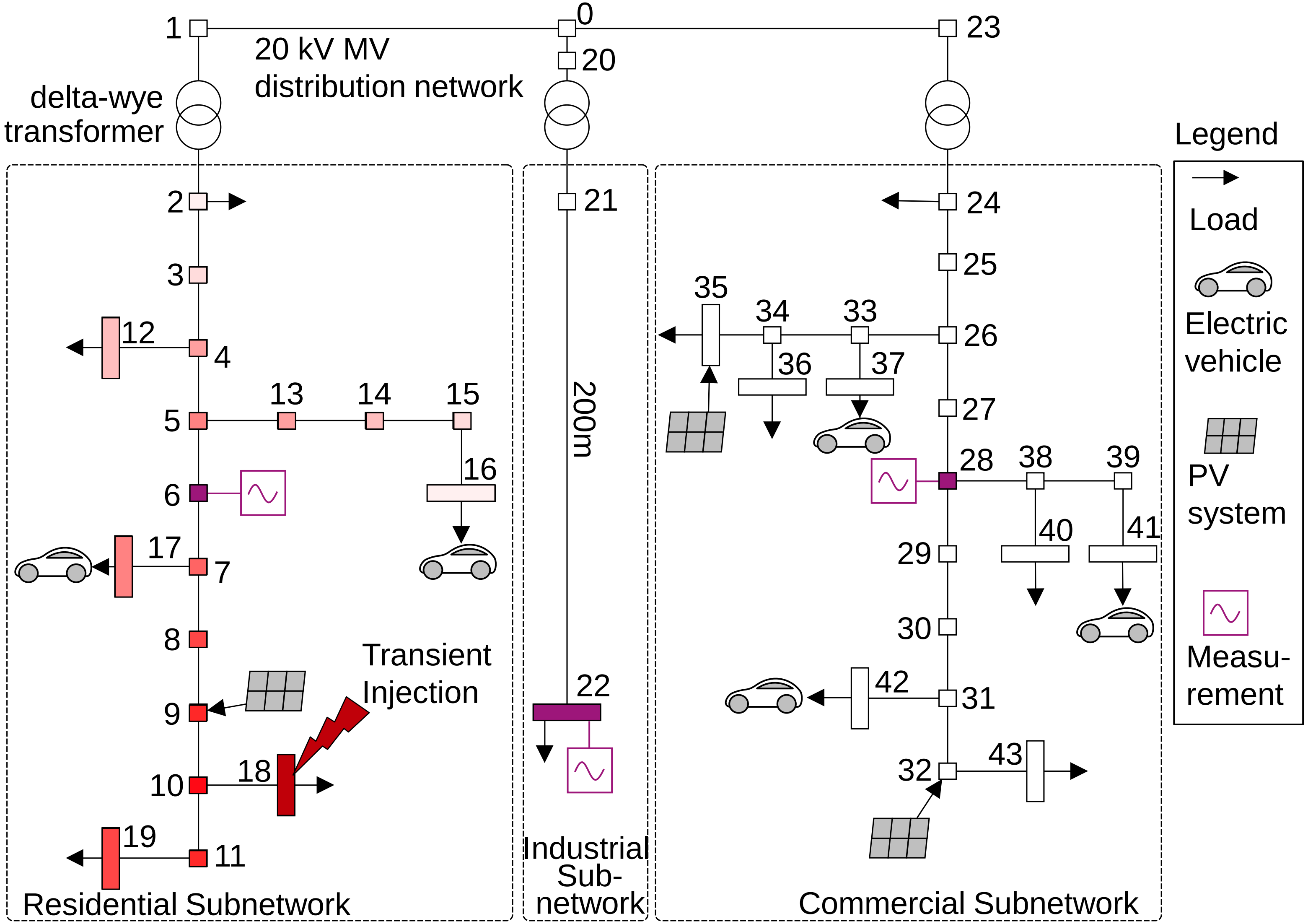
Disturbance location

Disturbance location: Test grid



- CIGRE benchmark grid
- Only three nodes with measurements
- Transient injected as disturbance

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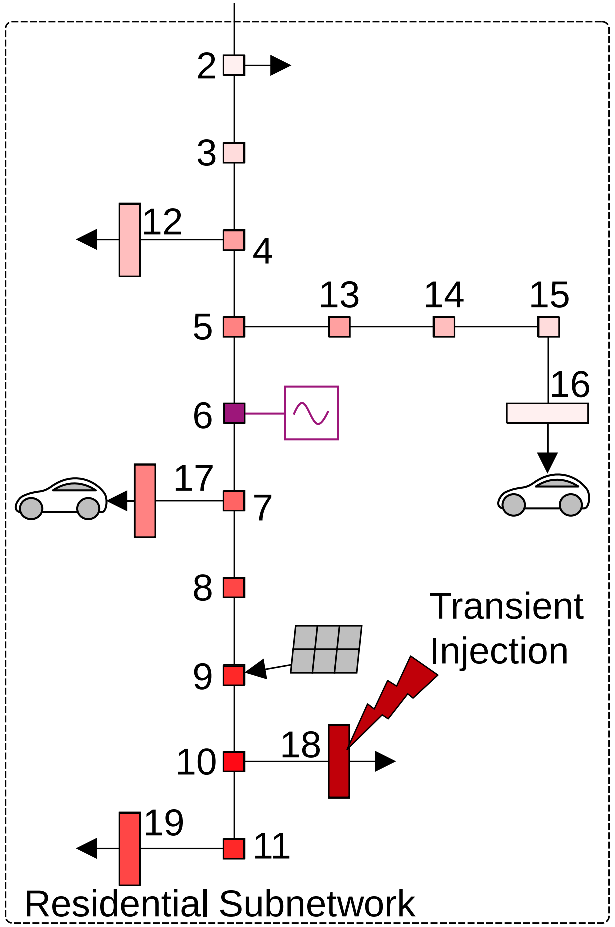
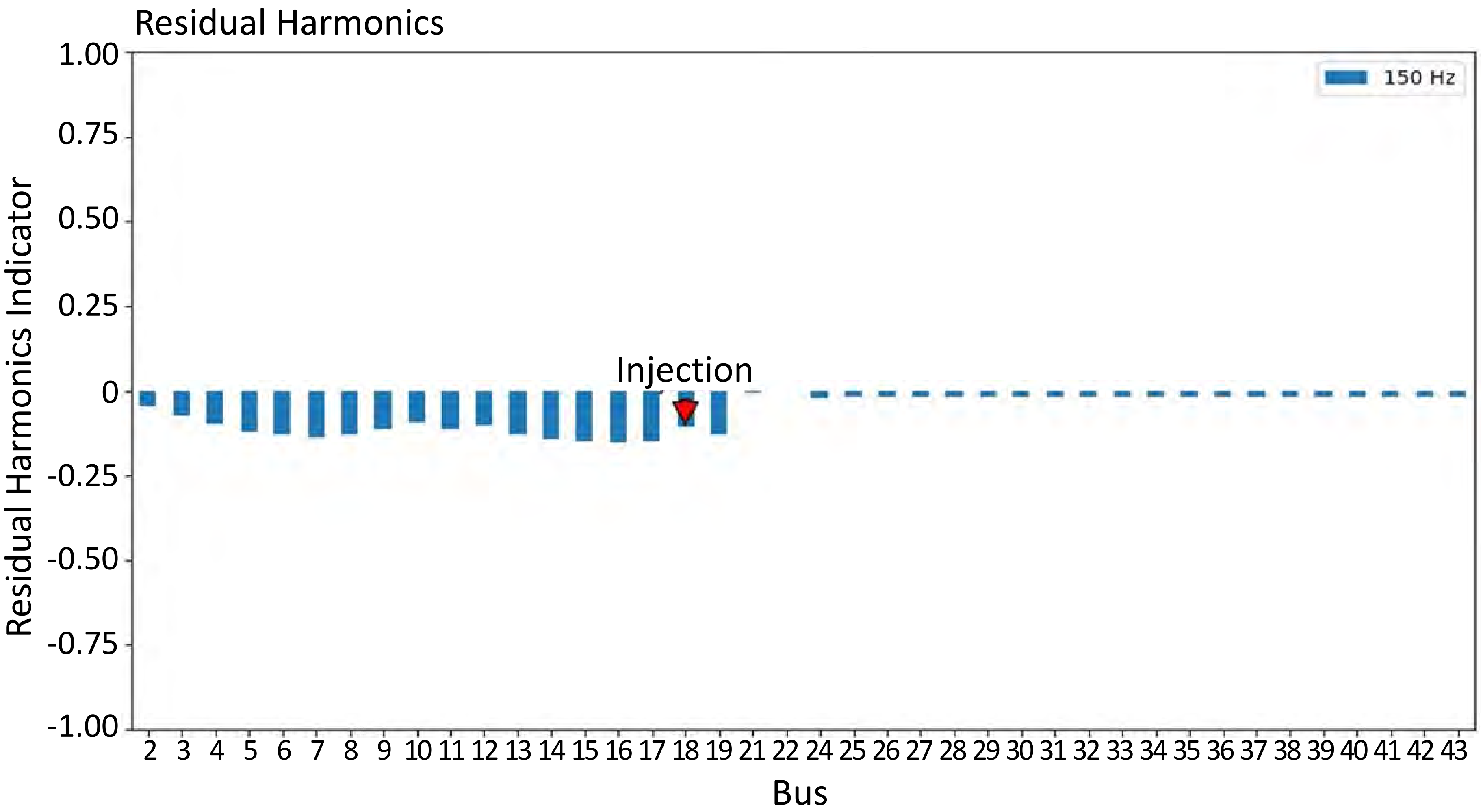
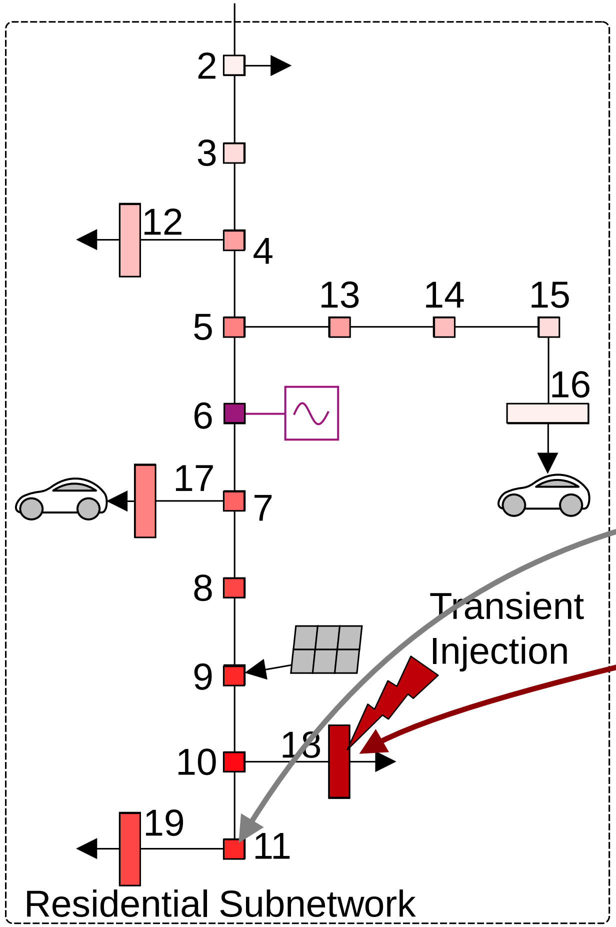
Disturbance location: Full simulation

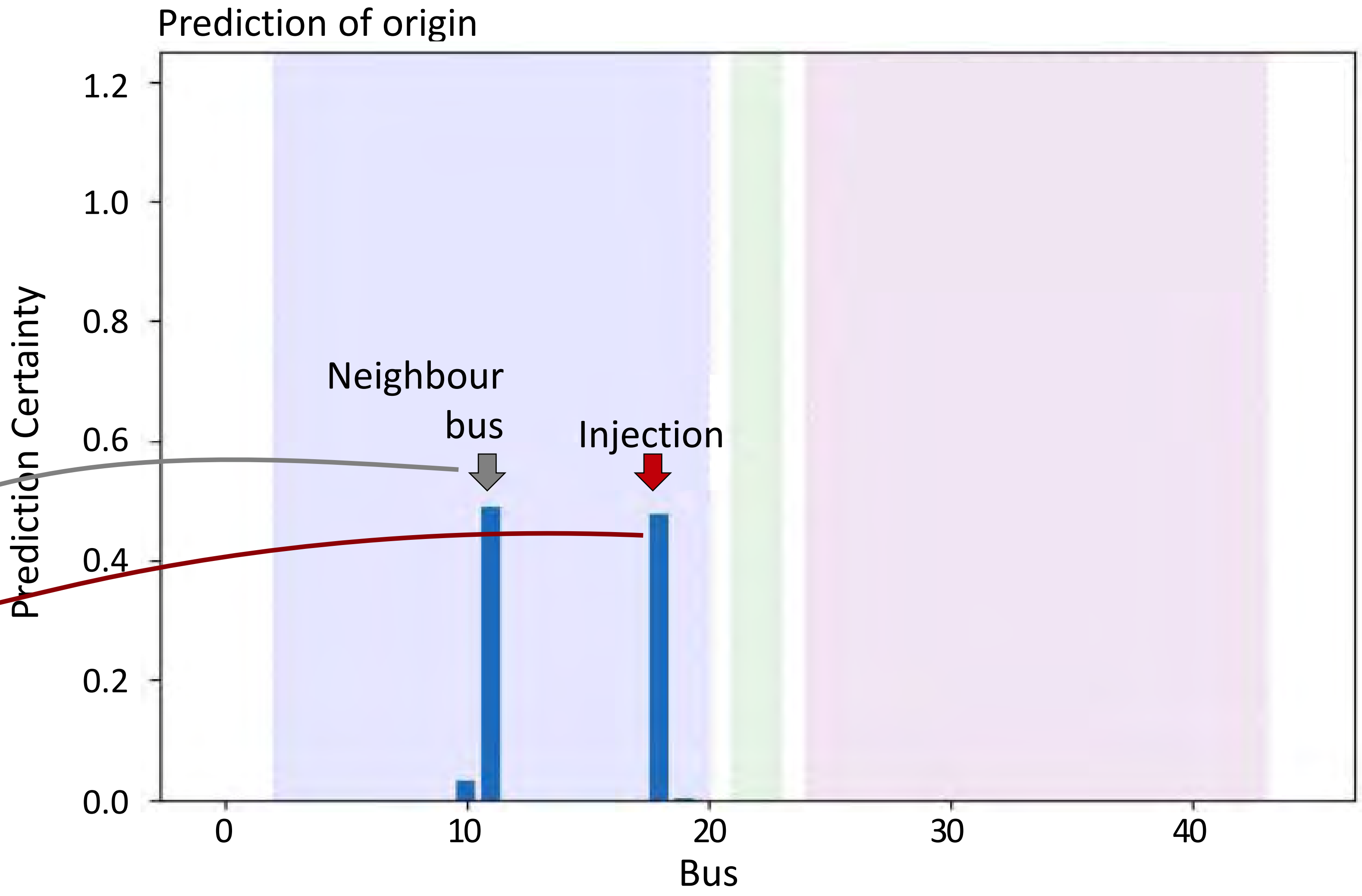




Patrick LEHNEN Patrick MACK Markus DE KOSTER, Ingo STADLER Eberhard WAFFENSCHMIDT, „SPECTRAL ANALYSIS FOR TRACKING TRANSIENT EFFECTS IN DISTRIBUTION GRID", CIRED Workshop on Resilience of Electric Distribution Systems Chicago, November 7-8, 2024, Paper n° 1223

Disturbance location: Origin prediction





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Further application

- Power grid control
  - Load management
  - Peak load prediction
  - Price estimation
- Heat and gas supply
- Optimal storage use

Further ideas?

Contact and further Information

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