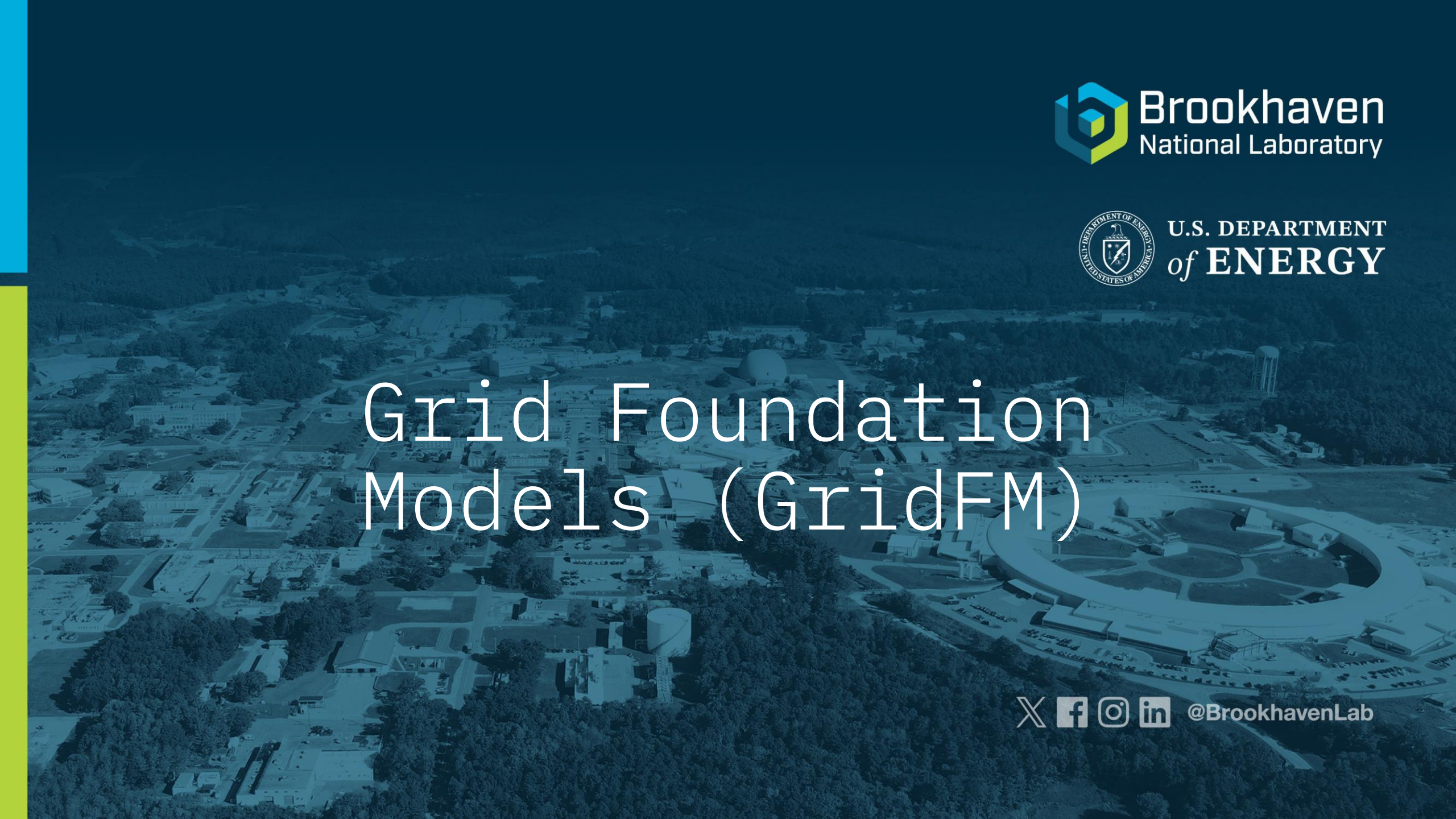
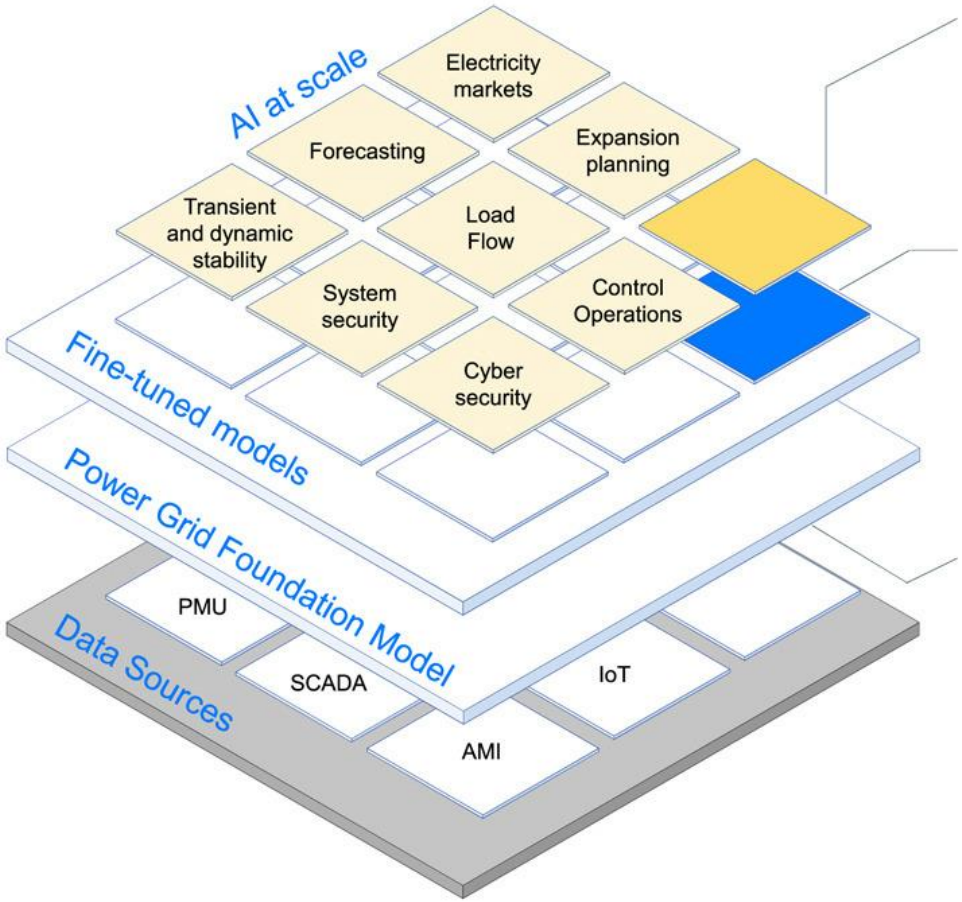

Brookhaven
National Laboratory
U.S. DEPARTMENT
of ENERGY
Grid Foundation
Models (GridFM)
@BrookhavenLab

The Vision of Grid Foundation Models



Leveraging AI at scale across the energy value change to deal with increased grid complexity and uncertainty

Finetune models leveraging

- **Data efficiency**
- **Generalizability**
- **Robustness**
- **Performance**
- **Scalability**
- Computational accelerations

FMs as AI representation of multi-modal grid

→ Create AI4Grid Foundation

GridFM.org was created... to develop GridFM

✓ "IBM Yorktown" workshop

Feb 24

✓ Founding of GridFM working group (now 380+ members from 120+ orgs)

✓ "Imperial College" workshop

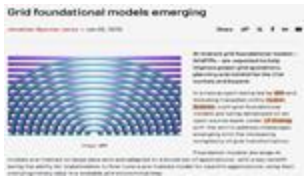
Jun 24

✓ Joule GridFM Perspective Paper

✓ OpenGridFM Linux Foundation Energy project

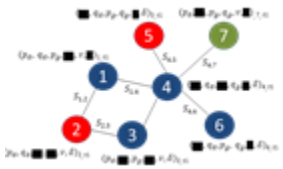
LFENERGY GridFM

✓ GridFM Announcement



Dec 24

✓ GridFM-v0 developed



✓ "Argonne workshop

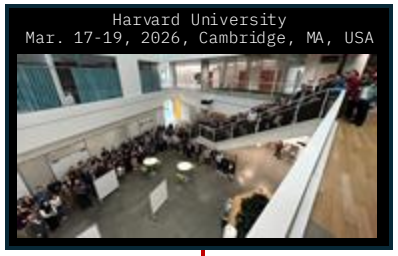
Mar 25

✓ gridfm-datakit
gridfm-graphkit

✓ "Aachen" workshop

Aug 25

✓ "Harvard" workshop



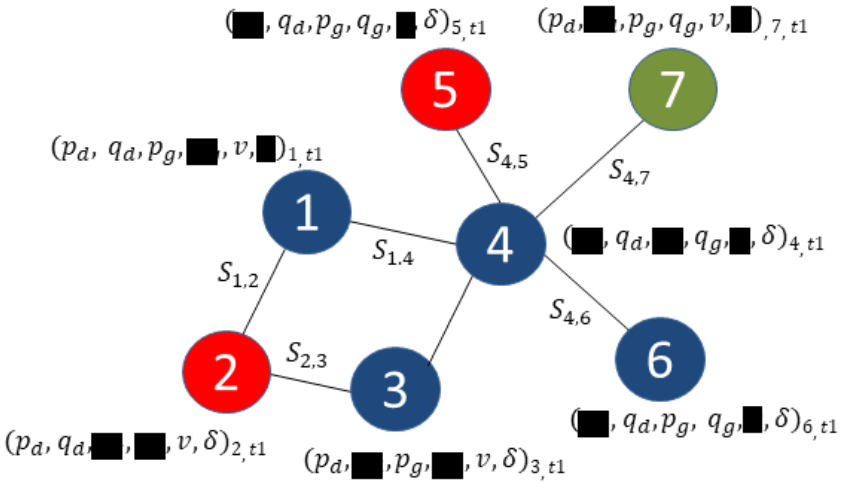
Feb 26

"Porto" conference

Please join us at gridfm.org
AI FOR THE ELECTRIC GRID

An initial focus of GridFM is (optimal) power flow

Masked Graph $\mathcal{G}'$



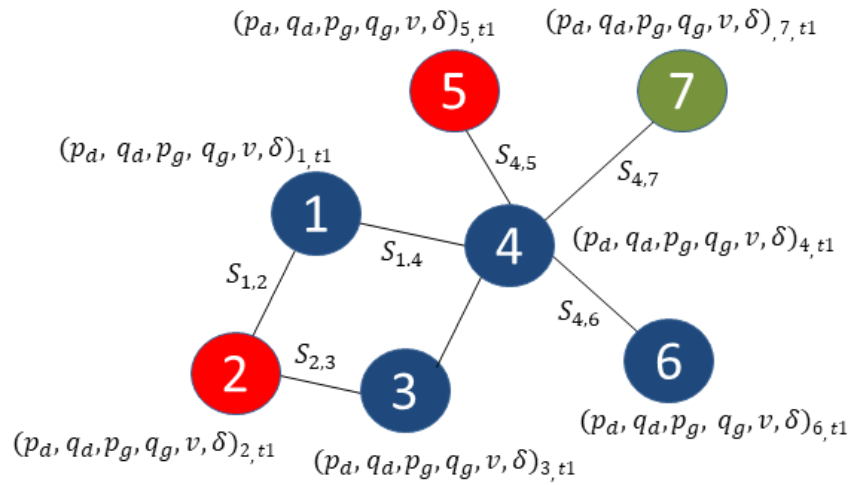
Pre-training

$\mathcal{G} = f(\mathcal{G}')$

$m_a(\mathcal{G}) = \mathcal{G}'$

Masking

Reconstructed Graph $\mathcal{G}$

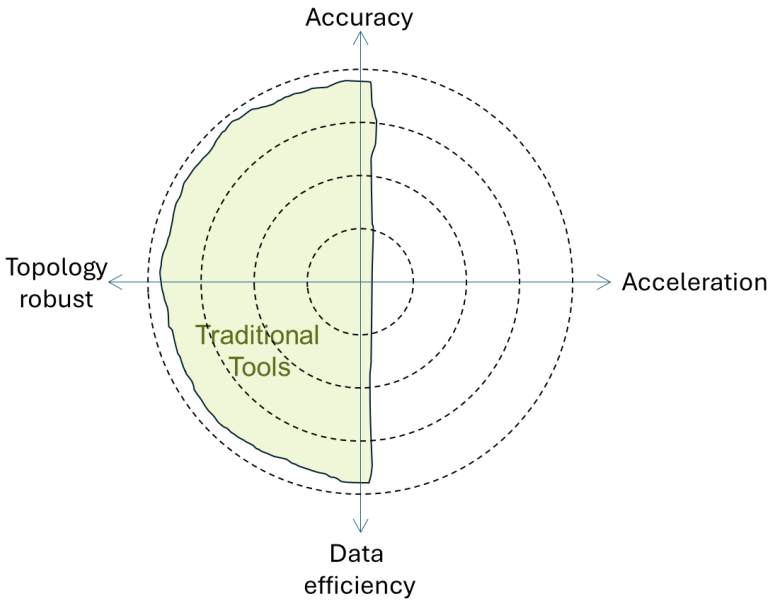


Load bus
Generator bus
Slack bus
Line

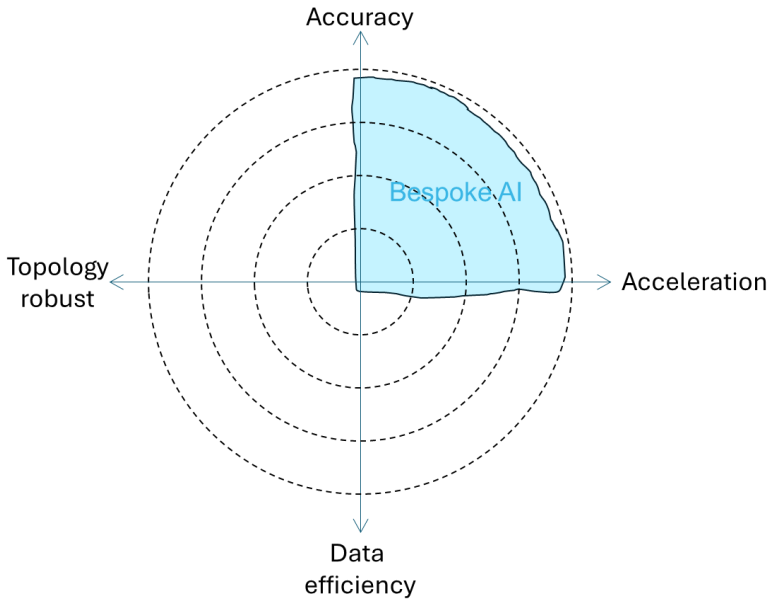
Puech, Alban, Jonas Weiss, Thomas Brunschwiler, and Hendrik F. Hamann. "Optimal Power Grid Operations with Foundation Models." *arXiv preprint arXiv:2409.02148* (2024).

What are we trying to achieve? Provide computational efficiency required to explore billions of future scenarios of large complex grids

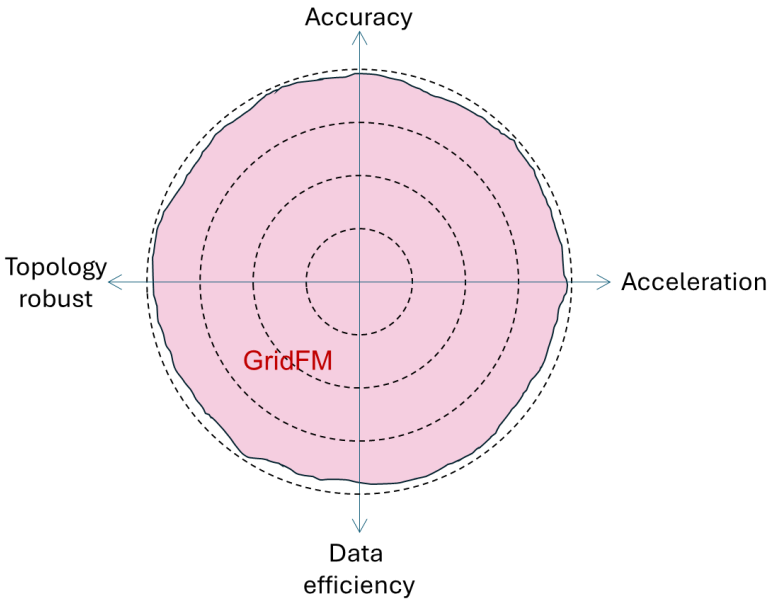
Physics-solvers



Previous AI

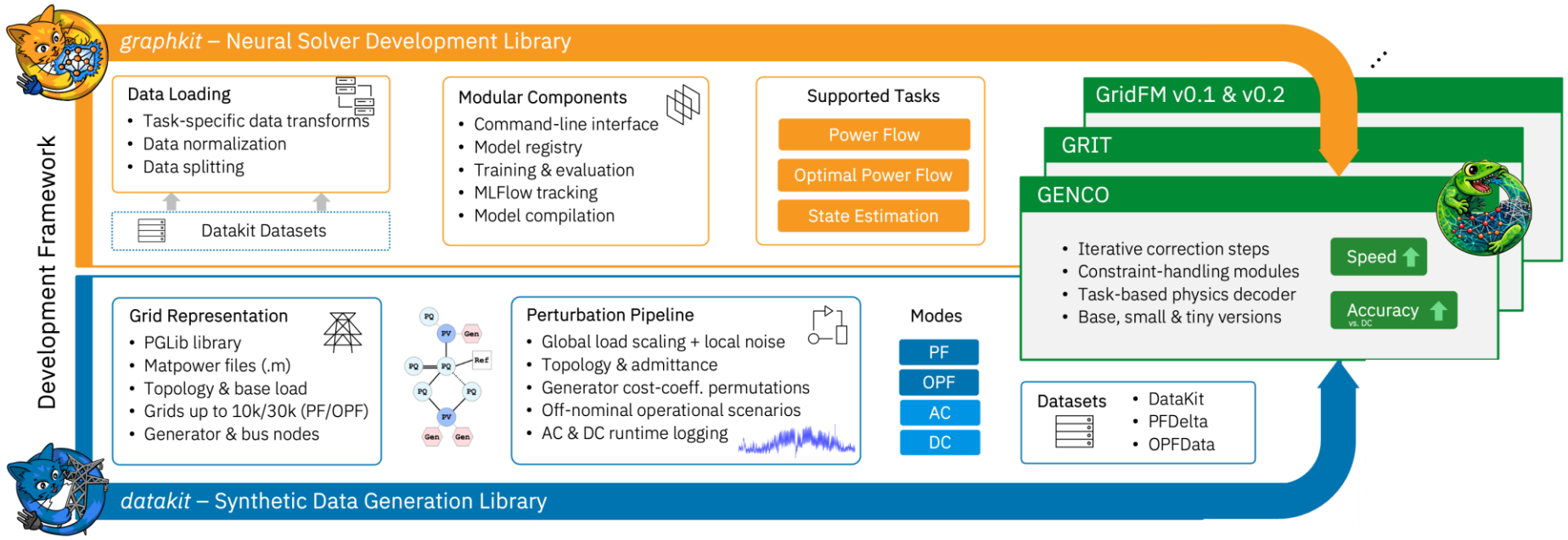


Foundation Models



...while being topology-robust, accurate and data efficient.

Where are we today? GridFM has evolved in a set of foundational capabilities for AI4Grid



✓ Data generation library + Open grid data sets
✓ Model framework + Multiple models
✓ Accessible as open source at Linux Foundation Energy

GridFM-Datakit capabilities are growing

Datakit

Modes

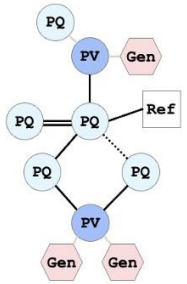
PF

OPF

AC DC

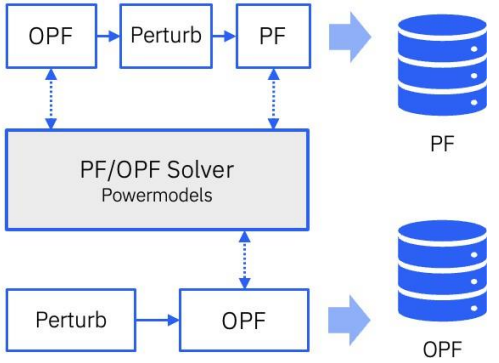
Grid Representation

- Provide Topology + base load
- Library: PGlib
- Format: Matpower
- Size: 14 – 30k buses
- Grid: Transmission
- Nodes: Generators & buses



Perturbations

- Global agg. load scaling + local multiplicative noise
- Topology (N-k) and admittance
- Generator cost-coefficient permutations



Power Flow (PF) Data Generation Methods

Library	Grid Size	Load Variations			N-k (k>2)	Gen Profiles	Admittance Variations	Include points outside operating limits
		Preserve Spatial Correlation	From Real Profiles	Diverse				
gridfm-datakit-pf	30K	✓	✓	✓	✓	✓	✓	✓
PFΔ	2K	✗	✗	✓	✗	✓	✗	✓
PowerFlowNet	6K	✓	✗	✗	✗	✓	✓	✗

Optimal Power Flow (OPF) Data Generation Methods

Library	Grid Size	Load Variations			N-k (k>2)	Gen Profiles	Admittance Variations
		Preserve Spatial Correlation	From Real Profiles	Diverse			
gridfm-datakit-opf	10K	✓	✓	✓	✓	✓	✓
OPFData (CANOS)	14K	✓	✗	✗	✗	✗	✗
OPFLearn	118	✗	✗	✓	✗	✗	✗
PGLearn	24K	✓	✗	✓	✗	✗	✗
PowerGraph	118	✓	✓	✗	✗	✗	✗

Puech et al., (2025), arXiv 2512.14658

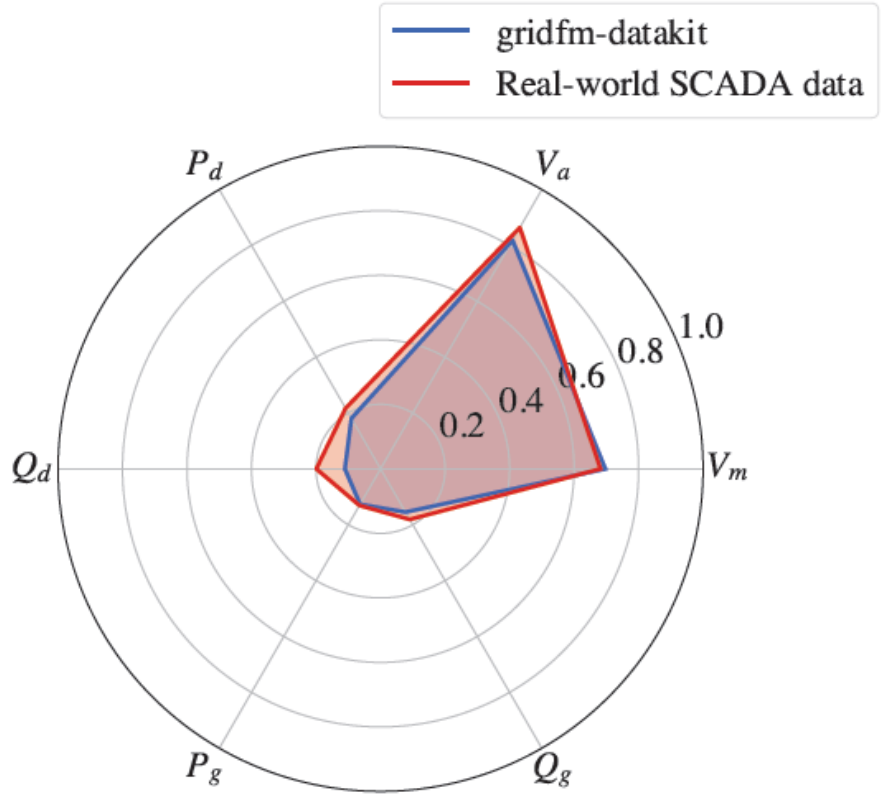
GridFM-Datakit generates efficiently “representative” data

Synthetic data generation speed

Grid name	Number of samples obtained	CPU hours	Convergence rate (%)
Power Flow (PF)			
IEEE 24-bus	199,540	2.69	99.77
IEEE 118-bus	199,339	6.44	99.67
GOC 2,000	198,858	247.55	99.43
GOC 10,000	199,880	1,384.24	99.94
Optimal Power Flow (OPF)			
IEEE 24-bus	190,387	21.33	95.19
IEEE 118-bus	197,769	46.10	98.88
GOC 2,000	198,308	1,103.67	99.15
GOC 10,000	195,920	3,628.01	97.96

- Case24 ➔ 200k Samples
  PF: <10mins
  OPF: 1hr
- Case118 ➔ 200k Samples
  PF: <20mins
  OPF: ~2hrs

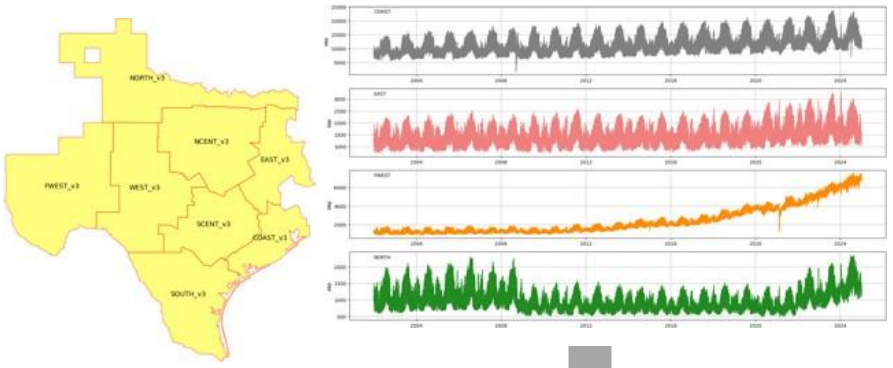
Entropy of synthetic data compared with Hydro Quebec (HQ1200) SCADA data



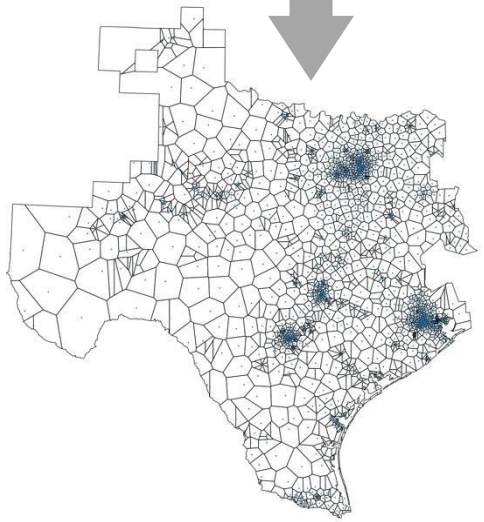
Puech et al., (2025), arXiv 2512.14658

GridFM-Datakit is being extended with “disaggregated” load profiles

Zone-level loads

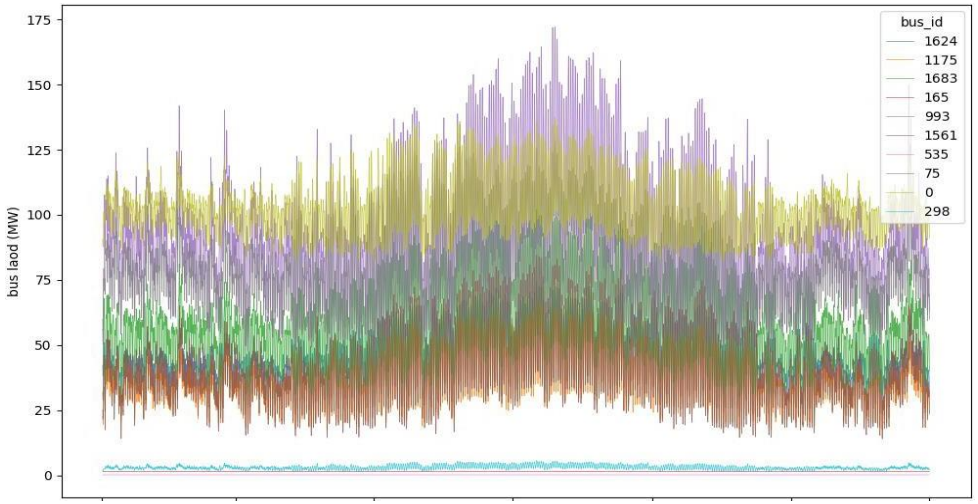


- 8 ERCOT weather zones (20yrs, hourly)
- Normalize load by population (per-capita load)
- Fit ERCOT zone-load with mixed-effects model & features: HDD/CDD, holiday, building type, oil/bas extraction, TOD, etc.
- Predict on bus-level with same features in Voronoi
- Convert per-capita load to load (x population)
- Aggregate and compare to ERCOT Zones.



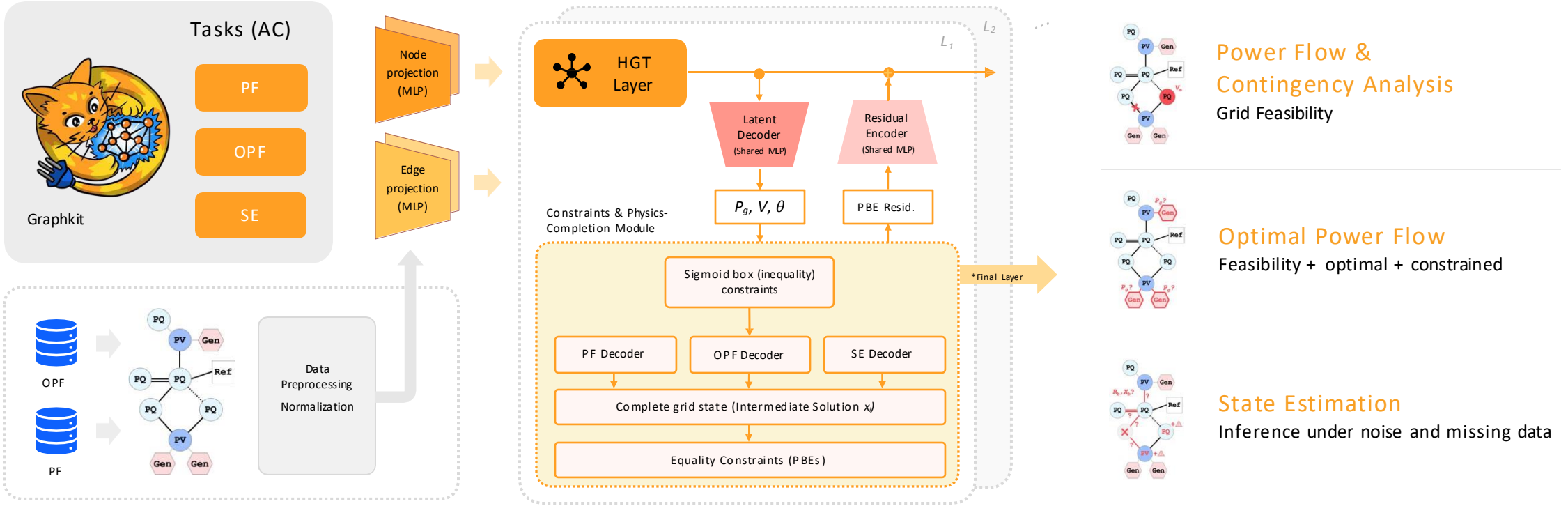
Vornoi Tesselation

Bus-level loads



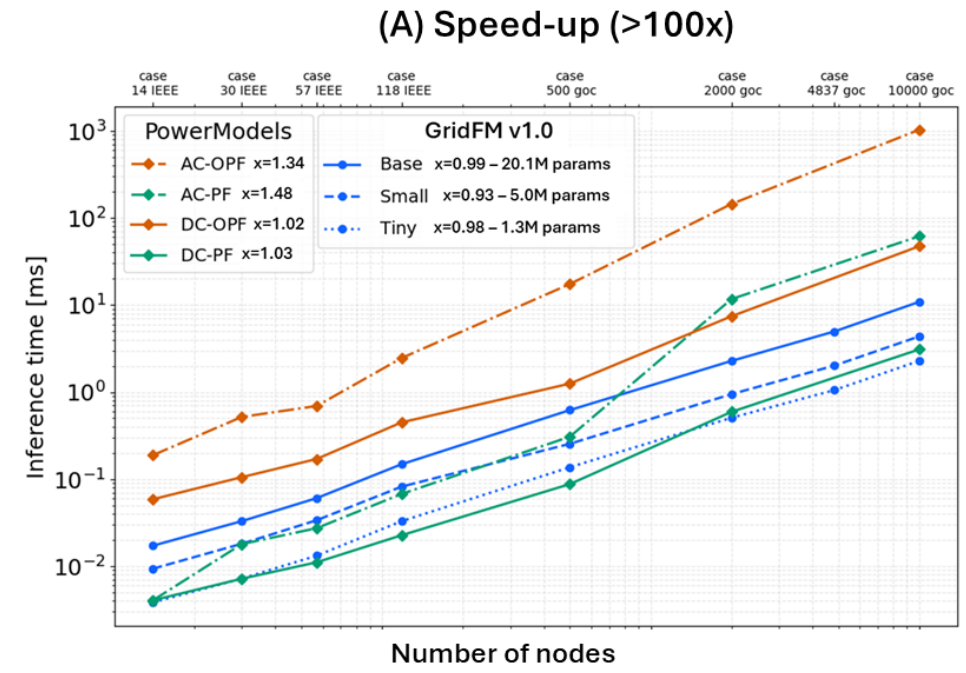
Credit: Marcus Freitag (IBM)

Latest model (GENCO – GEometric Neural Corrective Optimizer)supports multiple tasks with a single architecture



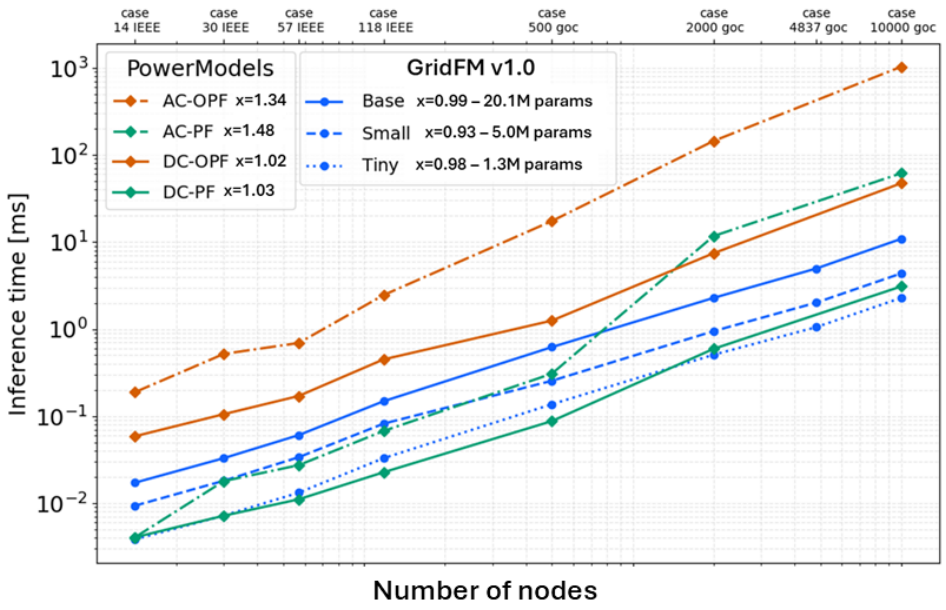
- Heterogeneous model to represent generators and buses as different node types
- Unified model that supports 3 tasks with 1 model with physics decoders – PF, OPF, SE
- Intra-layer correction and physics completion module to iteratively refine representations
- Grid-specific training from scratch on 1 GPU (& pre-training)

Some selected results

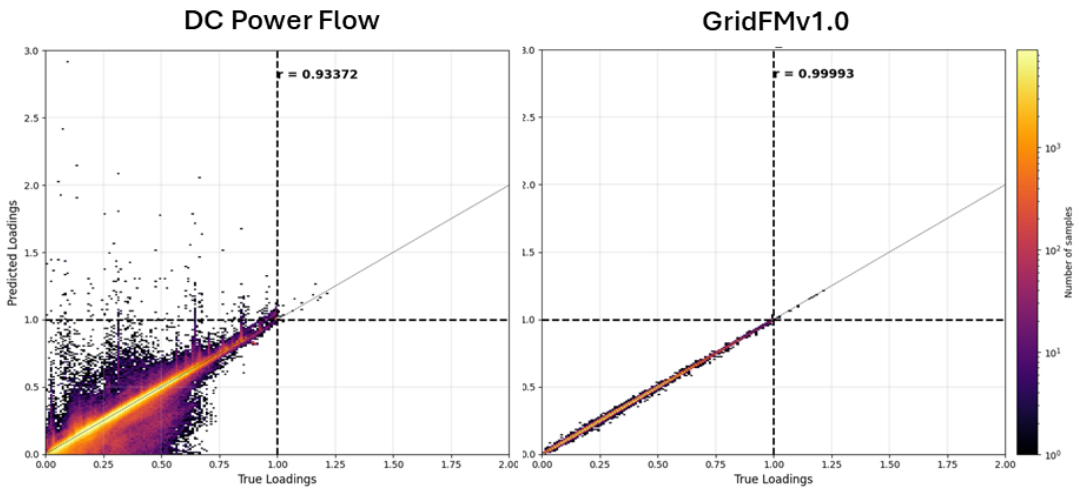


Some selected results

(A) Speed-up (>100x)



(B) Accuracy better than DC PF and very competitive with AC PF



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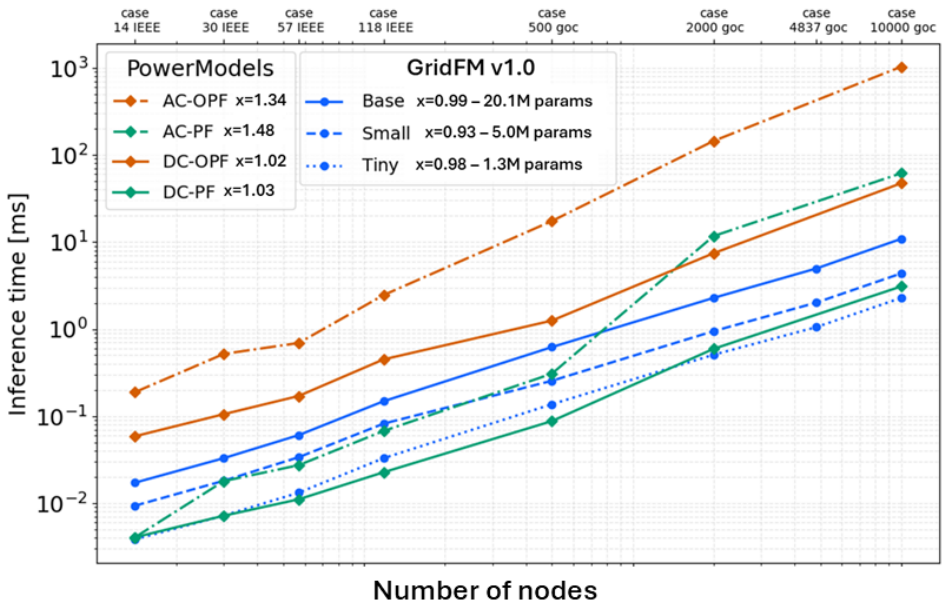

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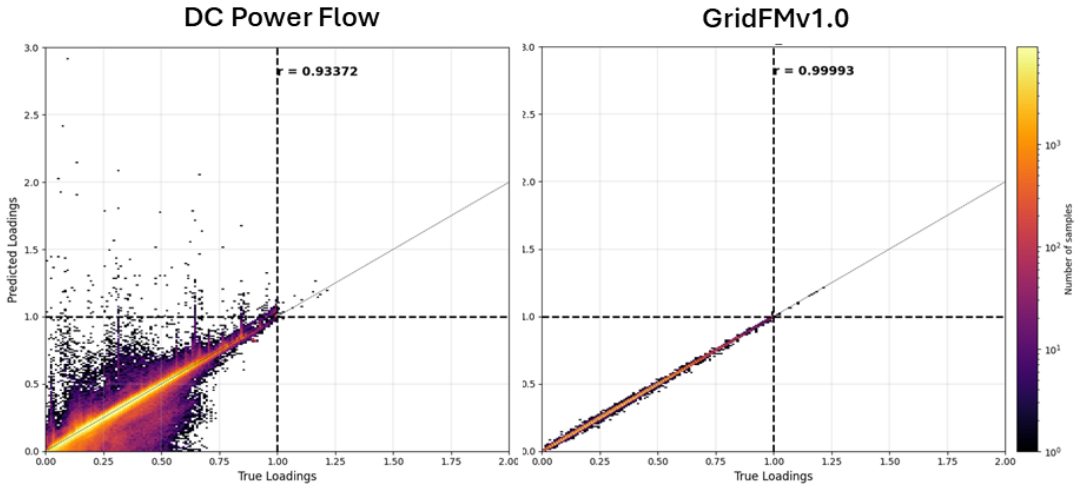
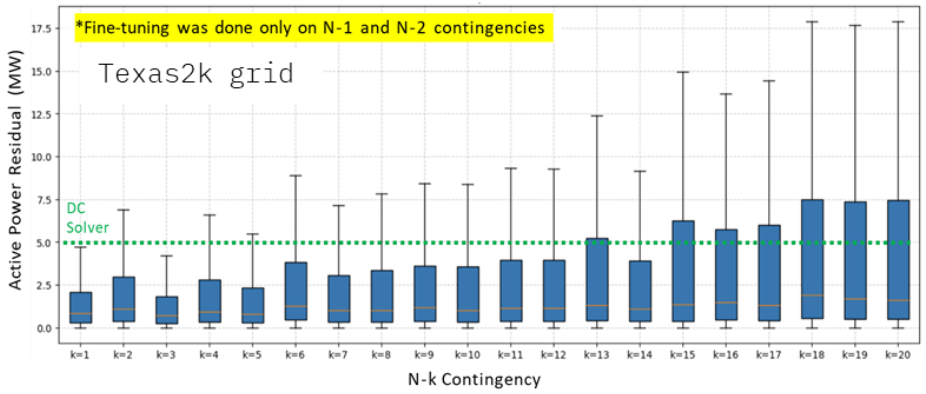


(C) Topology robust up to k=25 for N=2000



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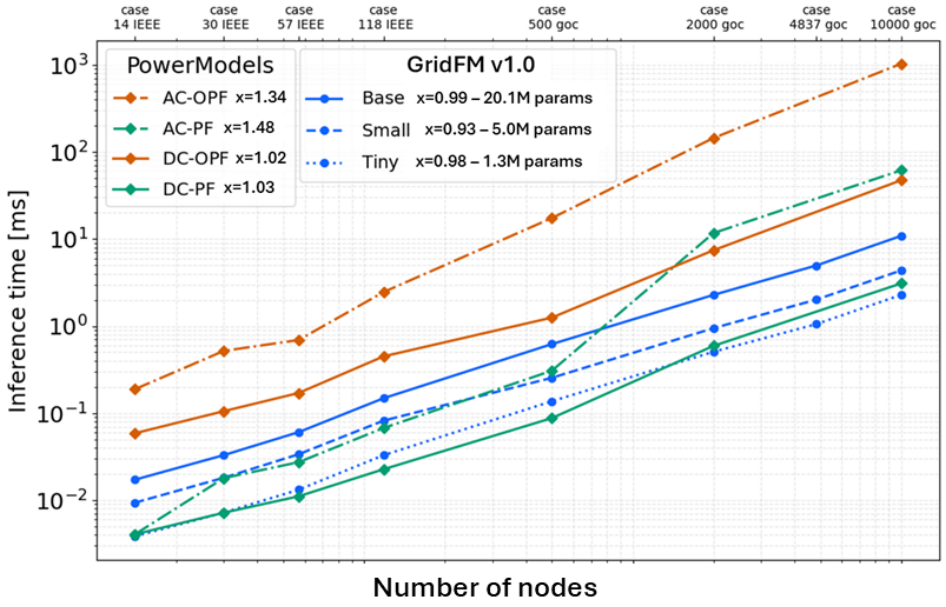

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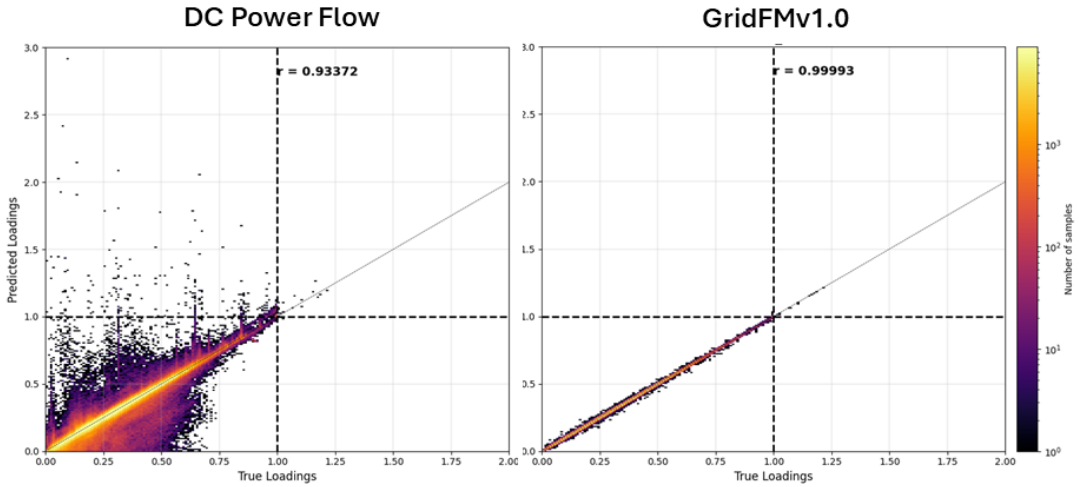

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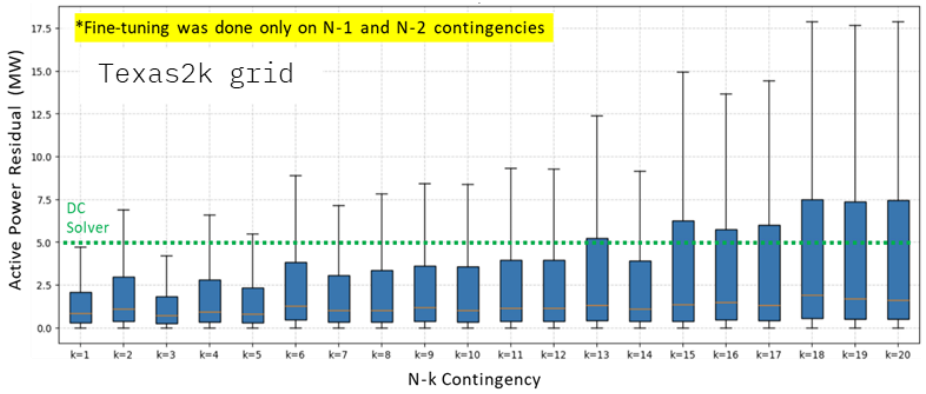
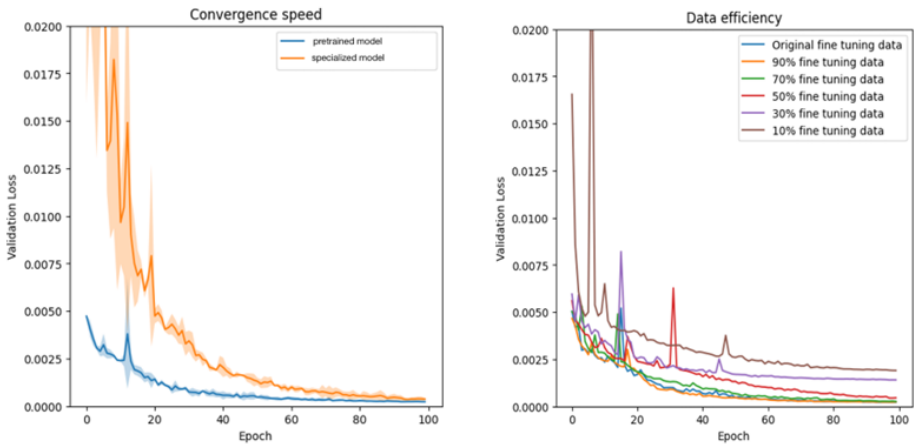
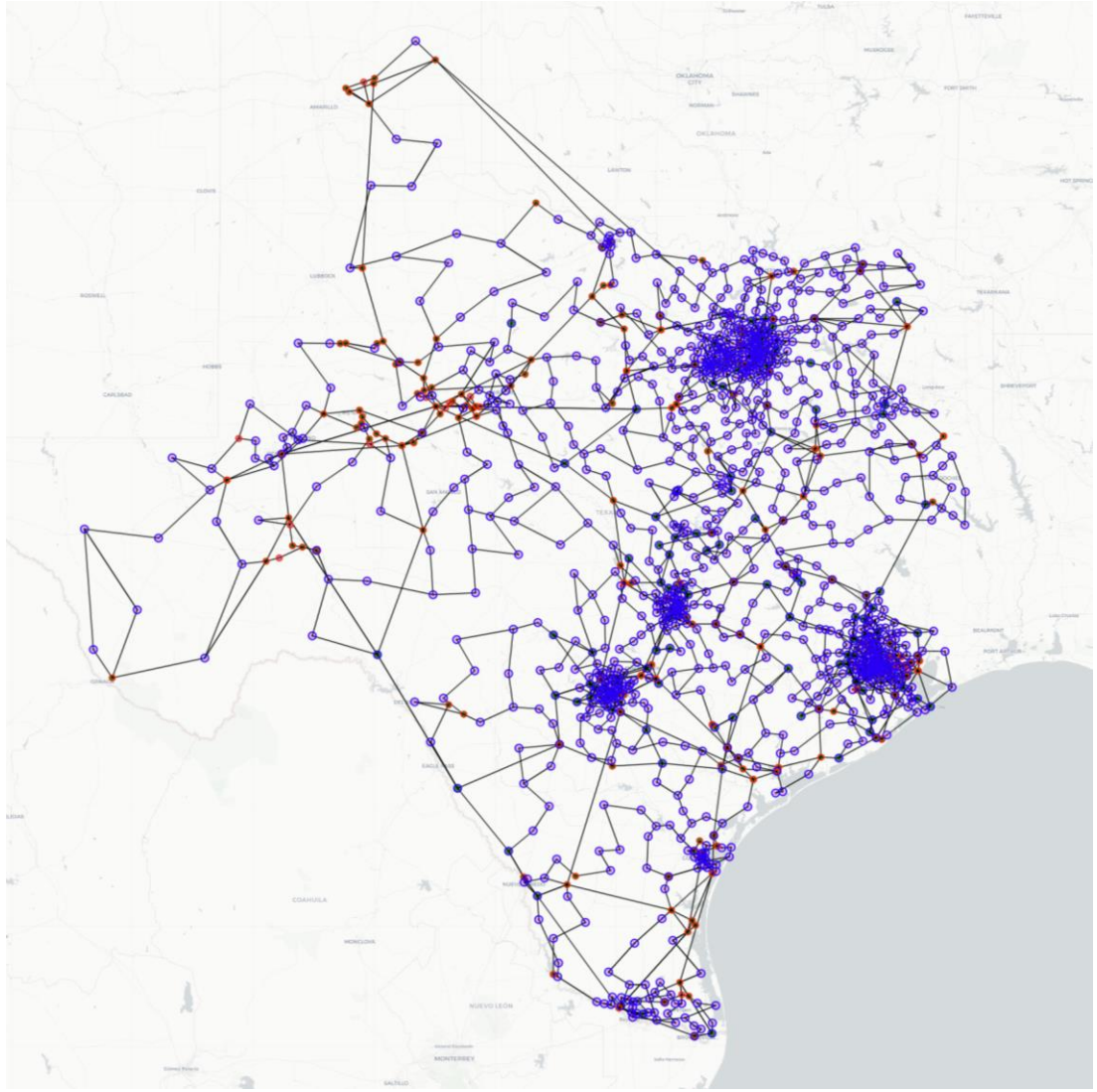


(D) Data efficiency of 50%



GridFM enables locating optimal interconnection points for new large loads (Data Center Hosting Maps)



Example: Synthetic Texas 2k grid

- 1125 connection points
- 24 hours summer peak load (hourly)
- Low wind and solar summer scenarios
- 2 different increments (50 and 100MW)

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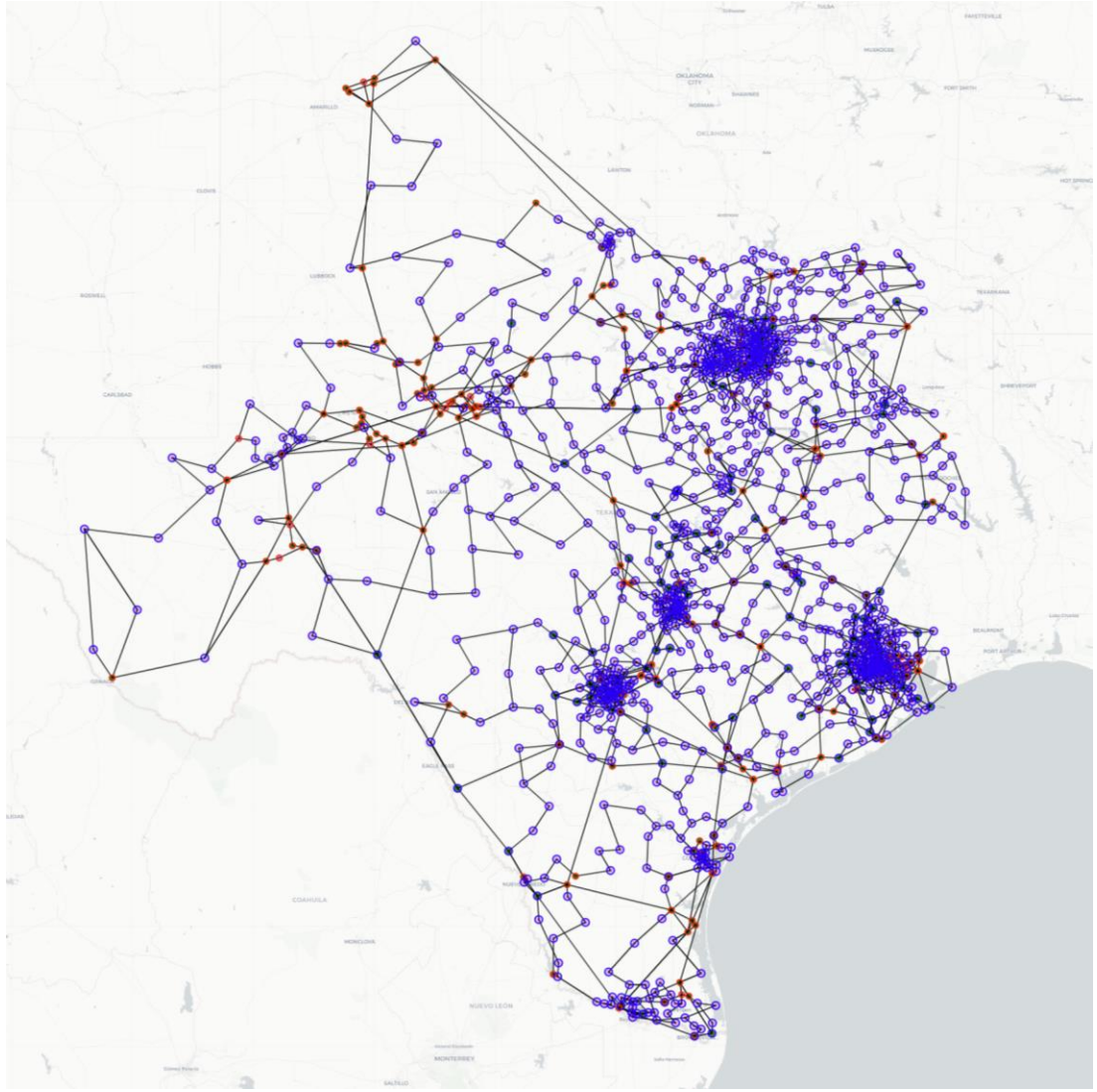

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GridFM enabled

- 82,000 OPFs
- 287 million PFs

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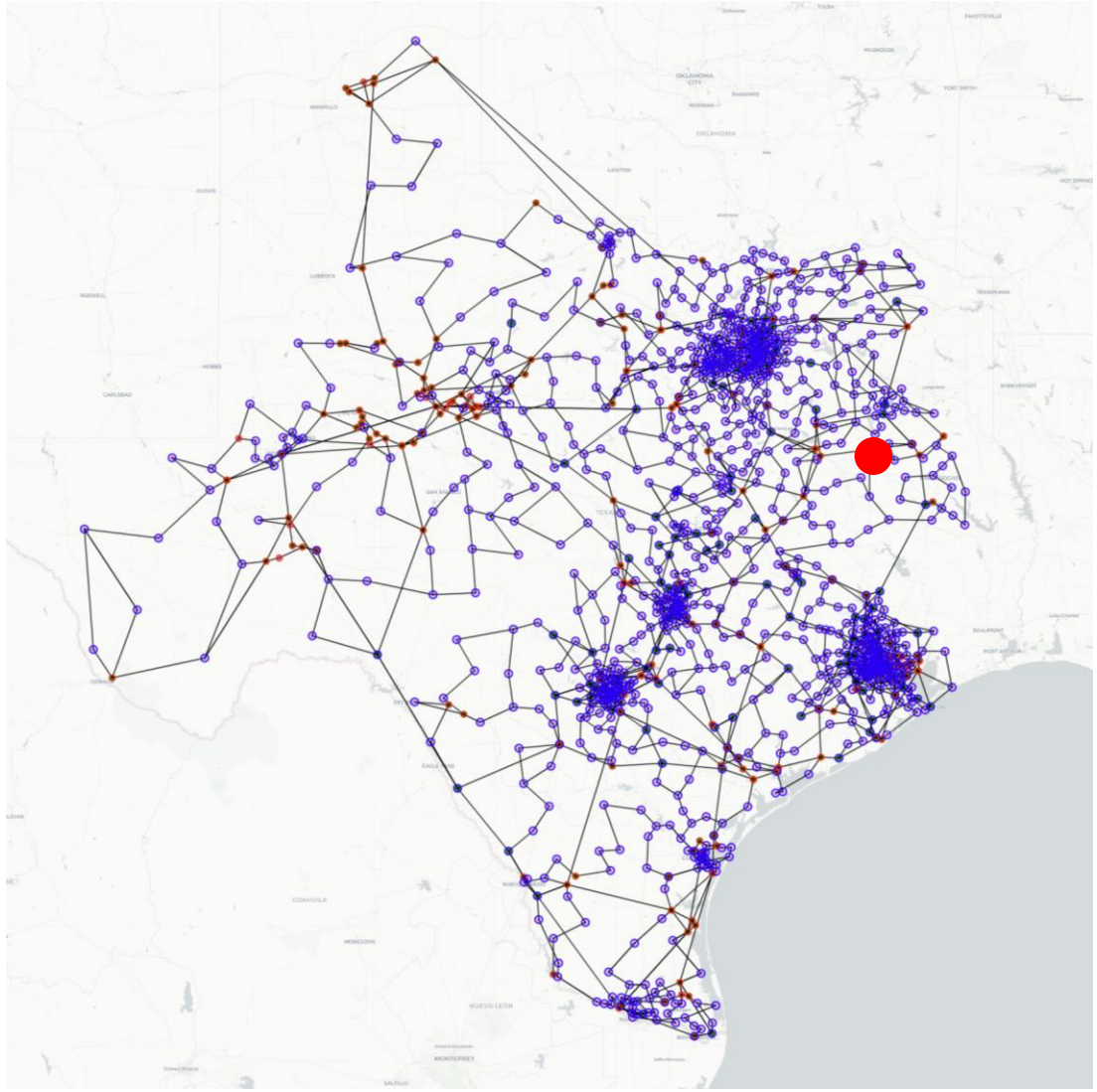

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GridFM enabled
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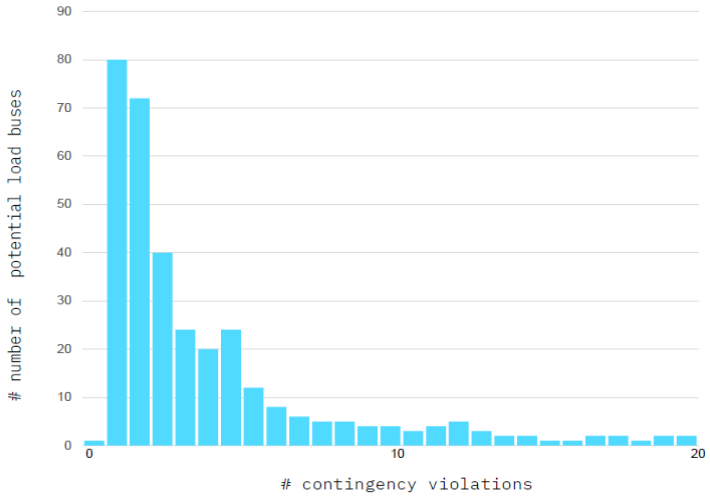
- Prioritized load buses with minimal connection challenges



Thank you…

hhamann@bnl.gov