LA-UR Applied For

T5: Applied Mathematics and Plasma Physics, Los Alamos National Laboratory

Towards ACOPF Feasibility: Exploring the Combined Perspectives of DCOPF and ACPF

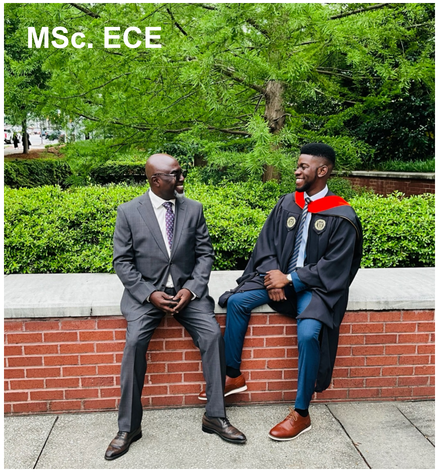
Prepared by:
Michael A. Boateng (ECE* PhD Student, Georgia Tech)

LANL Mentors:
Russell Bent (PhD), Sidhant Misra (PhD)

***ECE – Electrical and Computer Engineering**

Brief Bio

- Education (3rd Year ECE PhD)
- Research in Power Systems, ML, and Optimization
- Hobbies and Activities



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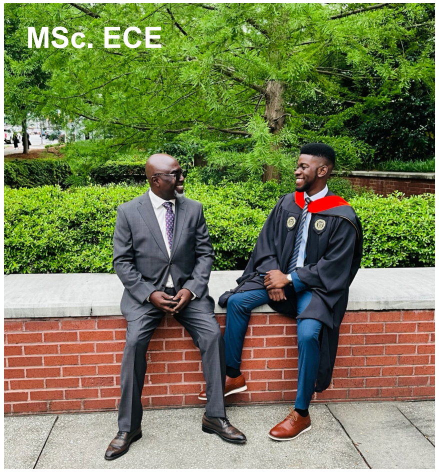

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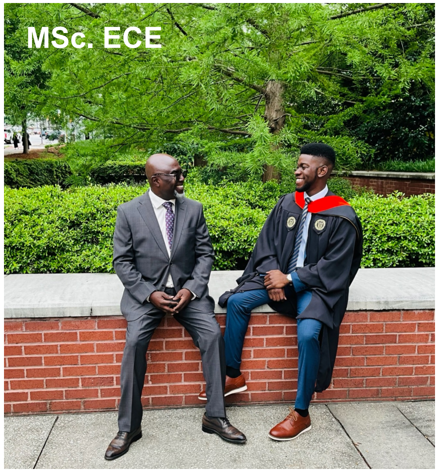

PhD. Intern…

[1] Getty Images: UEFA Nations League (2025) | NBA Finals MVP (2025) | Super Bowl LIX Crowning (2025)

Project Collaborators

- Los Alamos National Lab
- Georgia Tech
- AI Institute for Advances in Optimization

Georgia Tech
IIT ROORKEE

Towards ACOPF Feasibility: Exploring the Combined Perspectives of DCOPF and ACPF Constraints

Michael A. Boateng [1, 2, 3] Russell Bent [3] Sidhant Misra [3] Parikshit Pareek [4] Daniel Molzahn [1, 2] Pascal Van Hentenryck [1, 2]

[1]Georgia Institute of Technology [2]AI Institute for Advances in Optimization [3]Los Alamos National Lab [4]Indian Institute of Technology Roorkee

AI Institute for Advances in Optimization
Los Alamos NATIONAL LABORATORY

Fig.1 – Project Collaborators across LANL, GTech, IIT-Roorkee and AI4OPT

Market Clearing in Power Systems

- Balance Power Supply and Demand while setting Market Prices
- Requires a 2-Stage Approach (DCOPF [2], [3] , ACPF [4])

Fig.2 – Independent System Operators (ISO) on the U.S. Map

Markets

- **CAISO**
- **ERCOT**
- **SPP**
- **MISO**
- **WECC**
- **PJM-ISO**
- **ISO-NE**
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- **SERC**
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- **TOs in North America**

DCOPF – DC Optimal Power Flow | ACPF – AC Power Flow | ISO – Independent System Operators

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Project Workflow: The Lossy DCOPF + Principled ACPF

- Why not just use the ACOPF?
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- 🤔 Wait! I thought DCOPF is never AC feasible[5]!

Objective:

$$\min_{\mathbf{P}_\mathrm{g}} \quad \mathbf{c}^T \mathbf{P}_\mathrm{g} \qquad \text{Cost Function} \qquad (1)$$

subject to:

AC flow $$\mathbf{S}_\mathrm{g} - \mathbf{S}_\mathrm{d} = \mathrm{diag}(\overline{\mathbf{V}})\,\overline{\mathbf{Y}}_\mathrm{bus}\,\overline{\mathbf{V}}^* \qquad (2)$$

Line Current $$\left|\mathrm{Y}_{i\to j}\,\overline{\mathbf{V}}\right| \le \mathbf{I}^\mathrm{max}_\mathrm{line} \qquad (3)$$
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Voltage Magnitude $$\mathbf{V}^\mathrm{min} \le \mathbf{V} \le \mathbf{V}^\mathrm{max} \qquad (9)$$

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Eqn. set 1 – The Full ACOPF (Equations 1-10)

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- ● Different inputs to DC and AC engines
- ● Record violations to observe ACOPF feasibility
- ● Major engines can be swapped for varying DCOPFs and ACPFs

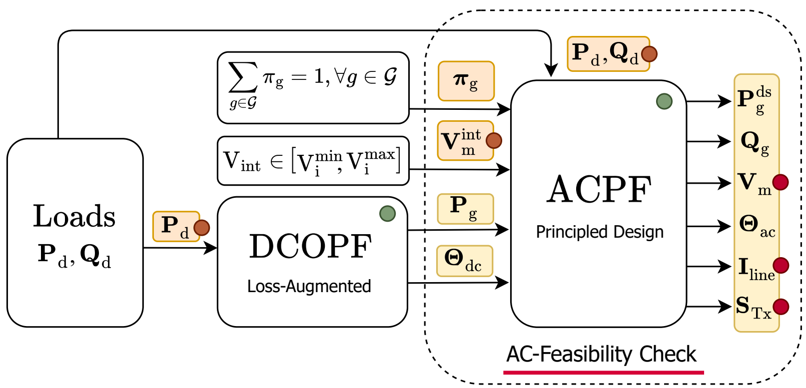

Fig.3 – Project Pipeline (DCOPF->ACPF)

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The Principled AC Power Flow

- 3 bus-types in an ACPF (Slack, Load, and Generator)
- Reserve-based Distributed Slack
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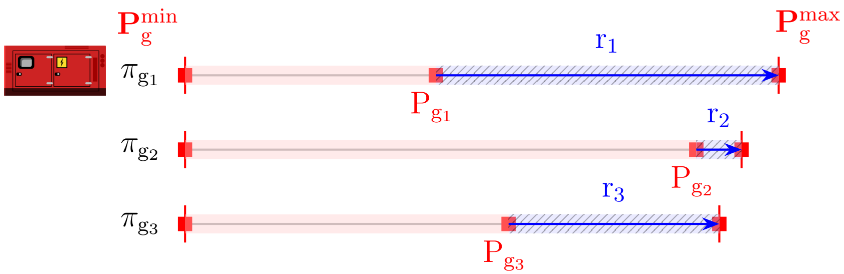

Fig.3 – Single Slack

r_i, r_j – Remaining Reserves | π_{g_i} – Participation Factor | $\mathcal{S}$ – Generators used for Loss Sharing | $\mathcal{G}$ – All Generators

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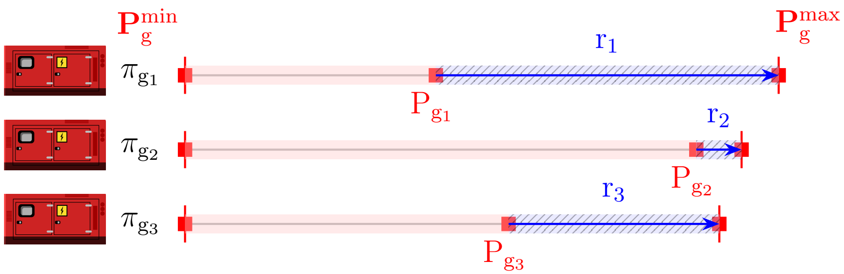

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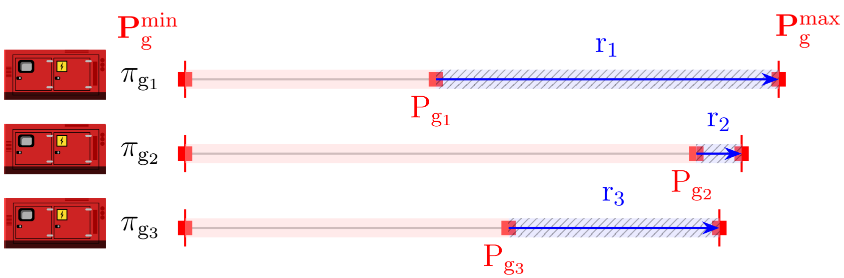

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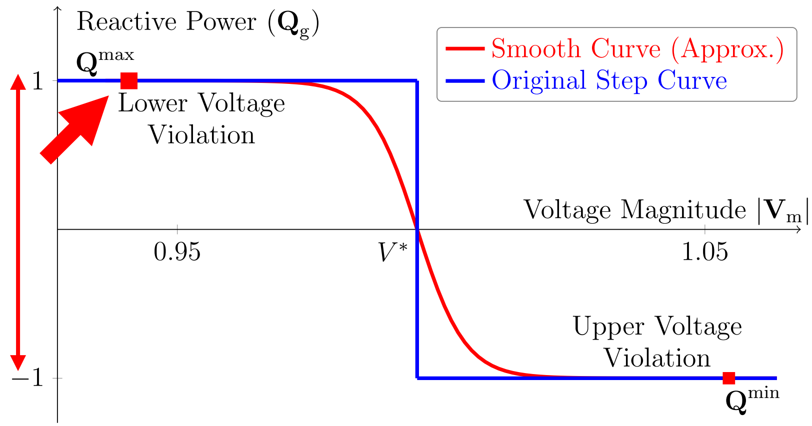

Fig.4 – Bus-type Switching

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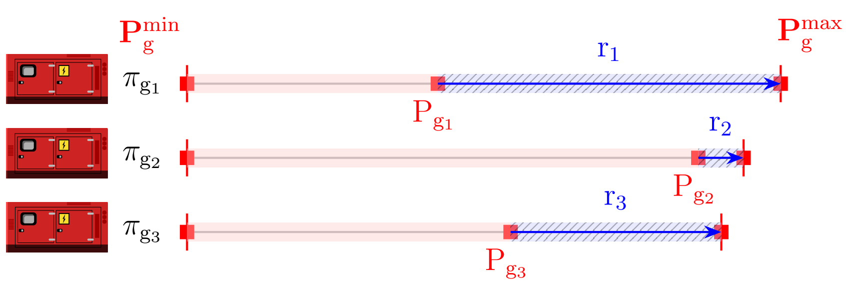

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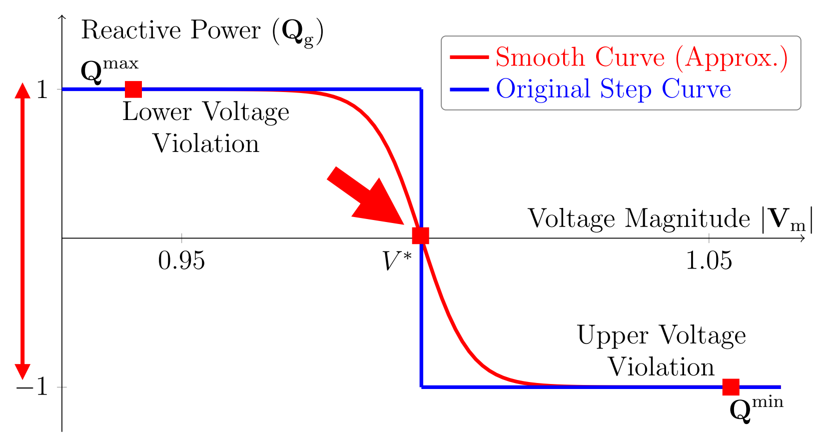

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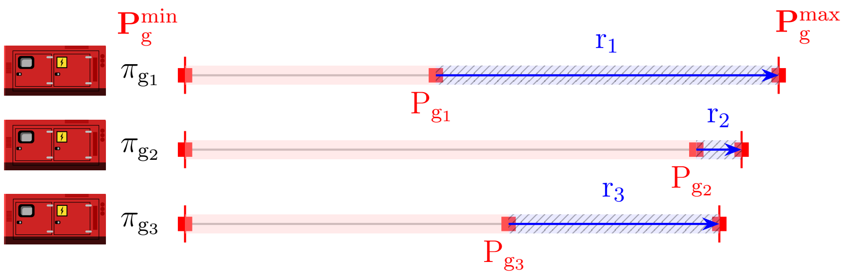

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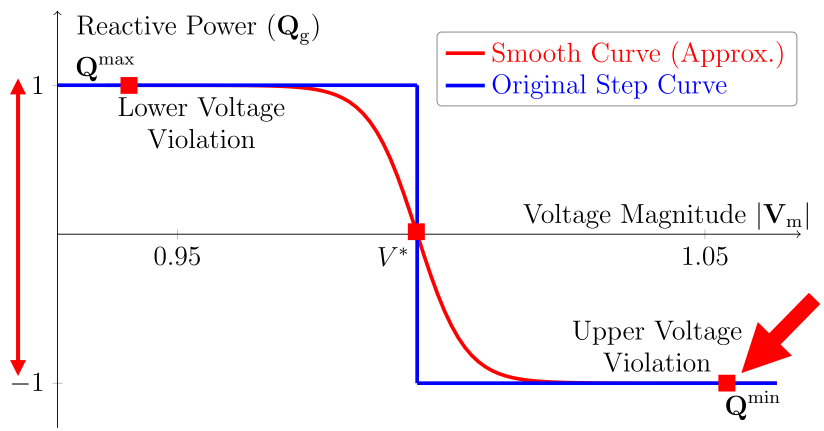

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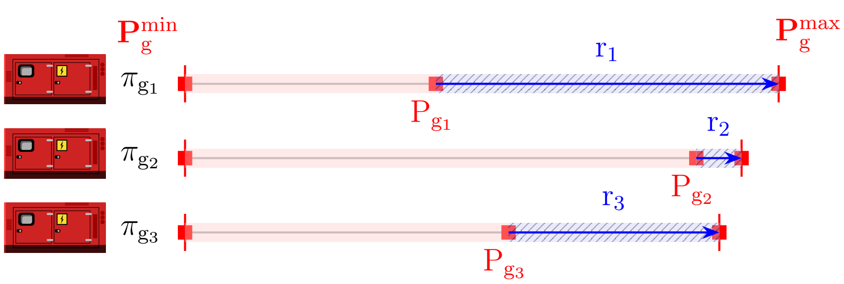

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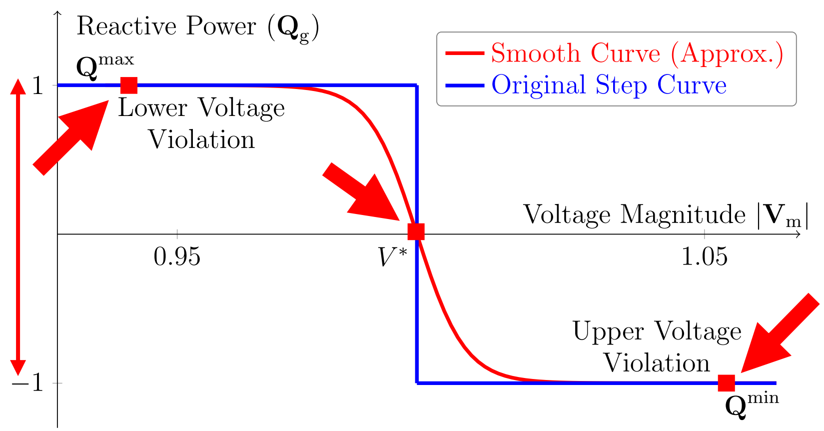

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Data: Tested Grid Cases

- Small, Medium, and Large (24 – 13,695)
- 0, 2, 5,10,15% (20,000 samples)
- ACTIVSg, PEGASE, RTE, and IEEE

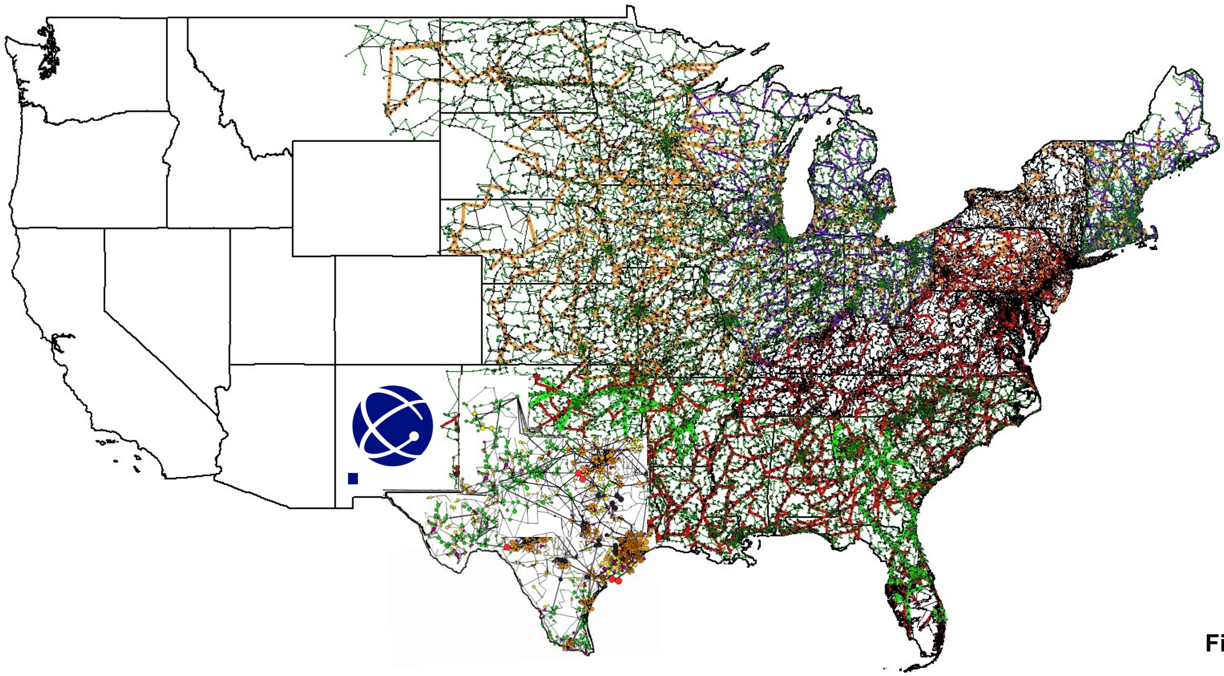

Fig.5 – U.S. Map of some cases used

ACTIVSg – Texas A&M Consortium Test Cases | PEGASE – Pan European Grid | RTE – Réseau de Transport d'Électricité | IEEE - Institute of Electrical and Electronics Engineers

[6] Zimmerman, R. D., Murillo-Sánchez, C. E., & Thomas, R. J. (2011). **MATPOWER:** Steady-State Operations, Planning, and Analysis Tools for Power Systems Research and Education. IEEE Transactions on Power Systems, 26(1), 12–19.

[7] Coffrin, C., Bent, R., & Sundar, K. (2018). **PowerModels.jl:** An Open-Source Framework for Exploring Power Flow Formulations. Proceedings of the 2018 Power Systems Computation Conference (PSCC), Dublin, Ireland.

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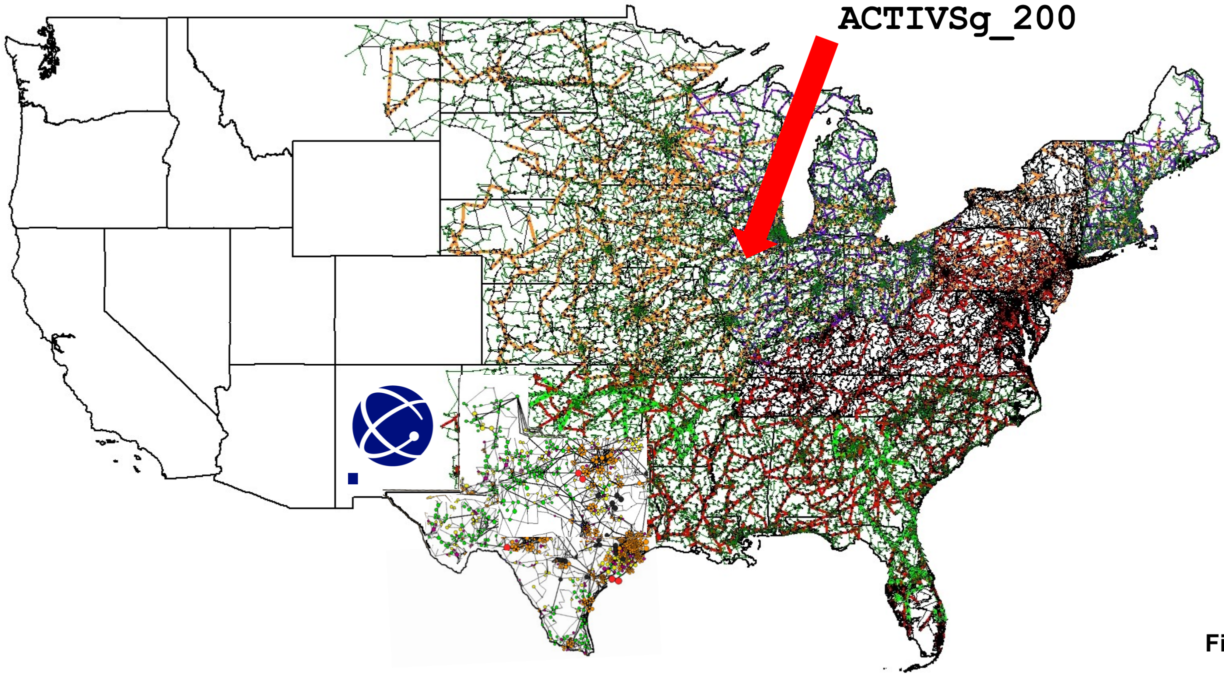

Fig.5 – U.S. Map of some cases used

ACTIVSg – Texas A&M Consortium Test Cases | PEGASE – Pan European Grid | RTE – Réseau de Transport d'Électricité | IEEE - Institute of Electrical and Electronics Engineers

[6] Zimmerman, R. D., Murillo-Sánchez, C. E., & Thomas, R. J. (2011). **MATPOWER:** Steady-State Operations, Planning, and Analysis Tools for Power Systems Research and Education. IEEE Transactions on Power Systems, 26(1), 12–19.

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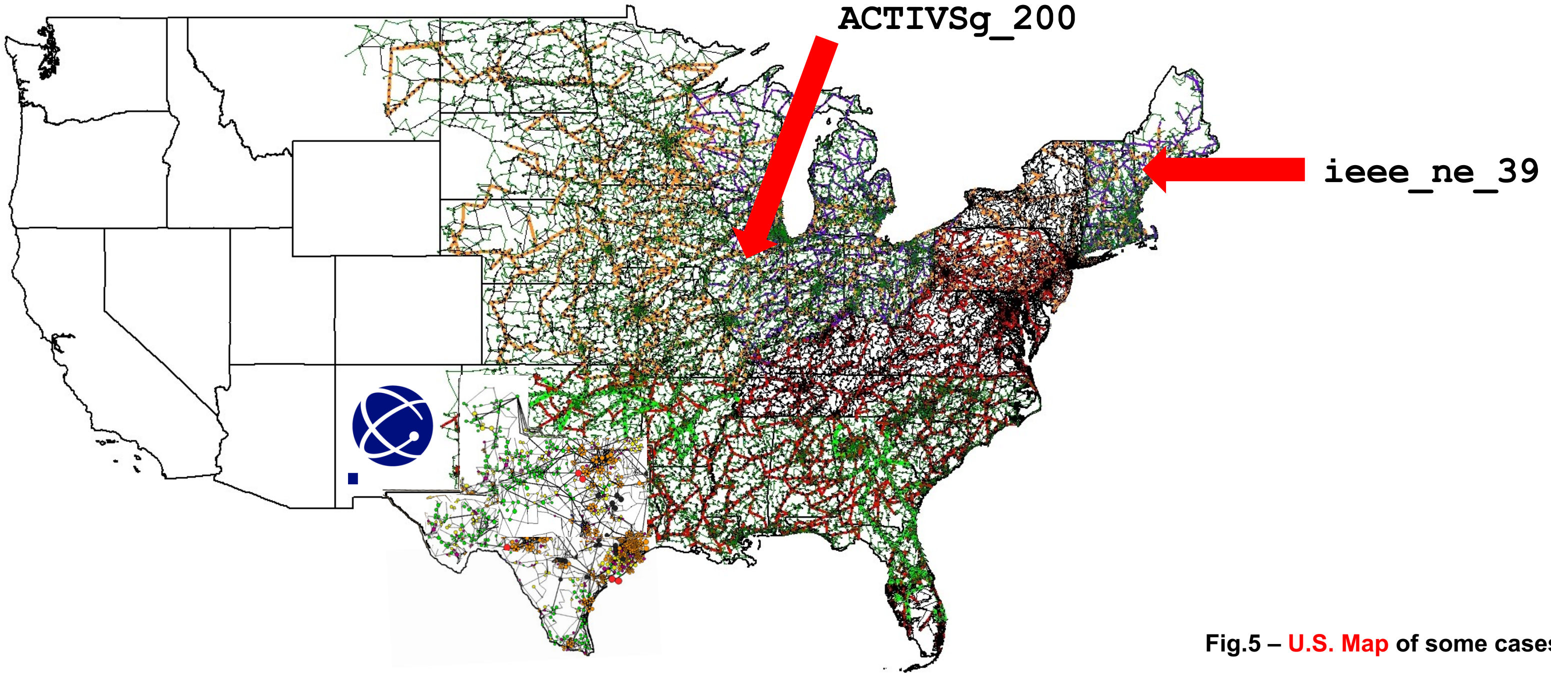
Data: Tested Grid Cases

- Small, Medium, and Large (24 – 13,695)
- 0, 2, 5,10,15% (20,000 samples)
- ACTIVSg, PEGASE, RTE, and IEEE



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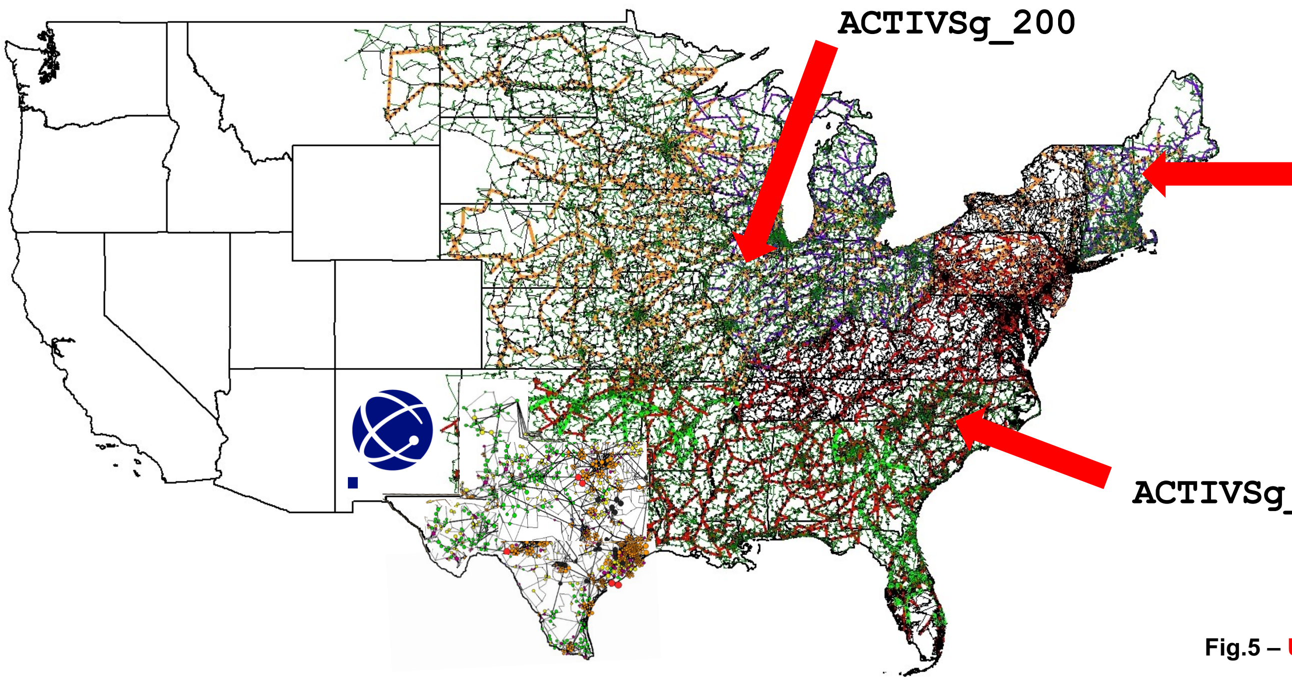

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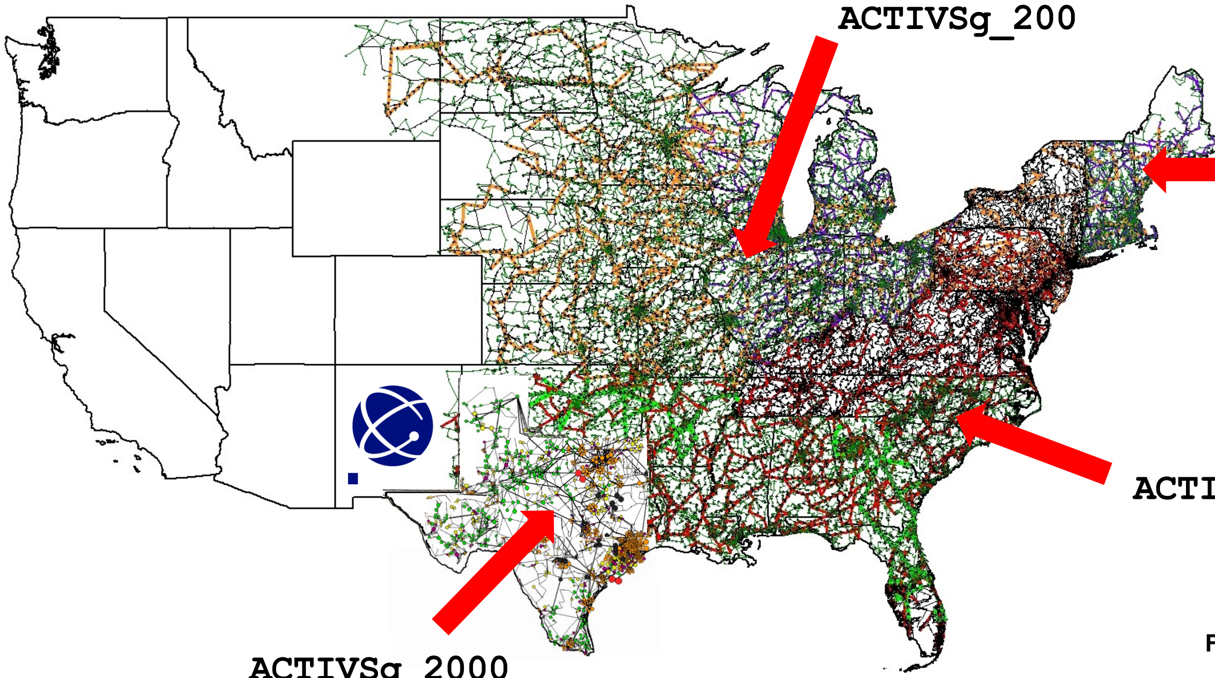

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1

Results: Max Power Violations (Base PF vs Principled PF)

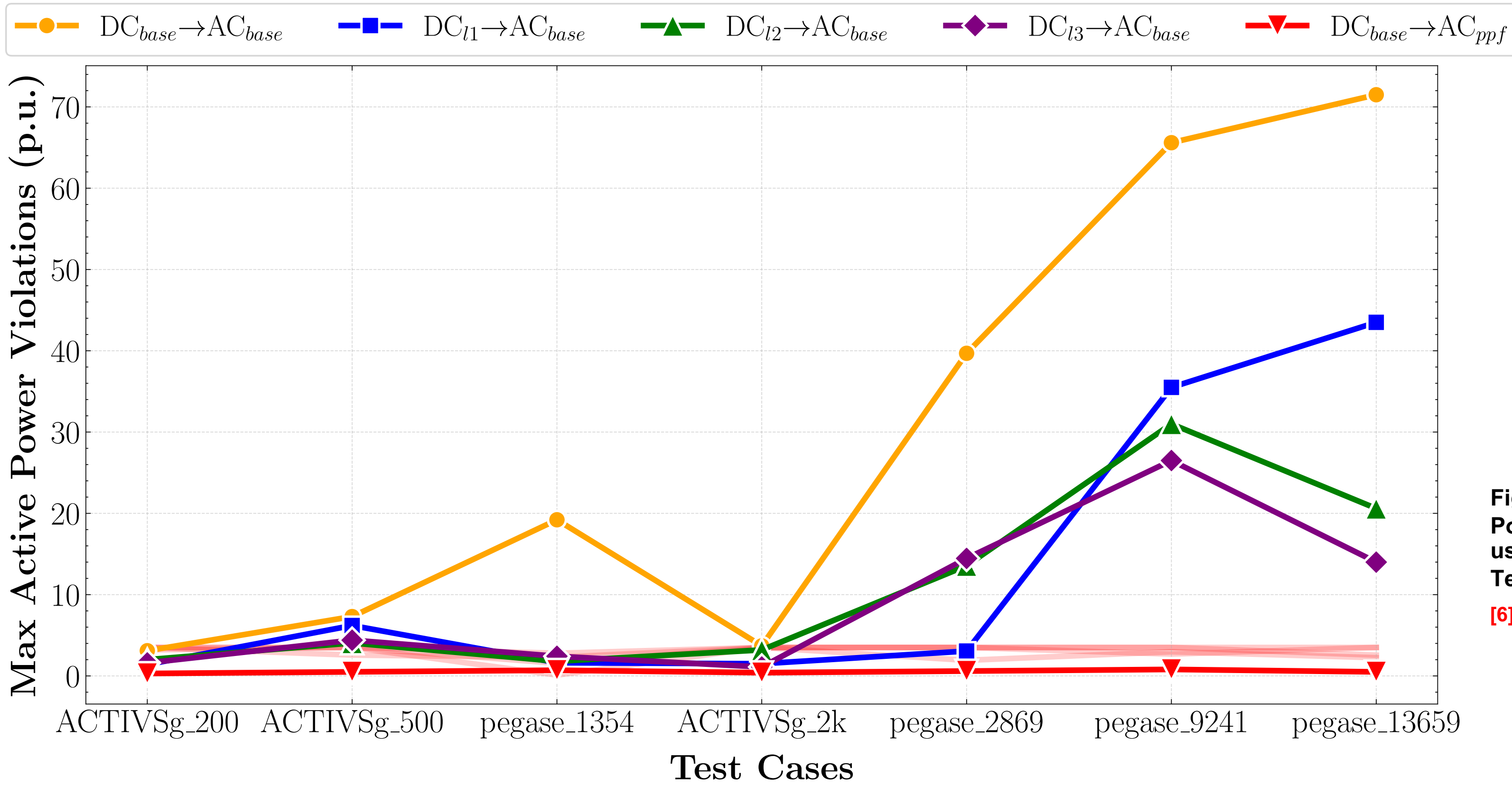

Fig.6a – Max Active Power Violations using DC*base* vs. Test Cases

[6], [7], [8].

- DC*base* -> Principled AC (with sensitives from 0, 2, 5,10%)
- Single Slack Cases have larger violations

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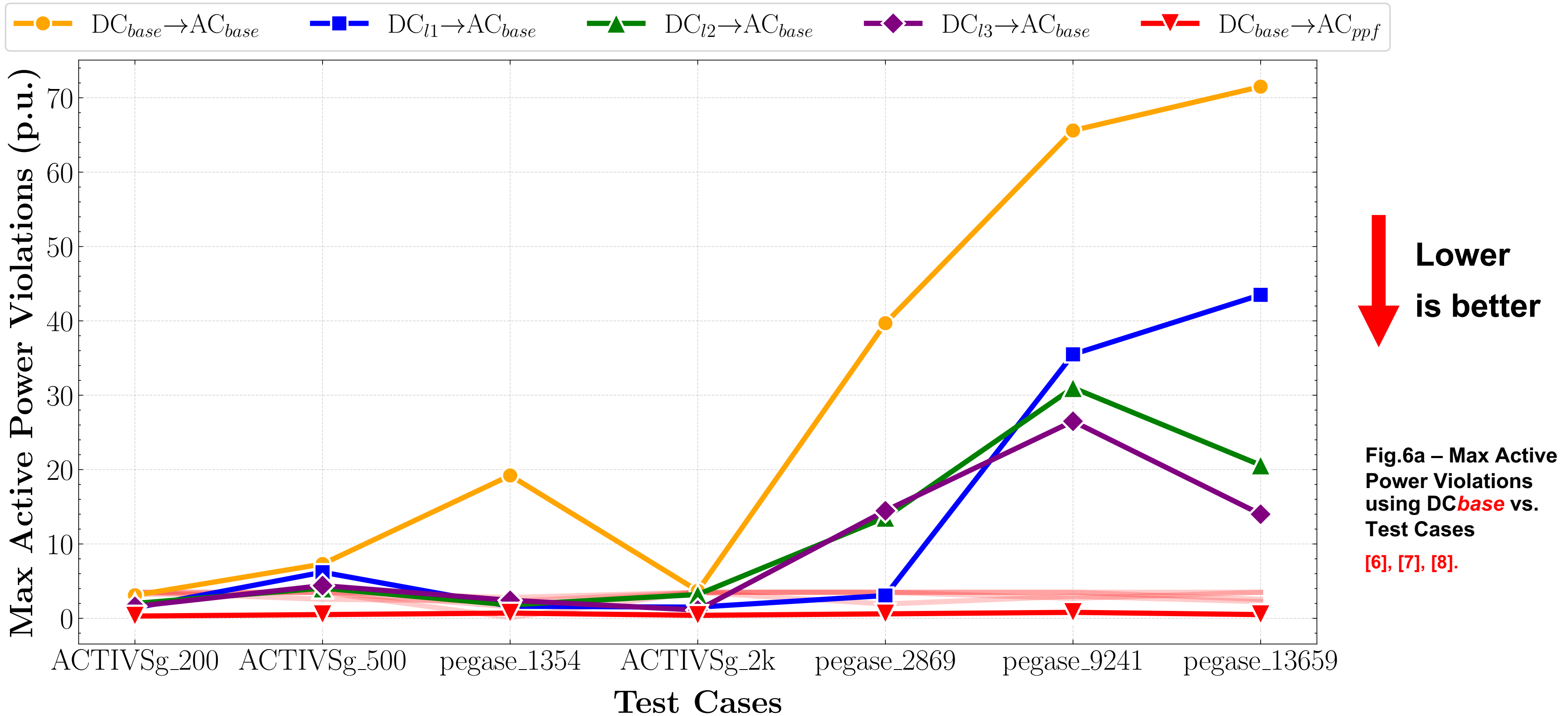

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2 Results: Max Power Violations (Base PF vs Principled PF)

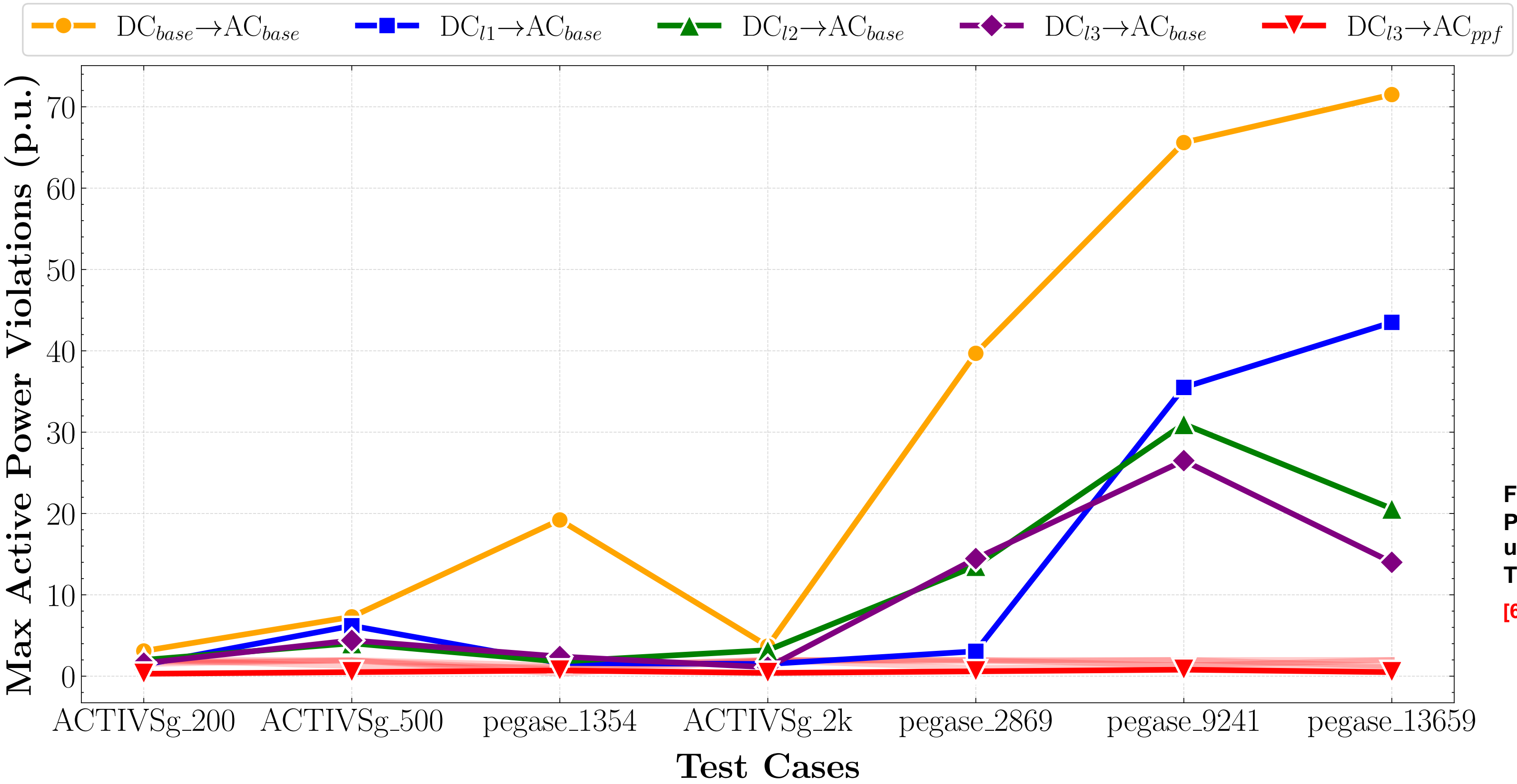

Fig.6b – Max Active Power Violations using DC*lossy* vs. Test Cases

[6], [7], [8].

- DC*lossy3* -> Principled AC (with sensitives from 0, 2, 5,10%)
- Best DC and Best AC = Fewer violations

[6] Zimmerman, R. D., Murillo-Sánchez, C. E., & Thomas, R. J. (2011). **MATPOWER:** Steady-State Operations, Planning, and Analysis Tools for Power Systems Research and Education. IEEE Transactions on Power Systems, 26(1), 12–19.

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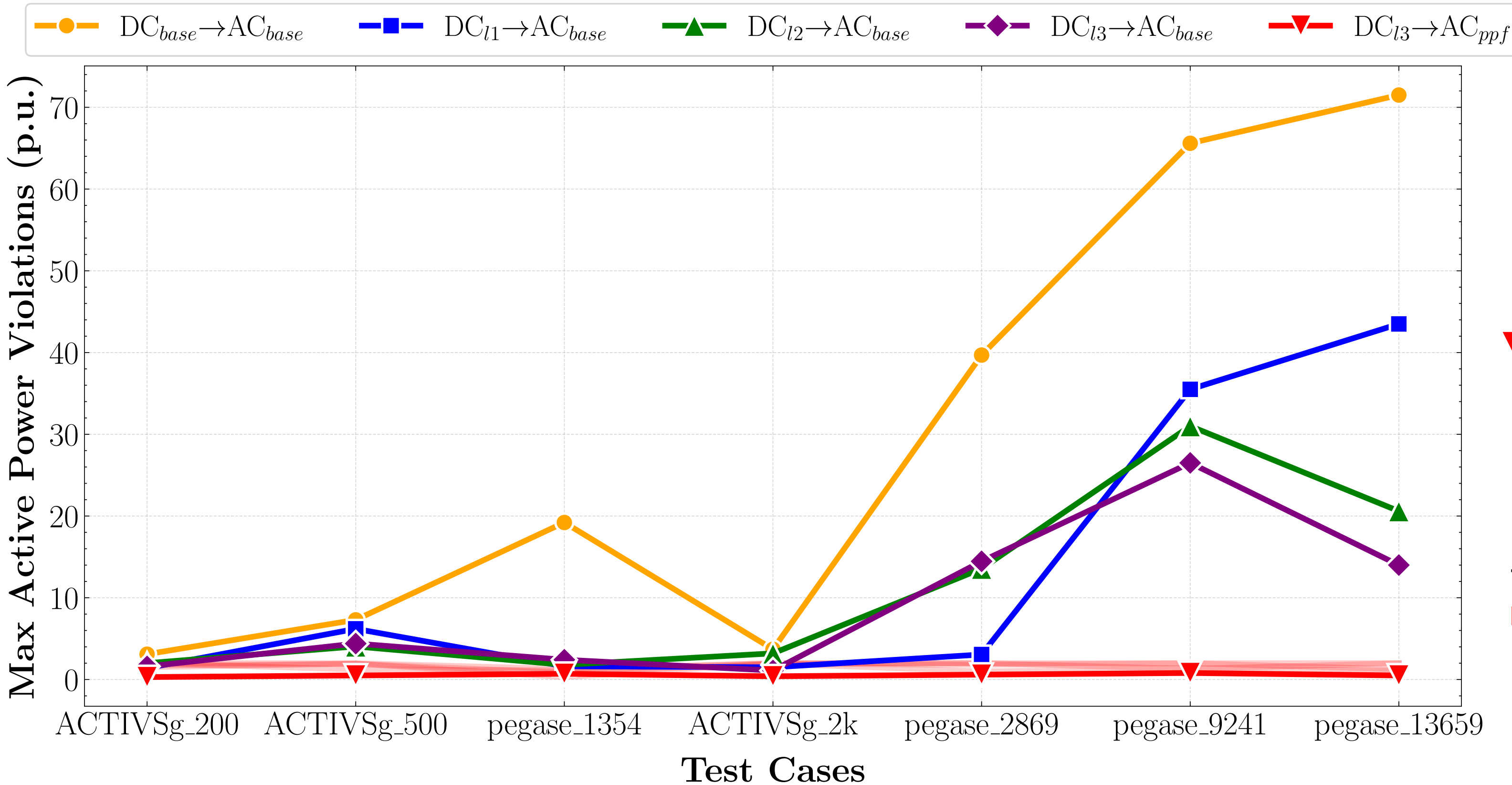

Lower is better

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3

Results: Max Line Violations (Base PF vs Principled PF)

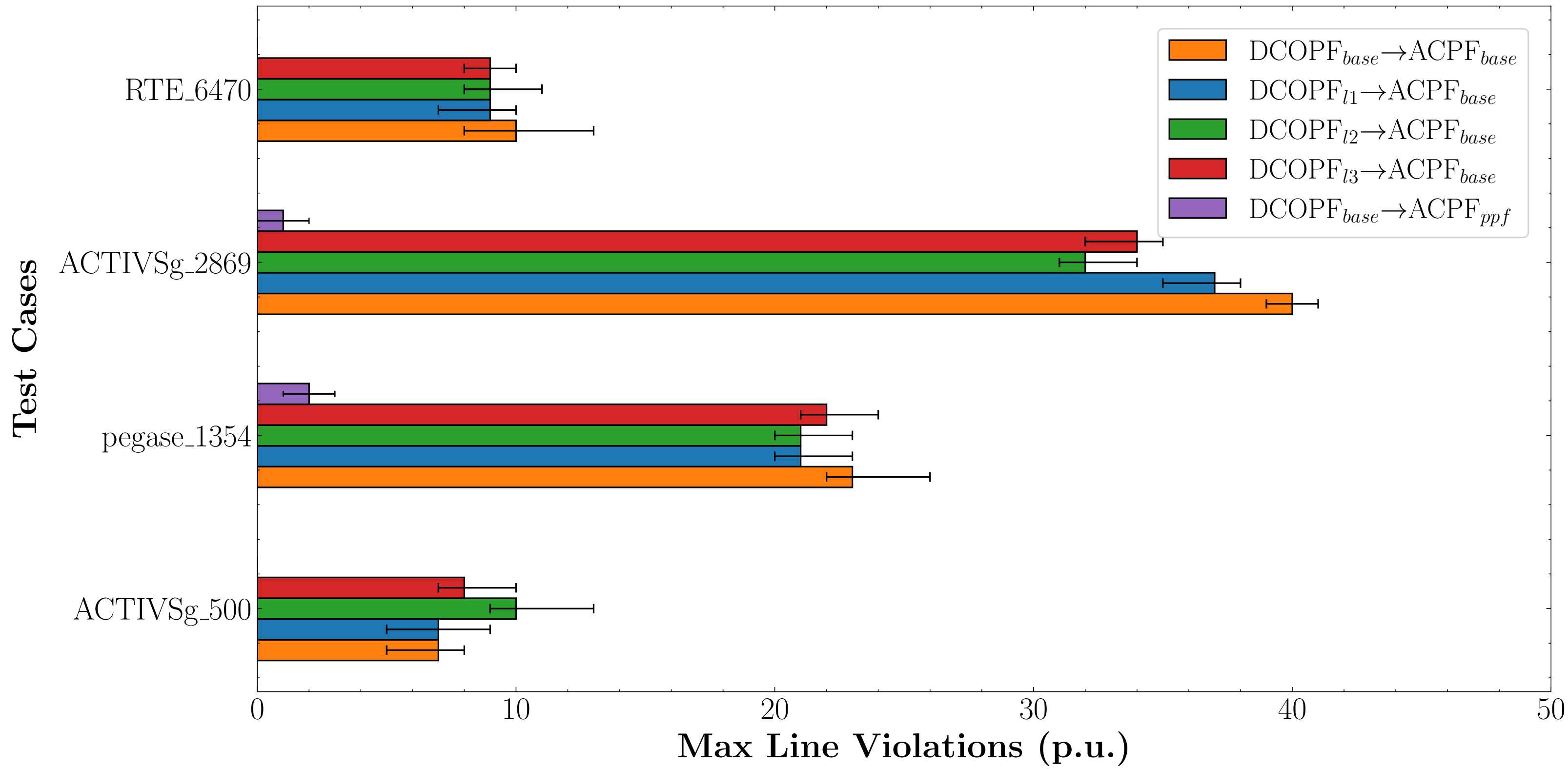

Fig.7 – Max Violations on Lines for different DC-AC pipelines.

[6], [7], [8].

- DC*base* -> Principled AC (with sensitives from 0, 2%)
- Line violations reduce drastically (even when using DC*base*)

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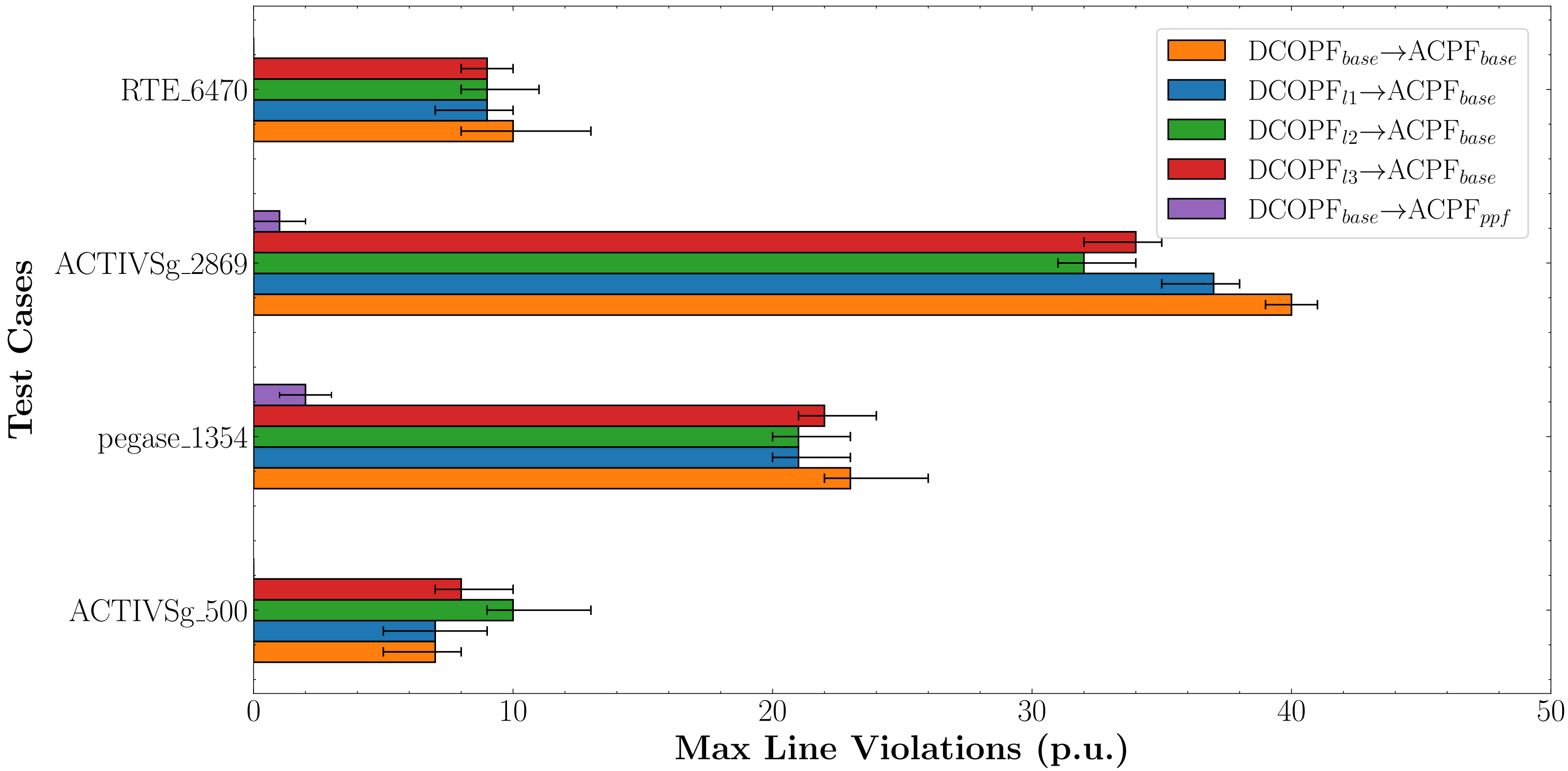

Larger is worse

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4 Results: Voltage Kernel Density Estimate (Principled PF)

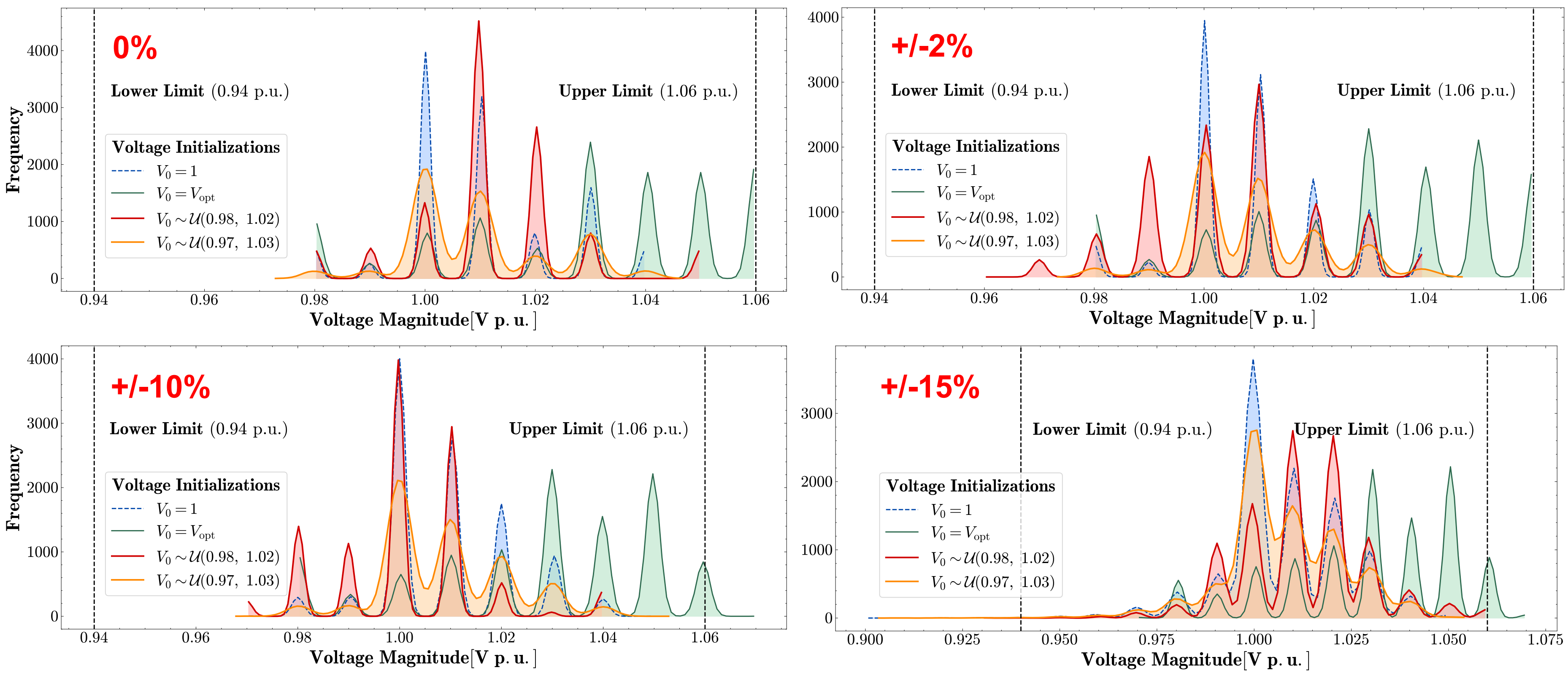

Fig.8 – Voltage Magnitude violations for DC-AC [6], [7], [8].

- Voltage Distribution (with sensitives from 0, 2,10, 15%) for case IEEE 39
- For reference with a Single slack ACPF violations in 0% 5 -10% with Lossy DC

[6] Zimmerman, R. D., Murillo-Sánchez, C. E., & Thomas, R. J. (2011). **MATPOWER:** Steady-State Operations, Planning, and Analysis Tools for Power Systems Research and Education. IEEE Transactions on Power Systems, 26(1), 12–19.

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Main Takeaways:

- Market Clearing requires a more Principled ACPF for Feasibility Check.
- DCOPF is never AC Feasible
- Significant Improvements in Violations for Voltage Magnitude (10%), Active Power Limits (60-70%), and Line Limits (x10), when using a Distributed Slack vs. a Single Slack bus.

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Next Steps:

Two Abstracts Submitted and Accepted at:

Power Systems Computational Conference 2026

[9] PSCC (2026) Logo

Final Submission is on October 1st

[9] Logo of the 2026 Power Systems Computation Conference (PSCC). Source: https://pscc2026.cy.

Thank You!

- **Mentors, Advisors, Colleagues, Family, Friends, Leaders, Administrative and Cleaning Staff.**

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Towards ACOPF Feasibility: Exploring the Combined Perspectives of DCOPF and ACPF Constraints

Michael A. Boateng [1, 2, 3] Russell Bent [3] Sidhant Misra [3] Parikshit Pareek [4] Daniel Molzahn [1, 2] Pascal Van Hentenryck [1, 2]

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Extras (QnA)

1

Algorithm 1a: Bus Switching Logic with Tolerances

Input: Initial state $s \in \{\mathbf{PV}, \mathbf{PQ}^{\min}, \mathbf{PQ}^{\max}\}$
Generator reactive limits: $\mathrm{Q}_{\mathrm{g}_i}^{\min}$, $\mathrm{Q}_{\mathrm{g}_i}^{\max}$
Generator setpoint: $\mathrm{Q}_{\mathrm{g}_i}$
Voltage magnitude V_i and setpoint V_i^{sp}
Tolerances: ε_q, $\varepsilon_v > 0$
Output: Updated bus type s_i for all $i \in \mathcal{N}$

```
foreach i ∈ N do
    if s_i = PV then
        if Q_{g_i} < Q_{g_i}^min − ε_q then
            Q_{g_i} ← Q_{g_i}^min;
            s_i ← PQ^min;
        else if Q_{g_i} > Q_{g_i}^max + ε_q then
            Q_{g_i} ← Q_{g_i}^max;
            s_i ← PQ^max;
        else
            s_i, remains unchanged;
    else if s_i = PQ^min and V_i > V_i^sp + ε_v then
        s_i ← PV;
    else if s_i = PQ^max and V_i < V_i^sp − ε_v then
        s_i ← PV;
    else
        s_i, remains unchanged;
```

2

Algorithm 1b: Smooth Bus Switching Formulation

Input: Voltage target: $\mathrm{V}_i^\star$ for all $i \in \mathcal{N}$
Reactive limits: $\mathbf{Q}^{\min}$, $\mathbf{Q}^{\max}$
Complex voltage: V_i for all $i \in \mathcal{N}$
Complex current: I_i for all $i \in \mathcal{N}$
Output: Slack variables $\{\mathrm{V}_i^+, \mathrm{V}_i^-, \mathrm{x}_i\}$ for all $i \in \mathcal{N}$

foreach $i \in \mathcal{N}$ **do**

- **Slack constraint:**
  $\mathrm{V}_{d,i}^2 + \mathrm{V}_{q,i}^2 \leftarrow (\mathrm{V}_i^\star)^2 - \mathrm{V}_i^- + \mathrm{V}_i^+$
- **Reactive mismatch:**
  $\mathrm{x}_i \leftarrow \mathrm{Q}_i^{\max} - f_Q(\mathrm{V}_{d,i}, \mathrm{V}_{q,i})$
- **Complementarity:**
  $$\mathrm{V}_i^- \cdot \mathrm{x}_i = 0, \quad \mathrm{V}_i^+ \cdot (\mathrm{Q}_i^{\max} - \mathrm{Q}_i^{\min} - \mathrm{x}_i) = 0$$
- **Feasibility:**
  $\mathrm{Q}_i^{\max} - \mathrm{Q}_i^{\min} - \mathrm{x}_i \geq 0$
- **Non-negativity:**
  $\mathrm{V}_i^+, \mathrm{V}_i^-, \mathrm{x}_i \geq 0$
- Reactive injection:
  $f_Q \leftarrow \mathrm{V}_{d,i} \cdot \mathrm{I}_{q,i} - \mathrm{V}_{q,i} \cdot \mathrm{I}_{d,i}$
- **Voltage decomposition:**
  $\mathrm{V}_{d,i} \leftarrow \Re(\mathrm{V}_i), \quad \mathrm{V}_{q,i} \leftarrow \Im(\mathrm{V}_i)$
- **Current computation:**
  $\mathrm{I}_i \leftarrow \mathrm{G}_{ii} \cdot \mathrm{V}_i + \sum_{j \in \mathcal{N}} \mathrm{Y}_{ij} \cdot \mathrm{V}_j$
- **return** $\{\mathrm{V}_i^+, \mathrm{V}_i^-, \mathrm{x}_i\}$

3

TABLE I: Overview of DCOPF Variants

Label	Formulation	Description
DC	Angle $[\mathbf{P}_{\mathrm{g}}, \mathbf{\Theta}_{\mathrm{g}}^{\mathrm{dc}}]$	Vanilla DC (Lossless)
DC_{ℓ_1}	PTDF $[\mathbf{P}_{\mathrm{g}}]$	Linearized Line Loss Factor
DC_{ℓ_2}	Angle $[\mathbf{P}_{\mathrm{g}}, \mathbf{\Theta}_{\mathrm{g}}^{\mathrm{dc}}]$	Quadratic Convex
DC_{ℓ_3}	PTDF $[\mathbf{P}_{\mathrm{g}}]$	Line Loss Outer Approximation
DC_{ℓ_4}	Angle $[\mathbf{P}_{\mathrm{g}}, \mathbf{\Theta}_{\mathrm{g}}^{\mathrm{dc}}]$	ML-based DC Parameter Optimizer

TABLE II: Summary of Test Systems from MATPOWER

Source	System	Buses	Branches	Generators
IEEE	ieee_rts_24	24	38	33
	ieee_30	30	41	6
	ieee_ne_39	39	46	10
	ieee_118	118	186	54
ACTIVSg	ACTIVSg_200	200	245	49
	ACTIVSg_500	500	597	90
	ACTIVSg_2000	2,000	3,206	544
RTE	rte_6468	6,468	9,000	1,296
	rte_6470	6,470	9,005	1,331
PEGASE	pegase_89	89	210	12
	pegase_1354	1,354	1,991	260
	pegase_2869	2,869	4,582	510
	pegase_9241	9,241	16,049	1,445
	pegase_13659	13,659	20,467	4,092

4

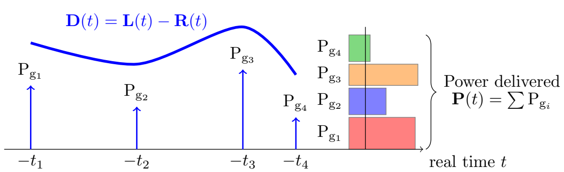

Fig. 1: Each vertical arrow marks a staged DCOPF dispatch at time t_i, based on the net demand forecast $\mathbf{D}(t) = \mathbf{L}(t) - \mathbf{R}(t)$, with $\mathbf{L}(t)$ as load and $\mathbf{R}(t)$ as expected renewables. As forecasts improve, updated set-points $\mathrm{P}_{\mathrm{g}_i}$ are determined and retained. The stacked bars at real-time t reveals the cumulative power injection, $\mathbf{P}(t) = \sum \mathrm{P}_{\mathrm{g}_i}$, which is checked for AC-feasibility under full network constraints.

5

Algorithm 2: Reserve-Based Slack Distribution

Input: Generator setpoints: $\mathrm{P}_{\mathrm{g}_i}^{\mathrm{set}}$
Max limits: $\mathrm{P}_{\mathrm{g}_i}^{\max}$
Total loss: ℓ_{total}
Output: Updated generation targets $\mathrm{P}_{\mathrm{g}_i}$ for all $i \in \mathcal{G}$

```
foreach i ∈ G do
    r_i ← max(P_{g_i}^max − P_{g_i}^set, 0);
S ← {i ∈ G | r_i > ε};
R ← ∑_{j∈S} r_j;
C ← ∑_{j∈S} P_{g_j}^max;
foreach i ∈ S do
    if R > 0 then
        π_i ← r_i / R;
    else
        π_i ← P_{g_i}^max / C;
    P_{g_i} ← P_{g_i}^set + π_i · |ℓ_total|;
return {P_{g_i}}_{i∈G}
```

6

$$\mathrm{MAE} = \frac{1}{G} \left\| \mathbf{p}_g^{*\,DC\rightarrow AC} - \mathbf{p}_g^{*\,AC} \right\|_1$$

7

VI. Sensitivity Analysis

In the sensitivity analysis, Gaussian multiplicative perturbations were applied to the active power demands P_{d} at each load bus. For $\mathrm{P}_{\mathrm{d}} > 0$, the demand was scaled by a factor $\boldsymbol{\xi} \sim \mathcal{N}(1.0, \sigma^2)$, where σ denotes the perturbation level (e.g., $\sigma = 0.10$ for approximately $\pm 10\%$ variation). The corresponding reactive power Q_{d} was recomputed using a randomly sampled power factor from the range $[0.95, 1.0]$, while preserving the original sign of Q_{d} to distinguish inductive and capacitive behavior. Loads with $\mathrm{P}_{\mathrm{d}} \leq 0$ were excluded from perturbation to maintain physical consistency.