Los Alamos NATIONAL LABORATORY

The Grid Optimization Competition Challenge 3 Benchmark Algorithm

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Our role in the competition

- Validate datasets
  - Temporal feasibility
  - AC feasibility
  - Reserve feasibility

- Develop a benchmark solver
- Goals:
  - Good solutions (positive scores)
  - Simplicity
  - Solve within the time limit

Benchmark algorithm overview

- No line switching!
- No contingencies!

Unit commitment approach: Copper-plate, full horizon

- Real and reactive copper-plate balances
  - Relaxed and penalized for 24k-bus network
  - Overcommit producers by 5%
- Full reserve model
- 3-binary UC formulation
- Division 1: Penalize deviation from initial schedule

ACOPF approach: Solve each time period independently

- Sequential option:
  - Time periods solved sequentially (no parallel solves)
  - Bounds tightened to respect ramping constraints after each solve
- Parallel option
  - Time periods solved in simultaneously, in parallel
  - Ramping constraints could be violated
  - Then sequentially project time points to satisfy ramping constraints
- Round shunt steps, then re-solve
- No reserves
- Penalize deviation from unit commitment solution
- No line switching (if allowed, all lines are active)

Reserve allocation approach

- Unit commitment considers reserves
- OPF does not
- Fixed unit commitment and OPF decisions
- Each time period is independent
- Fixed real/reactive power and commitment decisions
- Options:
  - Greedy allocation
  - Linear programming
  - Use reserves directly from UC

Implementation details

- Modeling: JuMP
- Unit commitment: Gurobi
- AC-OPF: Ipopt
  - Symbolic AD: MathOptSymbolicAD.jl
  - Linear solver: MA27
  - Heuristic callback to prevent long solve times
- Reserve allocation: HiGHS
- Parallelization: Julia `Threads`

Version 1: Greedy reserves

Case ID	Best-known solution ($)	Objective ($)	Gap	Res. penalty ($)	p-penalty ($)	q-penalty ($)	Solve time (s)
N00073D2-231	+1.49e+08	+1.49e+08	0.00%	-7.97e+04	-8.71e+00	-2.18e+01	169
N00073D2-236	+1.66e+08	+1.66e+08	0.05%	-8.55e+04	-3.21e+00	-3.48e+00	163
N00073D2-241	+1.49e+08	+1.49e+08	0.00%	-5.74e+04	-6.04e+00	-1.15e+01	170
N00073D2-248	+1.66e+08	+1.66e+08	0.10%	-1.41e+05	-3.51e+01	-1.79e+02	168
N00617D2-001	+2.76e+08	+2.75e+08	0.49%	-1.36e+06	-1.62e+02	-9.20e+02	384
N01576D2-027	+5.64e+08	+4.95e+08	12.35%	-6.05e+04	-1.83e+02	-8.09e+03	1041
N01576D2-032	+6.40e+08	+5.87e+08	8.21%	-9.98e+04	-1.76e+02	-5.86e+03	1127
N01576D2-036	+6.49e+08	+6.05e+08	6.76%	-1.10e+05	-1.78e+02	-4.61e+03	976
N01576D2-042	+6.37e+08	+5.86e+08	7.92%	-1.01e+05	-1.65e+02	-5.94e+03	926
N02000D2-001	+1.01e+09	+9.55e+08	5.22%	-5.36e+07	-1.57e+02	-7.78e+02	1168
N02000D2-011	+9.05e+08	+8.52e+08	5.83%	-5.30e+07	-2.90e+02	-2.56e+03	973
N02000D2-023	+8.59e+08	+8.43e+08	1.86%	-1.69e+07	-2.77e+02	-1.91e+03	1208
N02000D2-033	+1.35e+09	+1.34e+09	1.18%	-1.69e+07	-2.94e+02	-1.94e+03	1294
N04224D2-131	+4.94e+08	+4.85e+08	1.87%	-5.52e+05	-6.66e+03	-5.90e+06	2308
N04224D2-133	+7.19e+08	+4.98e+08	30.68%	-1.74e+08	-4.44e+07	-1.28e+06	2992
N04224D2-141	+4.94e+08	+4.91e+08	0.64%	-0.00e+00	-9.33e+03	-1.73e+06	2012
N04224D2-148	+5.45e+08	+4.27e+08	21.67%	-0.00e+00	-5.06e+07	-6.60e+07	2391
N06049D2-031	+6.07e+08	+5.09e+08	16.12%	-6.60e+06	-8.01e+04	-2.40e+07	5617
N06049D2-033	+8.23e+08	+7.11e+08	13.64%	-1.55e+07	-2.17e+04	-8.05e+04	4237
N06049D2-041	+6.07e+08	+5.92e+08	2.55%	-4.43e+06	-9.45e+04	-1.01e+07	5578
N06049D2-043	+8.19e+08	+7.66e+08	6.50%	-1.72e+07	-9.71e+02	-6.20e+04	3879
N06717D2-001	**+2.51e+08**	**+2.37e+08**	**5.47%**	**-1.44e+07**	**-7.00e+02**	**-5.84e+03**	**9234**
N06717D2-005	**+2.45e+08**	**+2.56e+08**	**0.00%**	**-5.47e+04**	**-7.42e+02**	**-6.27e+03**	**9029**
N06717D2-022	+1.01e+09	+1.01e+09	0.05%	-7.85e+05	-1.06e+02	-7.61e+01	6019
N06717D2-031	+1.51e+09	+1.51e+09	0.28%	-4.82e+06	-1.14e+02	-3.58e+02	6406
N08316D2-001	**+7.15e+09**	**+6.98e+09**	**2.37%**	**-1.53e+08**	**-1.12e+05**	**-2.79e+04**	**7657**

- Dominant penalties are reserves
- Total market surplus: 2.16e10

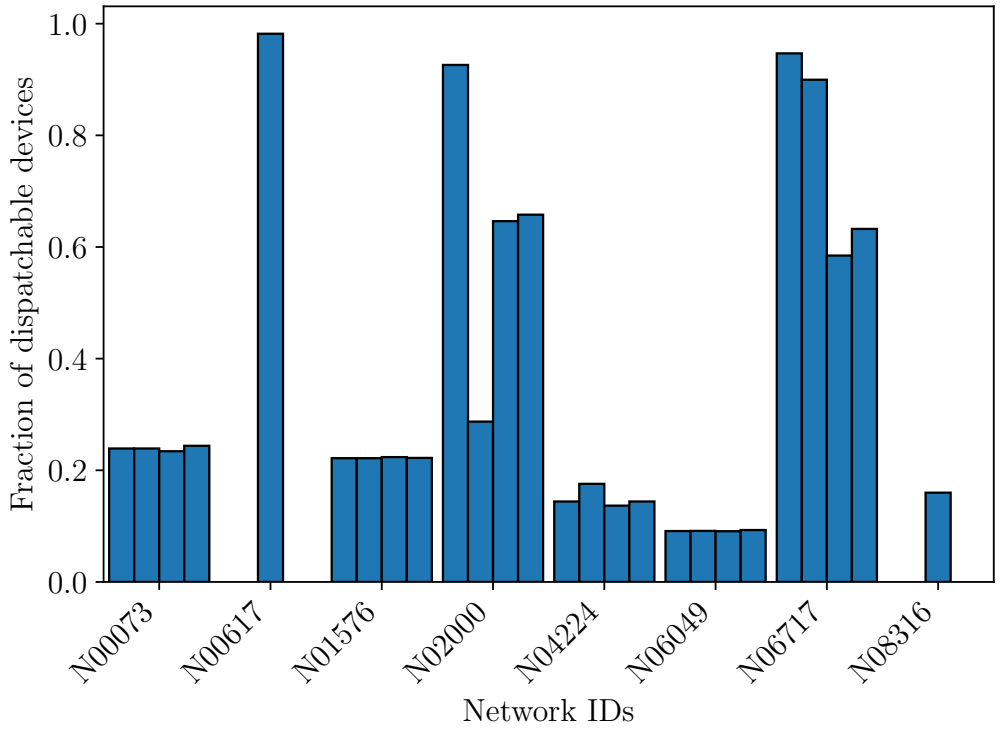
Version 2: Reserve-preserving

Case ID	Best-known solution ($)	Objective ($)	Gap	Res. penalty ($)	p-penalty ($)	q-penalty ($)	Solve time (s)
N00073D2-231	+1.49e+08	+1.49e+08	0.00%	-2.33e+05	-9.16e+00	-2.30e+01	182
N00073D2-236	+1.66e+08	+1.66e+08	0.03%	-2.36e+05	-3.21e+00	-3.48e+00	185
N00073D2-241	+1.49e+08	+1.49e+08	0.00%	-2.36e+05	-6.04e+00	-1.15e+01	191
N00073D2-248	+1.66e+08	+1.66e+08	0.11%	-2.48e+05	-3.51e+01	-1.79e+02	180
N00617D2-001	+2.76e+08	+2.76e+08	0.10%	-4.81e+04	-3.18e+02	-1.84e+03	376
N01576D2-027	+5.64e+08	+5.29e+08	6.24%	-1.95e+03	-1.92e+02	-7.94e+03	619
N01576D2-032	+6.40e+08	+6.17e+08	3.56%	-1.49e+03	-2.72e+02	-1.03e+04	668
N01576D2-036	+6.49e+08	+6.41e+08	1.23%	-7.57e+03	-2.56e+02	-9.57e+03	687
N01576D2-042	+6.37e+08	+6.17e+08	3.11%	-5.27e+03	-2.74e+02	-1.02e+04	685
N02000D2-001	+1.01e+09	+1.01e+09	0.17%	-1.38e+06	-1.57e+02	-1.59e+03	958
N02000D2-011	**+9.05e+08**	**-4.84e+09**	**634.89%**	**-6.89e+07**	**-5.63e+09**	**-4.80e+07**	**692**
N02000D2-023	**+8.59e+08**	**-1.20e+09**	**239.99%**	**-3.88e+07**	**-1.72e+09**	**-2.51e+06**	**855**
N02000D2-033	**+1.35e+09**	**-7.20e+08**	**153.22%**	**-3.82e+07**	**-1.55e+09**	**-2.50e+06**	**895**
N04224D2-131	+4.94e+08	+3.16e+08	36.09%	-8.76e+07	-1.26e+07	-6.23e+07	1730
N04224D2-133	+7.19e+08	+3.72e+08	48.24%	-3.45e+08	-9.13e+05	-4.55e+04	1183
N04224D2-141	+4.94e+08	+2.15e+08	56.56%	-8.23e+07	-7.38e+07	-1.04e+08	2600
N04224D2-148	+5.45e+08	+5.57e+07	89.77%	-1.40e+08	-1.53e+08	-1.86e+08	1458
N06049D2-031	+6.07e+08	+4.30e+08	29.16%	-1.32e+06	-7.56e+05	-3.03e+07	5232
N06049D2-033	+8.23e+08	+5.51e+08	33.01%	-2.89e+06	-4.48e+04	-6.09e+04	2773
N06049D2-041	+6.07e+08	+4.96e+08	18.25%	-1.16e+06	-2.67e+05	-1.54e+07	6602
N06049D2-043	+8.19e+08	+6.42e+08	21.63%	-2.23e+06	-1.41e+05	-3.88e+05	2484
N06717D2-001	**+2.51e+08**	**-8.78e+08**	**449.55%**	**-1.46e+06**	**-9.64e+08**	**-1.59e+08**	**6697**
N06717D2-005	+2.45e+08	+1.31e+08	46.46%	-3.48e+04	-9.67e+07	-2.31e+07	6453
N06717D2-022	+1.01e+09	+5.40e+08	46.34%	-3.35e+07	-4.03e+08	-1.01e+07	3654
N06717D2-031	+1.51e+09	+1.00e+09	33.59%	-4.91e+07	-3.56e+08	-8.17e+06	3750
N08316D2-001	+7.15e+09	+6.73e+09	5.83%	-2.07e+07	-2.27e+08	-7.81e+07	15345

- Dominant penalties are power balances

Why are power balance penalties so high?

In some cases, over 90% of devices provide reserves

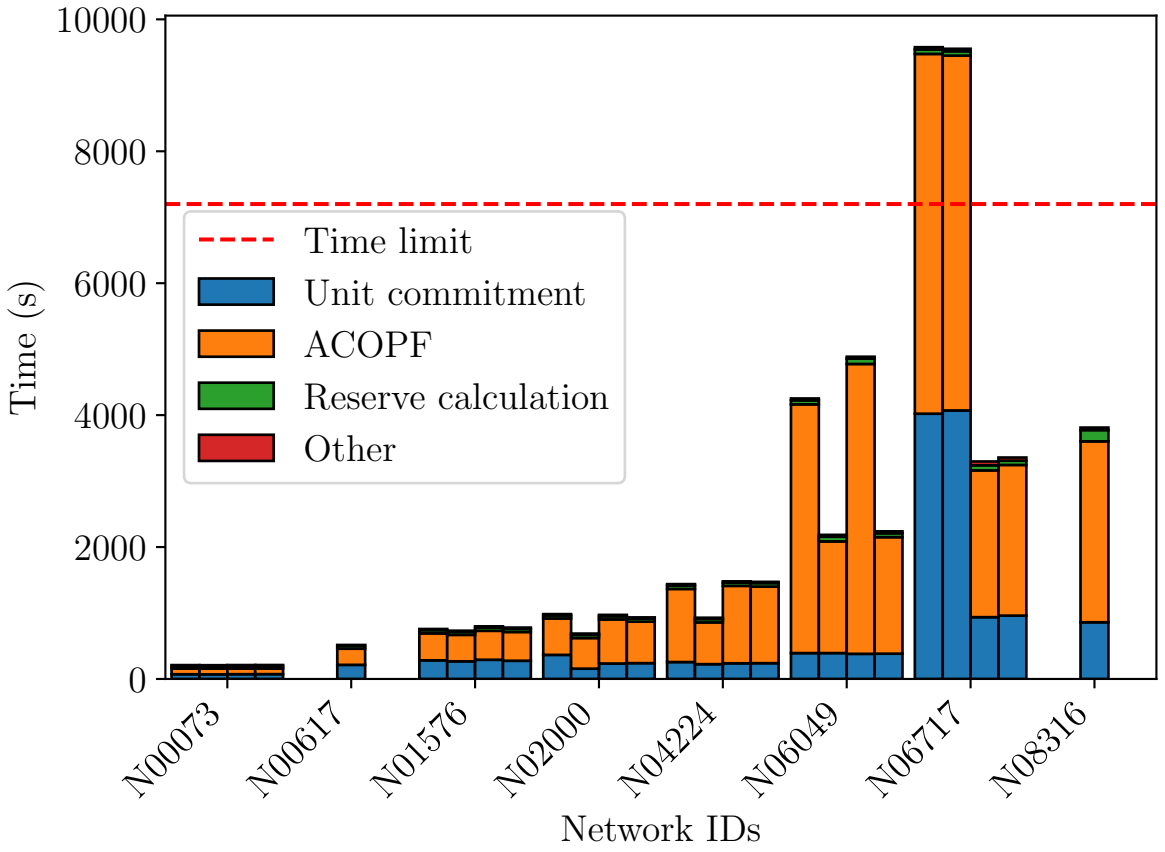


Version 3: Balancing heuristic

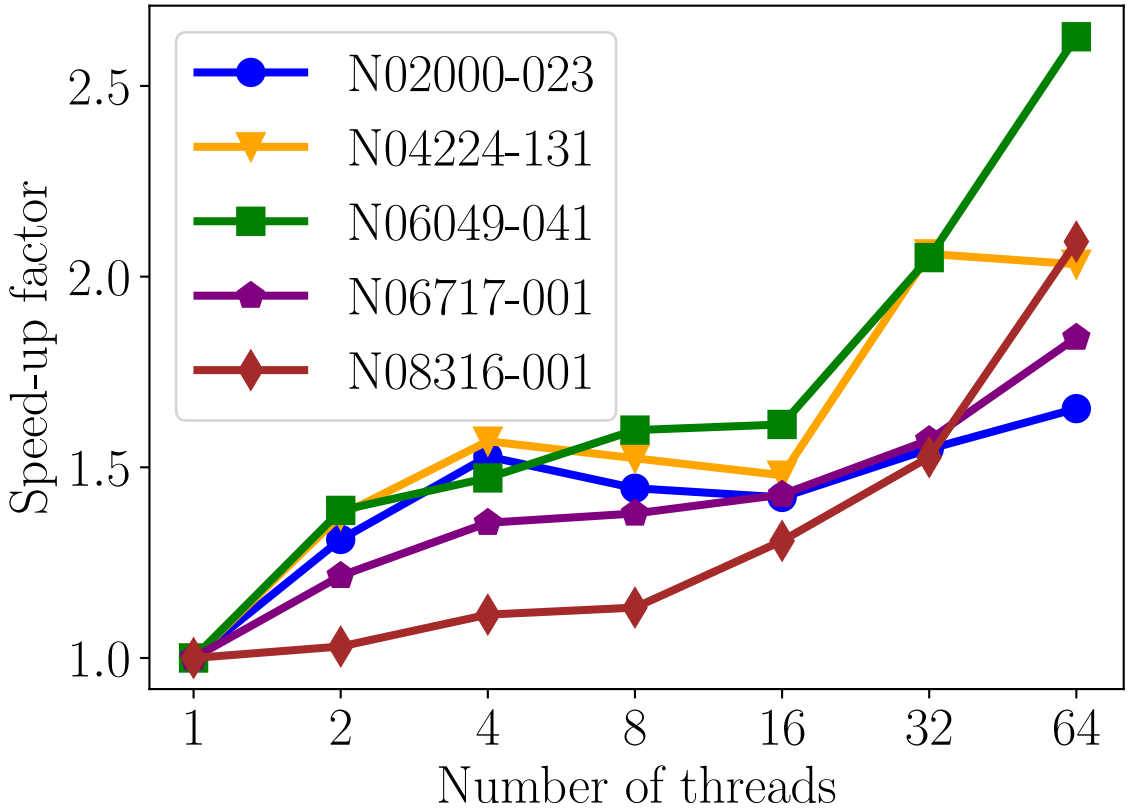
Case ID	Best-known solution ($)	Objective ($)	Gap	Res. penalty ($)	p-penalty ($)	q-penalty ($)	Solve time (s)
N00073D2-231	+1.49e+08	+1.49e+08	0.04%	-1.50e+05	-4.50e+01	-2.71e+02	212
N00073D2-236	+1.66e+08	+1.66e+08	0.09%	-1.08e+05	-5.72e+01	-3.58e+02	208
N00073D2-241	+1.49e+08	+1.49e+08	0.03%	-1.20e+05	-3.70e+01	-1.90e+02	217
N00073D2-248	+1.66e+08	+1.66e+08	0.06%	-1.92e+05	-7.26e+01	-4.11e+02	211
N00617D2-001	+2.76e+08	+2.76e+08	0.11%	-7.46e+03	-2.50e+01	-1.49e+02	508
N01576D2-027	+5.64e+08	+5.35e+08	5.12%	-3.58e+03	-1.82e+02	-8.76e+03	749
N01576D2-032	+6.40e+08	+6.10e+08	4.65%	-4.48e+03	-1.47e+02	-5.16e+03	736
N01576D2-036	+6.49e+08	+6.31e+08	2.90%	-2.57e+03	-8.65e+01	-3.27e+03	771
N01576D2-042	+6.37e+08	+6.14e+08	3.64%	-1.28e+03	-1.30e+02	-6.23e+03	793
N02000D2-001	+1.01e+09	+1.01e+09	0.06%	-5.30e+05	-8.61e+02	-1.09e+04	964
N02000D2-011	+9.05e+08	+8.57e+08	5.24%	-9.91e+06	-3.23e+07	-5.45e+03	728
N02000D2-023	+8.59e+08	+7.30e+08	15.02%	-9.82e+06	-1.09e+08	-6.44e+03	982
N02000D2-033	+1.35e+09	+1.30e+09	3.65%	-7.63e+06	-3.28e+07	-6.13e+03	977
N04224D2-131	+4.94e+08	+4.94e+08	0.00%	-1.71e-02	-6.08e+01	-2.52e+02	1483
N04224D2-133	+7.19e+08	+7.19e+08	0.00%	-6.88e-07	-2.63e+03	-2.63e+04	941
N04224D2-141	+4.94e+08	+3.86e+08	21.89%	-7.28e-01	-3.94e+07	-6.49e+07	1478
N04224D2-148	+5.45e+08	+4.05e+08	25.54%	-9.26e-07	-5.19e+07	-8.21e+07	1393
N06049D2-031	+6.07e+08	+4.63e+08	23.73%	-1.50e+04	-1.26e+05	-3.57e+07	4567
N06049D2-033	+8.23e+08	+6.69e+08	18.66%	-1.38e+06	-6.08e+03	-7.96e+04	2272
N06049D2-041	+6.07e+08	+5.67e+08	6.65%	-9.95e+05	-1.89e+05	-1.23e+07	4781
N06049D2-043	+8.19e+08	+7.49e+08	8.51%	-3.24e+06	-6.95e+04	-1.83e+05	2237
N06717D2-001	**+2.51e+08**	**+2.45e+08**	**2.27%**	**-1.26e+06**	**-3.05e+06**	**-1.84e+06**	**9621**
N06717D2-005	**+2.45e+08**	**+2.50e+08**	**0.00%**	**-1.10e+04**	**-2.82e+06**	**-2.66e+04**	**9560**
N06717D2-022	+1.01e+09	+1.00e+09	0.41%	-7.55e+05	-2.18e+03	-2.06e+04	3529
N06717D2-031	+1.51e+09	+1.51e+09	0.41%	-2.35e+06	-1.87e+03	-1.80e+04	3419
N08316D2-001	+7.15e+09	+7.12e+09	0.42%	-1.53e+07	-6.45e+04	-4.60e+04	3841

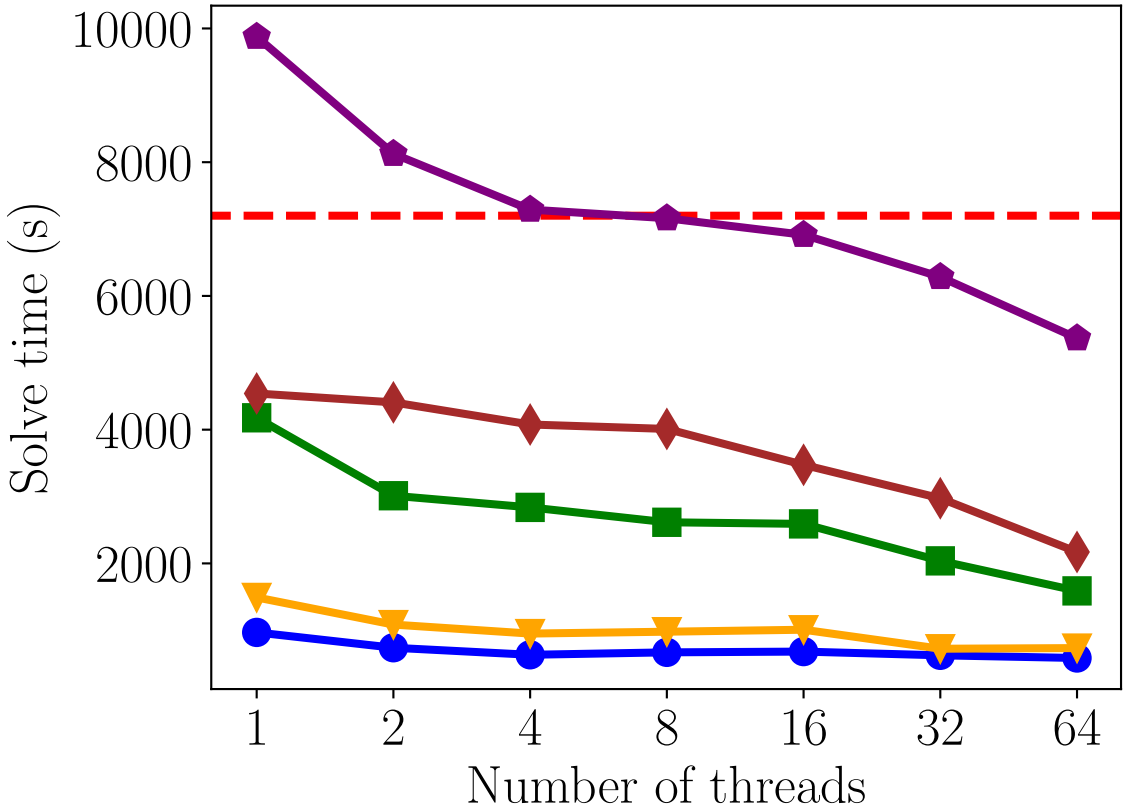
- Dominant penalties are reserves or power balances
- Total market surplus: 2.18e10
- Some cases take longer than the time limit

Sequential OPF is the dominant computational cost



Parallelization is necessary to finish within the solve time



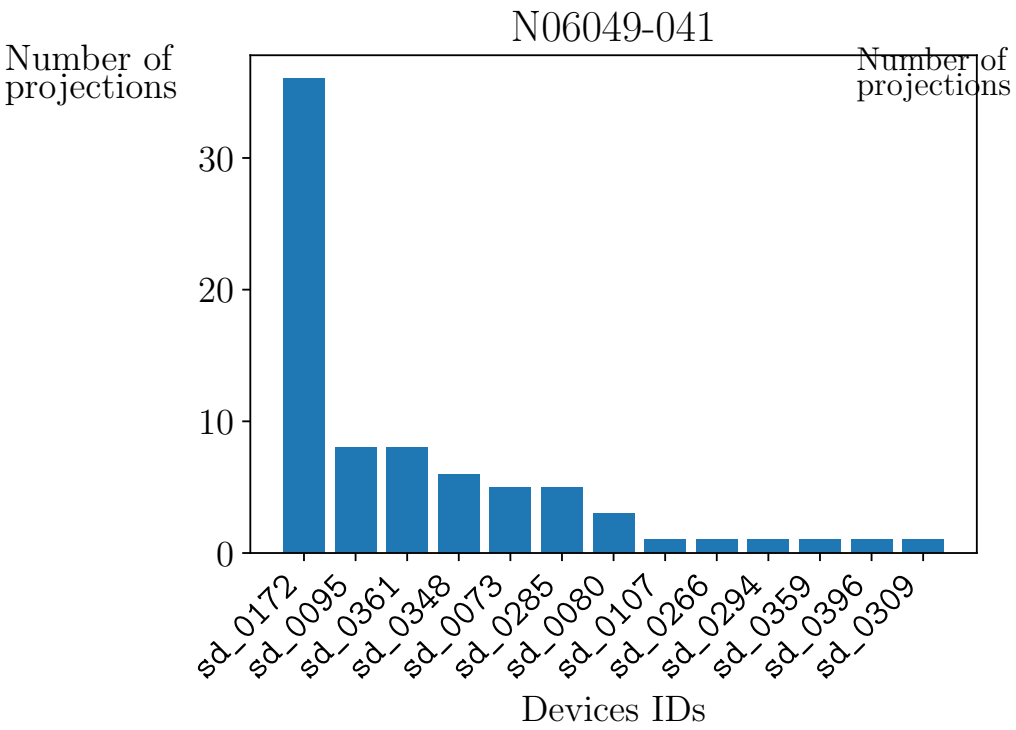


But ramping projections cause power balance violations

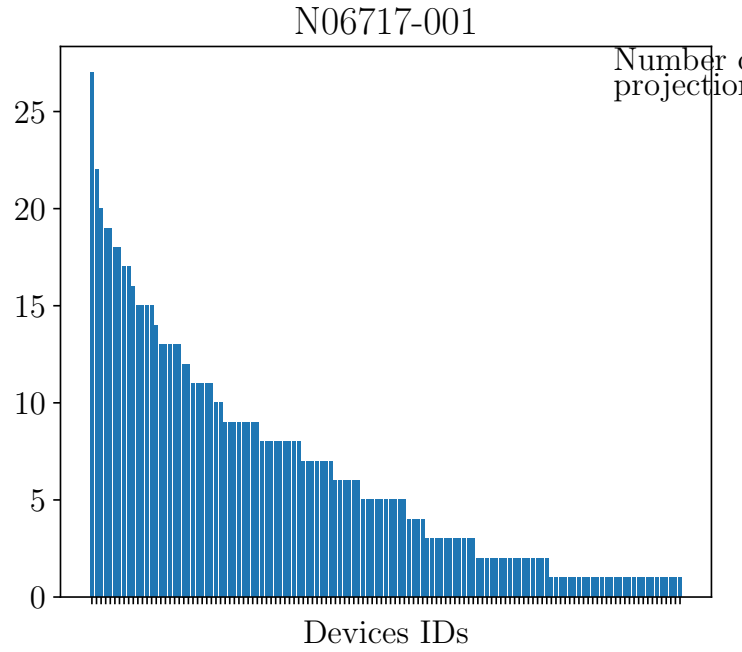
Case ID	Best-known solution ($)	Objective ($)	Gap	Res. penalty ($)	p-penalty ($)	q-penalty ($)	Solve time (s)
N00073D2-231	+1.49e+08	+1.49e+08	0.04%	-1.50e+05	-4.50e+01	-2.71e+02	246
N00073D2-236	+1.66e+08	+1.66e+08	0.09%	-1.08e+05	-5.72e+01	-3.58e+02	242
N00073D2-241	+1.49e+08	+1.49e+08	0.03%	-1.20e+05	-3.70e+01	-1.90e+02	241
N00073D2-248	+1.66e+08	+1.66e+08	0.06%	-1.92e+05	-7.26e+01	-4.11e+02	237
N00617D2-001	+2.76e+08	+2.76e+08	0.11%	-7.43e+03	-2.09e+01	-1.44e+02	414
N01576D2-027	+5.64e+08	+5.35e+08	5.12%	-3.58e+03	-1.82e+02	-8.76e+03	613
N01576D2-032	+6.40e+08	+6.10e+08	4.65%	-4.48e+03	-1.47e+02	-5.16e+03	609
N01576D2-036	+6.49e+08	+6.31e+08	2.90%	-2.57e+03	-8.65e+01	-3.27e+03	617
N01576D2-042	+6.37e+08	+6.14e+08	3.64%	-1.28e+03	-1.30e+02	-6.23e+03	522
N02000D2-001	+1.01e+09	+1.01e+09	0.06%	-5.30e+05	-8.60e+02	-1.09e+04	695
N02000D2-011	+9.05e+08	+8.57e+08	5.24%	-9.91e+06	-3.23e+07	-5.45e+03	464
N02000D2-023	+8.59e+08	+7.30e+08	15.02%	-9.82e+06	-1.09e+08	-6.44e+03	617
N02000D2-033	+1.35e+09	+1.30e+09	3.65%	-7.63e+06	-3.28e+07	-6.13e+03	585
N04224D2-131	+4.94e+08	+3.33e+08	32.67%	-8.74e-01	-1.53e+08	-4.85e+06	735
N04224D2-133	+7.19e+08	+7.19e+08	0.05%	-8.71e-07	-4.30e+05	-2.52e+04	661
N04224D2-141	+4.94e+08	+3.29e+08	33.36%	-4.62e-01	-1.50e+08	-1.18e+07	773
N04224D2-148	+5.45e+08	+1.93e+08	64.50%	-6.94e-07	-2.49e+08	-9.74e+07	756
N06049D2-031	+6.07e+08	+4.59e+08	24.34%	-1.66e+04	-1.56e+06	-3.81e+07	1587
N06049D2-033	+8.23e+08	+6.64e+08	19.28%	-1.36e+06	-5.08e+06	-8.69e+04	1249
N06049D2-041	+6.07e+08	+5.66e+08	6.74%	-1.00e+06	-1.13e+06	-1.21e+07	1641
N06049D2-043	+8.19e+08	+7.48e+08	8.72%	-3.25e+06	-1.84e+06	-1.76e+05	1547
N06717D2-001	+2.51e+08	+1.10e+08	56.17%	-1.21e+06	-1.38e+08	-1.83e+06	5383
N06717D2-005	+2.45e+08	+8.50e+07	65.33%	-1.13e+04	-1.68e+08	-2.71e+04	5461
N06717D2-022	+1.01e+09	+1.00e+09	0.41%	-7.55e+05	-2.18e+03	-2.06e+04	2064
N06717D2-031	+1.51e+09	+1.51e+09	0.41%	-2.35e+06	-1.87e+03	-1.80e+04	1985
N08316D2-001	+7.15e+09	+7.12e+09	0.42%	-1.53e+07	-6.44e+04	-4.60e+04	2412

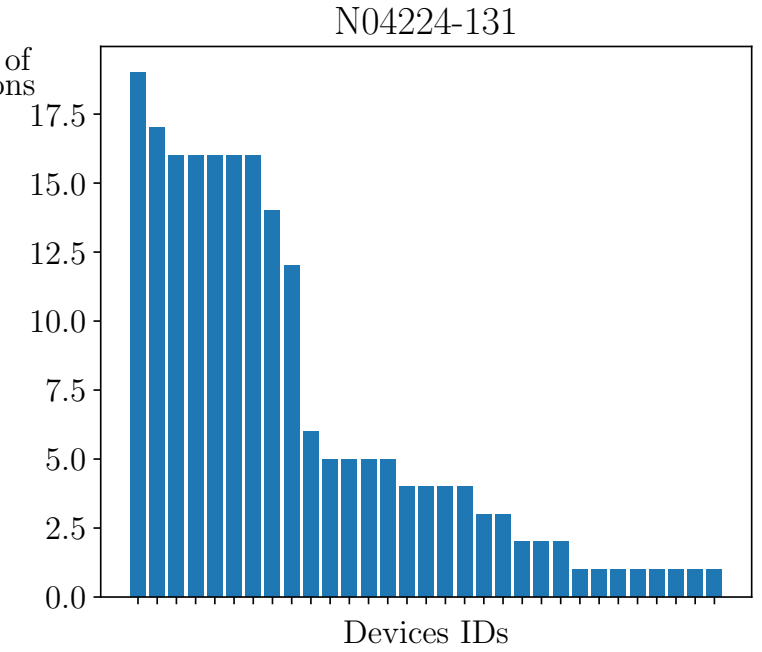
- Parallel OPF solution is projected onto ramping constraints
- Projections cause power balance violations

Projections can be clustered by device



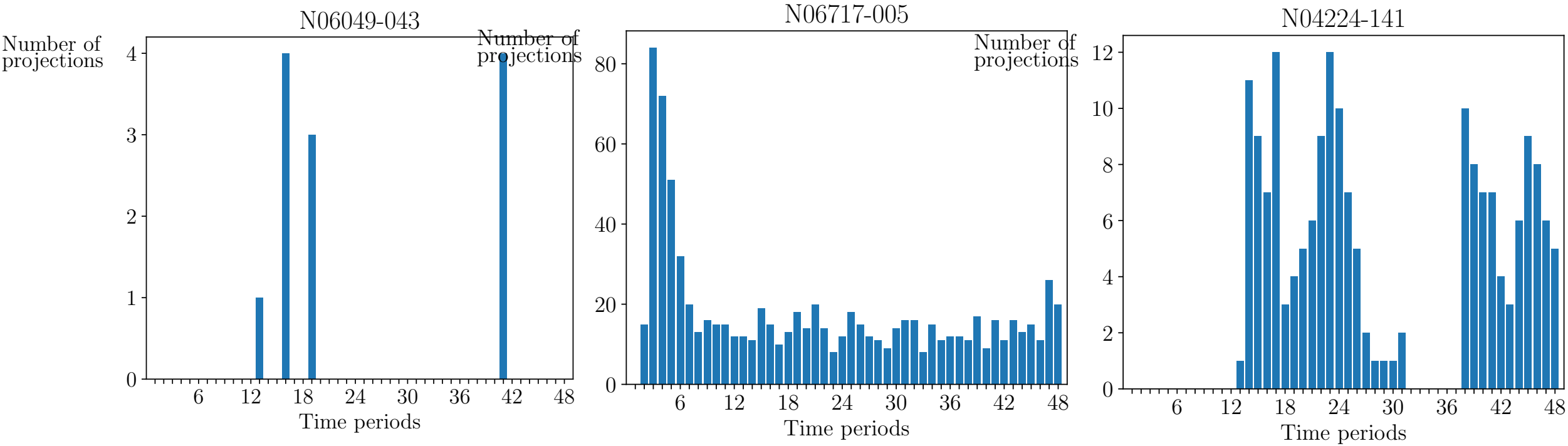
13 devices projected





31 devices projected

Projections can be clustered by time period



Take-aways

- Benchmark algorithm used three main subroutines:
  - Unit commitment
  - Optimal power flow
  - Reserve allocation
- Unit commitment and multi-period ACOPF were both computationally expensive
- Simple algorithm was sufficient to get “good” solutions

Questions?