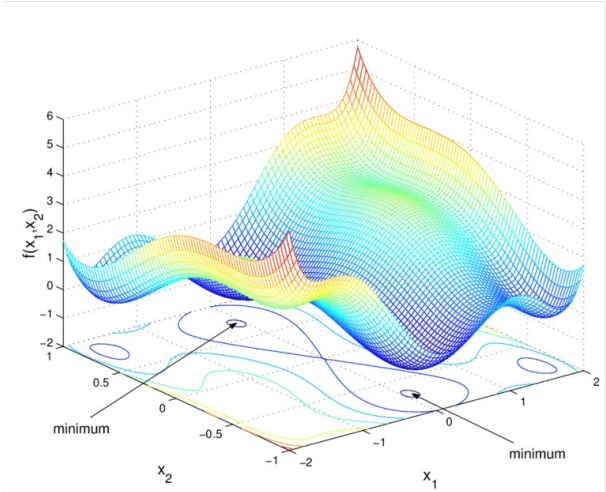
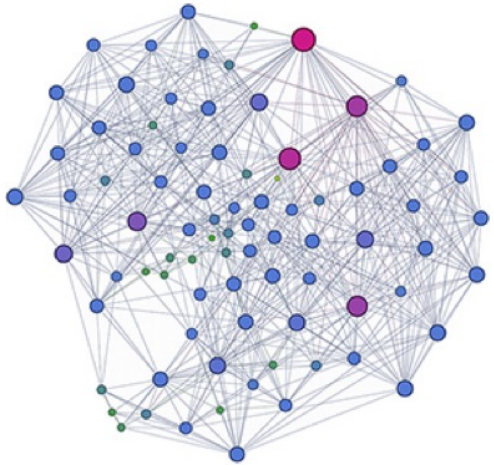
GravityX

ARPA-E Grid Software Annual Meeting 2023

Hassan Hijazi





Why a Competition?

Transparent unbiased evaluation

Equal treatment

Zero BS/faking

Off-the-chart motivation levels

Challenge 3: The Hardest Challenge of them All

CHALLENGE 3

The Grid Optimization (GO) Competition Challenge 3 started on December 8, 2022, with the opening of Sandbox submissions of S0 datasets. It is not too late to enter. Win up to $750,000. The first Event took place at the end of January 2023. The second Event took place in April 2023. The third Event is taking place in June 2023; the fourth and final Event will take place in early September 2023. Prizes will be awarded in Events 3 and 4.

Event 4 submissions are now CLOSED.

The Grid Optimization (GO) Competition Challenge 3, focuses on the security-constrained optimal power flow (SCOPF)

2019-2020 2020-2021 2021-2022 2022-2023

Challenge 3: What Was so Challenging About it?

The Answer: Temporal Constraints

- Division 1: Real-Time Market with 8-hour look ahead -- 8 0.25-hour periods, 8 0.5-hour periods, 2 1-hour periods
- Division 2: Day-Ahead Market with 48-hour look ahead -- 48 1-hour periods
- Division 3: Week-Ahead Advisory with 7-day (168-hour) look ahead -- 42 4-hour periods.

Challenge 3: What Was so Challenging About it?

Other Challenges:

- 1e-8 Constraint Satisfaction (4 orders of magnitude drop!)
- Dense Reserve Constraints (thousands of nnz in one constraint)
- Different N-1 Post-Contingency Model

Challenge 3: What Was so Challenging About it?

Most Importantly: Other Competitors

C3E3N06717D1	46	1	TIM-GO	156,932,909	577	YongOptimization	154,196,442	482
C3E3N06717D1	47	1	YongOptimization	162,542,585	450	TIM-GO	161,279,556	588
C3E3N06717D1	48	1	YongOptimization	164,750,180	590	TIM-GO	163,121,957	577
C3E3N08316D1	1	1	YongOptimization	1,189,381,421	168	TIM-GO	1,179,768,680	523
C3E3N08316D2	1	1	YongOptimization	7,151,907,899	778	TIM-GO	7,089,733,833	4,022

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A mere $9.6M in market surplus difference in the real-time market

Challenge 3: What Was so Challenging About it?

Most Importantly: Other Competitors

C3E3N00617D2	1	1	GravityX	275,911,451	296	YongOptimization	275,864,132	241
C3E3N00617D3	1	1	GravityX	967,609,873	345	The Blackouts	967,586,640	14,408
C3E3N01576D1	27	1	TIM-GO	100,953,249	381	GOT-BSI-OPF	99,005,474	123
C3E3N01576D2	27	1	TIM-GO	564,297,765	861	YongOptimization	551,568,231	162

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My guess: TIM-GO was already including contingencies in Event 3!

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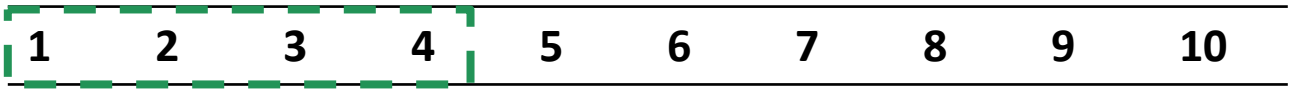
The Power of Competitions: Seeing is Believing!

GravityX's Approach

Decomposition + MIP + NLP



Rolling Horizon Time Decomposition

GravityX's Approach

Decomposition + MIP + NLP

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\min \ & \boldsymbol{c_1}^t x + \boldsymbol{c_2}^t y \\
s.t. \ & \boldsymbol{A_1} x + \boldsymbol{A_2} y \leq \boldsymbol{b} \\
& x \in \mathbb{R}^n, y \in \mathbb{Z}^n
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GUROBI OPTIMIZATION

*Thanks for the free license!

From Lossless to Lossy Mixed-Integer Linear Power Flow Model (including reactive power)

Modeling Power Flow Losses

Busting a few myths*

* Another advantage of competitions

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&\quad - b^{\mathrm{sr}}_j \sin(\theta_{it} - \theta_{i't} - \phi_{jt}))v_{it}v_{i't}/\tau_{jt}) \ \forall t \in T, j \in J^{\mathrm{ac}}, i = i^{\mathrm{fr}}_j, i' = i^{\mathrm{to}}_j \\
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- Line resistance is always positive

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MYTH BUSTED

How to include Voltage Variables in the MIP?

And still have Gurobi solve it in time..

$$\begin{aligned} \min \ & \boldsymbol{c_1}^t x + \boldsymbol{c_2}^t y \\ s.t. \ & \boldsymbol{A}_1 x + \boldsymbol{A}_2 y \leq \boldsymbol{b} \\ & x \in \mathbb{R}^n, y \in \mathbb{Z}^n \end{aligned}$$

GUROBI OPTIMIZATION

From Lossless to Lossy Mixed-Integer Linear Power Flow Model (including reactive power)

Linear Relationship Linking Voltage Magnitude Square to P and Q?

$$P_{hi} - P_{to} = \left(g^{sr} + g^{ch}\right) V_{hi}^2 - \left(g^{sr} + g^{to}\right) V_{to}^2$$

$$- 2\, b^{sr} \sin\left(\theta_i - \theta_j - \phi_{ij}\right) V_i V_j$$

$$Q_{hi} - Q_{to} = \left(-b^{sr} - b^{ch} - \frac{b}{2}\right) V_{hi}^2 - \left(-b^{sr} - b^{to} - \frac{b}{2}\right) V_{to}^2$$

$$- 2\, g^{sr} \sin\left(\theta_i - \theta_j - \phi_{ij}\right) V_i V_j$$

Linear Relationship Linking Voltage Magnitude Square to P and Q?

$$g^{sr}\left(P_{gi}-P_{to}\right) - b^{sr}\left(Q_{gi}-Q_{to}\right) =$$

$$g^{sr}\left(g^{sr}+g^{fr}\right)\frac{V_i^2}{t_{ij}^2} - g^{sr}\left(g^{sr}+g^{to}\right)V_j^2$$

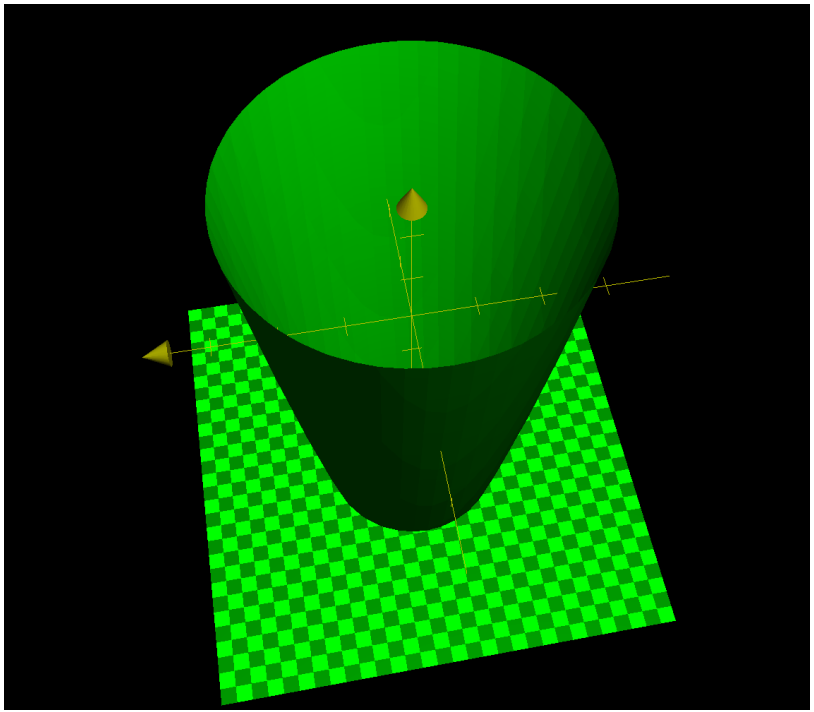
$$+ b^{sr}\left(b^{sr}+b^{fr}+\frac{b^{ch}}{2}\right)V_i^2/t^2 + b^{sr}\left(-b^{sr}-b^{to}-\frac{b^{ch}}{2}\right)V_j^2$$

Modeling Thermal Limit Constraints

Outer-Approximation Cuts using Gurobi's Lazy Callback

$$\left(\left(p_{jt}^{\text{fr}}\right)^2 + \left(q_{jt}^{\text{fr}}\right)^2\right)^{1/2} \leq s_j^{\max} + s_{jt}^{+} \;\forall t \in T, j \in J^{\text{ac}}$$

$$\left(\left(p_{jt}^{\text{to}}\right)^2 + \left(q_{jt}^{\text{to}}\right)^2\right)^{1/2} \leq s_j^{\max} + s_{jt}^{+} \;\forall t \in T, j \in J^{\text{ac}}$$



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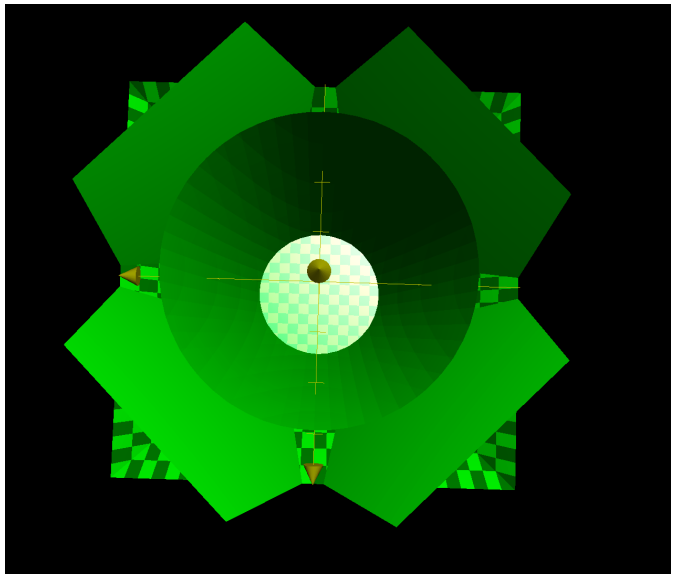

$$\nabla_x f_j(\hat{x})^{\mathrm{T}}[x - \hat{x}] \leq 0 \quad \forall i = \{1, \ldots m\}$$

GravityX's Approach

Decomposition + MIP + NLP

- Run ACOPF with unit commitment fixed to previous operating point
- Set rolling horizon length and heuristically decide which contingency to include
- Run rolling horizon MIP
- Fix all unit commitment binaries
- Run rolling horizon NLP

Taking Advantage of Parallelism (access to 64 threads)

6 Parallel workers (10 threads each)

```
/* Worker 0: no mip, slack, reserve */
/* Worker 1: 1 mip, slack, reserve */
/* Worker 2: mip, no slack, no reserve */
/* Worker 3: mip, slack, reserve, 1 step  horizon */
/* Worker 4: mip, tuned */
/* Worker 5: mip, slack, reserve, LineSW or full horizon */
```

Taking Advantage of Parallelism (access to 64 threads)

6 Parallel workers (10 threads each)

Network Instance: C3S3N08316D2

Worker 0	Worker 1	Worker 2	Worker 3	Worker 4	Worker 5
$7,062.28M	$7,115.62M	$7,093.97M	$6,166.02M	$4,027.52M	FAILED

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/* Worker 0: no mip, slack, reserve */
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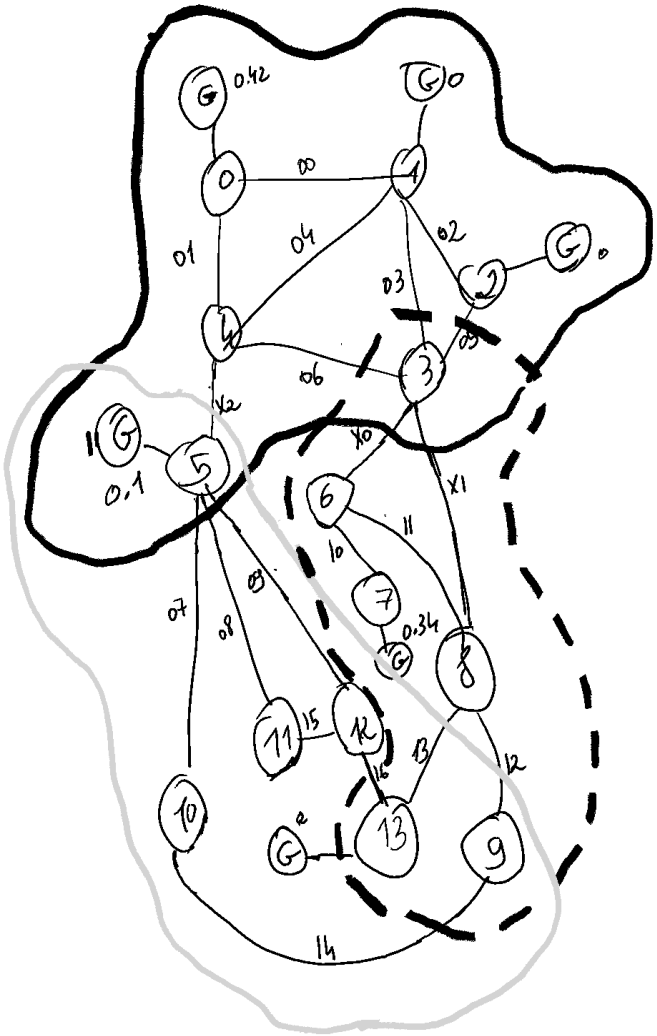
14 lines switched ON!

Network Instance: C3S4N00617D1

Worker 0	Worker 1	Worker 2	Worker 3	Worker 4	Worker 5
$44,511,677	$45,274,116	Time Out	$45,272,853	$45,274,116	$45,286,951

Things I started but did not have time to finish:

1) Spatial Decomposition



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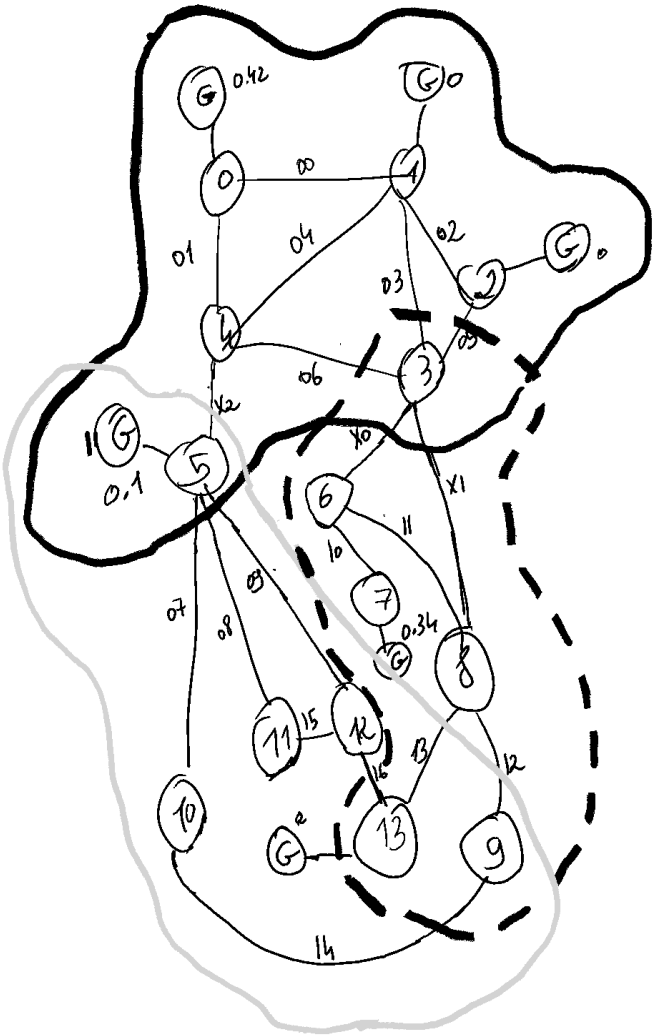
Things I started but did not have time to finish:

1) Spatial Decomposition

2) Dynamic Contingency Constraint Generation

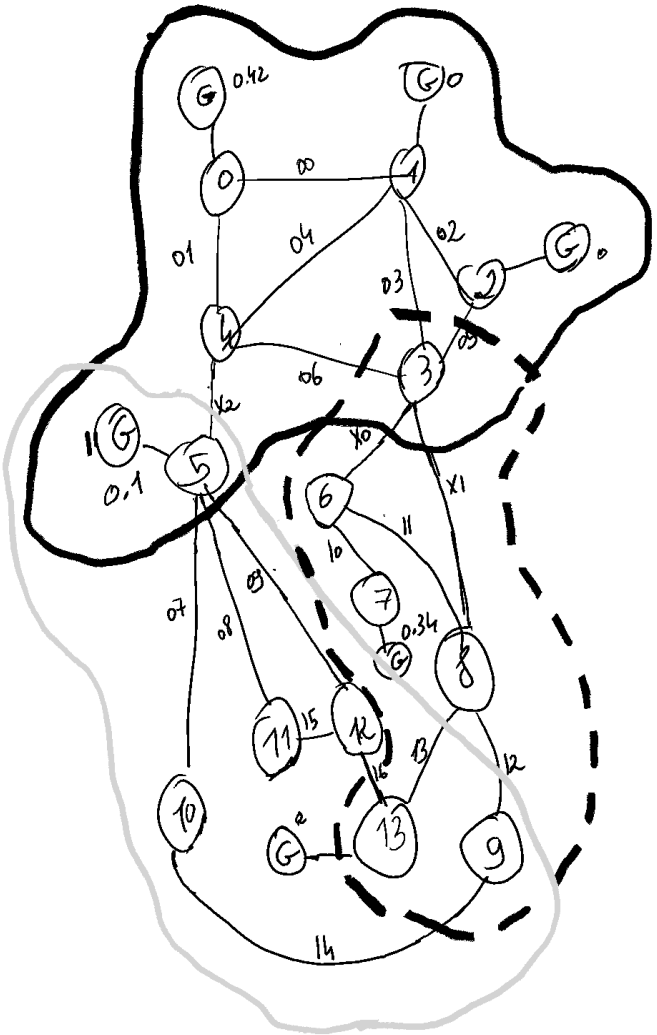


Things I started but did not have time to finish:

1) Spatial Decomposition

2) Dynamic Contingency Constraint Generation

3) Project the slack variables and use on/off constraints for line switching

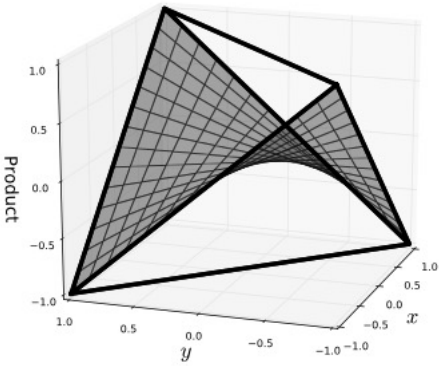


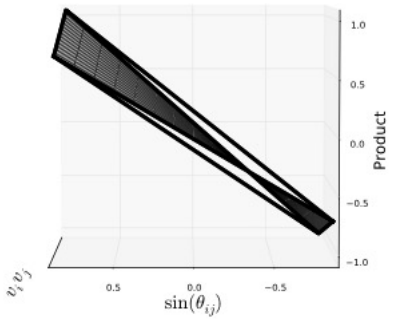
Things I tried that miserably failed:

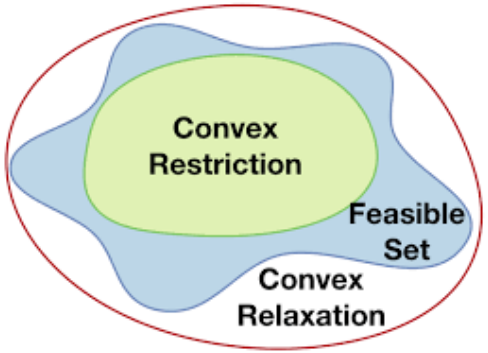
1) Conic Relaxations

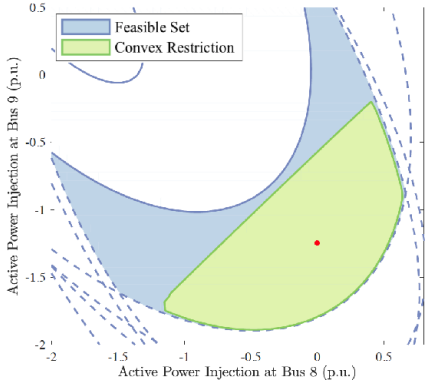
2) Convex Restrictions

3) Rounding Heuristics









D. Lee et al. "Convex Restriction of Power Flow Feasibility Sets," in *IEEE Transactions on Control of Networ Systems*, vol. 6, no. 3, pp. 1235-1245, Sept. 2019

Thanks!

”Competition is a lot like cod liver oil. First it makes you sick. Then it makes you better.” - *Unattributed*

“If you can't win, make the fellow ahead of you break the record.” - *EVAN ESAR*

“It is in vain for us to devise schemes by which competition can be put out of civilized life. Competition is the condition of life.” - *LYMAN ABBOTT*

“The ultimate victory in competition is derived from the inner satisfaction of knowing that you have done your best and that you have gotten the most out of what you had to give” - *Howard Cosell*