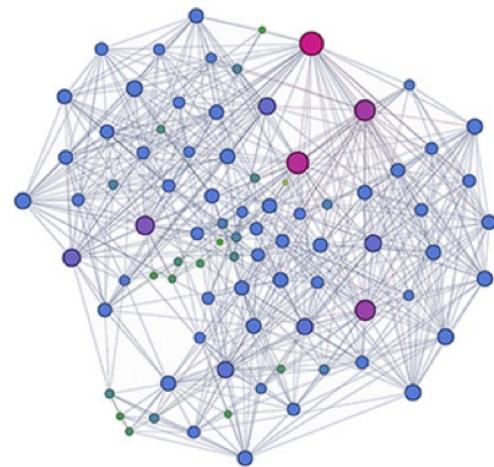
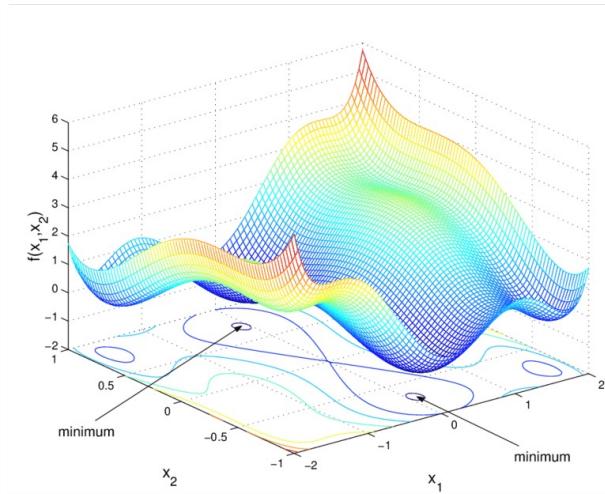


GravityX: The Last Challenge (?)

Hassan Hijazi

INFORMS Annual Meeting 2023



Challenge 3: The Hardest Challenge of them All



Main Challenges:

- Temporal Constraints (18 to 48 time-steps)
- 1e-8 Constraint Satisfaction (4 orders of magnitude drop!)
- Dense Reserve Constraints (thousands of nnz in one constraint)
- Different N-1 Post-Contingency Model

2019-2020



2020-2021



2021-2022

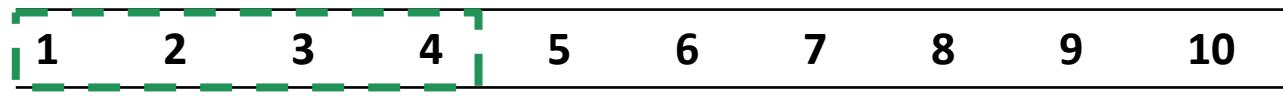


2022-2023



GravityX's Approach

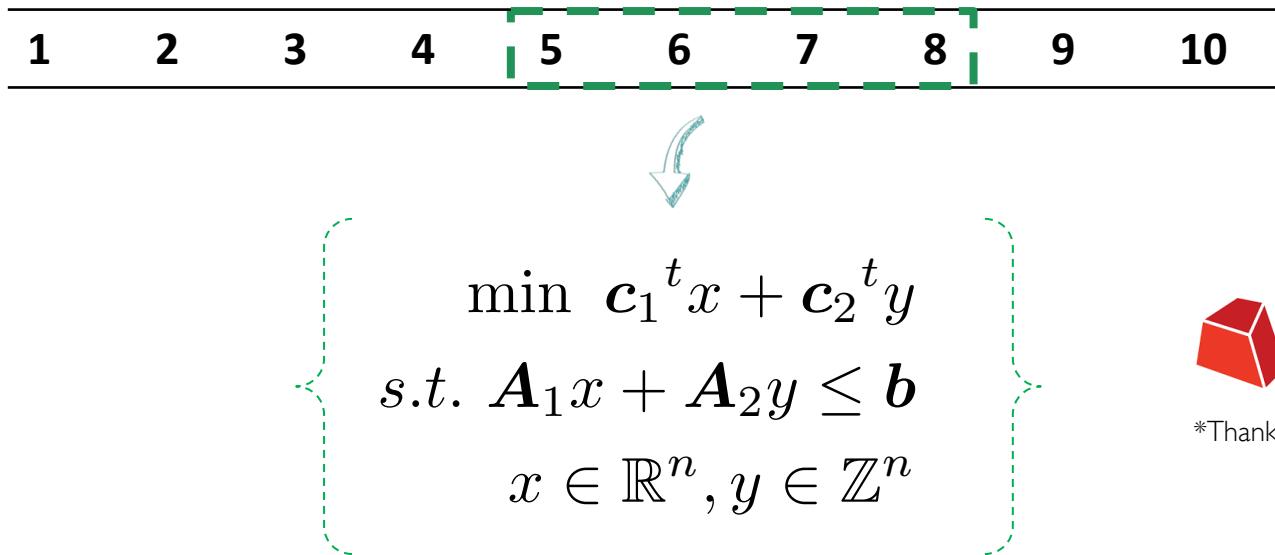
Decomposition + MIP + NLP



Rolling Horizon Time Decomposition

GravityX's Approach

Decomposition + MIP + NLP



*Thanks for the free license!

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

GravityX's Approach

Algorithm 2 MIP-NLP Decomposition with Backtracking

- 1: Fix UC binaries to the previous operating point solution.
 - 2: Solve resulting ACOPF and compute line losses.
 - 3: Fix active and reactive line losses using AC solution
 - 4: Decompose UC MIP & solve using rolling-horizon.
 - 5: **while** not fix point or time limit reached **do**
 - 6: Fix UC binaries to the previous MIP solution.
 - 7: Solve resulting ACOPF and compute line losses.
 - 8: Fix active and reactive line losses using AC solution
 - 9: Decompose UC MIP & solve using rolling-horizon.
 - 10: **if** infeasible MIP **then** backtrack the initial time step
 - 11: **end if**
 - 12: **end while**
 - 13: **while** not time limit reached **do**
 - 14: Fix UC binaries to the optimal MIP solution.
 - 15: Decompose NLP & solve using rolling-horizon.
 - 16: **if** infeasible NLP **then** backtrack the initial time step
 - 17: **end if**
 - 18: **end while**
-

Main Contributions

Valid Linear Constraints (Exact)

$$\begin{aligned} \mathbf{g}_e(p_e^{fr} - p_e^{to}) - \mathbf{b}_e(q_e^{fr} - q_e^{to}) &= \\ \mathbf{g}_e \left(\mathbf{g}_e + \mathbf{g}_e^{fr} \right) \frac{w_i}{\tau_e^2} - \mathbf{g}_e \left(\mathbf{g}_e + \mathbf{g}_e^{to} \right) w_j + \\ \mathbf{b}_e \left(\mathbf{b}_e + \mathbf{b}_e^{fr} + \frac{\mathbf{b}_e^{ch}}{2} \right) \frac{w_i}{\tau_e^2} - \mathbf{b}_e \left(\mathbf{b}_e + \mathbf{b}_e^{to} + \frac{\mathbf{b}_e^{ch}}{2} \right) w_j \end{aligned}$$

Main Contributions

Transformer Power Flow Reformulation

$$p_e^{fr} = \left(\mathbf{g}_e + \mathbf{g}_e^{fr} \right) \frac{v_i^2}{\tau_e^2} - \frac{v_i v_j}{\tau_e} (\mathbf{g}_e \cos(\theta_i - \theta_j - \theta_e) + \mathbf{b}_e \sin(\theta_i - \theta_j - \theta_e))$$

$$p_e^{to} = \left(\mathbf{g}_e + \mathbf{g}_e^{to} \right) v_j^2 - \frac{v_i v_j}{\tau_e} (\mathbf{g}_e \cos(\theta_j - \theta_i + \theta_e) + \mathbf{b}_e \sin(\theta_j - \theta_i + \theta_e))$$

$$q_e^{fr} = - \left(\mathbf{b}_e + \mathbf{b}_e^{fr} + \frac{\mathbf{b}_e^{ch}}{2} \right) \frac{v_i^2}{\tau_e^2} + \frac{v_i v_j}{\tau_e} (\mathbf{b}_e \cos(\theta_i - \theta_j - \theta_e) - \mathbf{g}_e \sin(\theta_i - \theta_j - \theta_e))$$

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Main Contributions

Transformer Power Flow Reformulation

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$$\tau'_e \tau_e^2 = 1$$



$$p_e^{fr} = \left(\mathbf{g}_e + \mathbf{g}_e^{fr} \right) v_i^2 \tau'_e - v_i v_j \tau'_e \tau_e (\mathbf{g}_e \cos(\theta_i - \theta_j - \theta_e) + \mathbf{b}_e \sin(\theta_i - \theta_j - \theta_e))$$

$$p_e^{to} = \left(\mathbf{g}_e + \mathbf{g}_e^{to} \right) v_j^2 - v_i v_j \tau'_e \tau_e (\mathbf{g}_e \cos(\theta_j - \theta_i + \theta_e) + \mathbf{b}_e \sin(\theta_j - \theta_i + \theta_e))$$

$$q_e^{fr} = - \left(\mathbf{b}_e + \mathbf{b}_e^{fr} + \frac{\mathbf{b}_e^{ch}}{2} \right) v_i^2 \tau'_e + v_i v_j \tau'_e \tau_e (\mathbf{b}_e \cos(\theta_i - \theta_j - \theta_e) - \mathbf{g}_e \sin(\theta_i - \theta_j - \theta_e))$$

$$q_e^{to} = - \left(\mathbf{b}_e + \mathbf{b}_e^{to} + \frac{\mathbf{b}_e^{ch}}{2} \right) v_j^2 + v_i v_j \tau'_e \tau_e (\mathbf{b}_e \cos(\theta_j - \theta_i + \theta_e) - \mathbf{g}_e \sin(\theta_j - \theta_i + \theta_e))$$

NLP Reformulation

Does it make a difference?

Instance	Scenario	Original	Reformulation
C3E3N01576D1	scenario_027	14 sec	8 sec
C3E3N04224D1	scenario_131	14 sec	10 sec
C3E3N06049D1	scenario_031	20 sec	14 sec
C3E3N06717D1	scenario_031	>145 sec	26 sec
C3E3N08316D1	scenario_001	>145 sec	33 sec

Main Contributions

Linear AC Losses

$$p_{eij} + p_{eji} = pl_e$$

$$q_{eij} + q_{eji} = ql_e$$

Algorithm 2 MIP-NLP Decomposition with Backtracking

```
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13: while not time limit reached do  
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15:   Decompose NLP & solve using rolling-horizon.  
16:   if infeasible NLP then backtrack the initial time step  
17:   end if  
18: end while
```

Linear AC Losses

Does it make a difference?

Instance	Scenario	Lossless-NF	Lossless-DC	Lossy-DC	LAC-Losses
C3E3N01576D1	scenario_027	96,227,154	98,057,070	97,780,021	98,298,517
C3E3N04224D1	scenario_131	91,168,493	91,141,339	91,142,009	91,169,130
C3E3N06049D1	scenario_031	104,152,318	104,095,683	104,093,510	104,135,871
C3E3N06717D1	scenario_031	Fail	-889,688,701	136,130,464	136,589,493
C3E3N08316D1	scenario_001	1,158,730,927	Fail	Fail	1,180,957,975

Event 4 Results

Team	nth best score count					
	1	2	3	4	5	1-5
ARPA-e Benchmark	0	12	27	58	114	211
Artelys_Columbia	29	24	25	43	47	168
Electric-Stampede	0	2	7	7	61	77
Gatorgar	3	8	7	8	2	28
GOT-BSI-OPF	47	137	150	99	81	514
GravityX	105	125	142	134	60	566
LLGoMax	3	20	37	25	57	142
Occams razor	4	21	48	88	93	254
quasiGrad	0	2	4	18	41	65
The Blackouts	56	20	12	19	32	139
TIM-GO	89	120	129	134	70	542
YongOptimization	331	176	79	34	8	628
total	667	667	667	667	666	3334

Thanks!

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

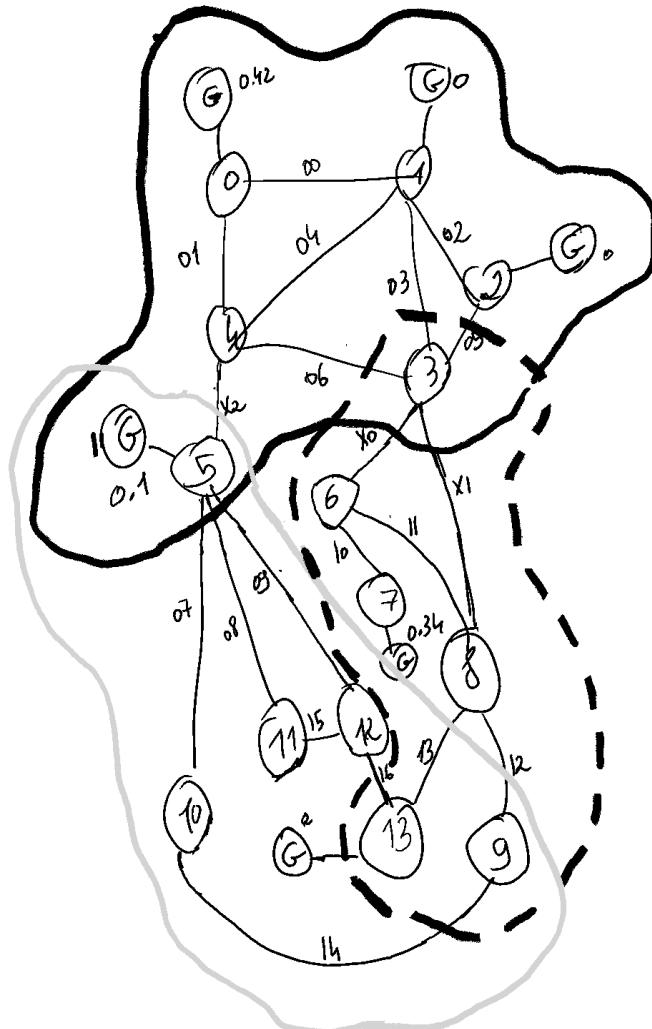
"If you can't win, make the fellow ahead of you break the record." - *EVAN ESAR*

"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*

Things I started but did not have time to finish:

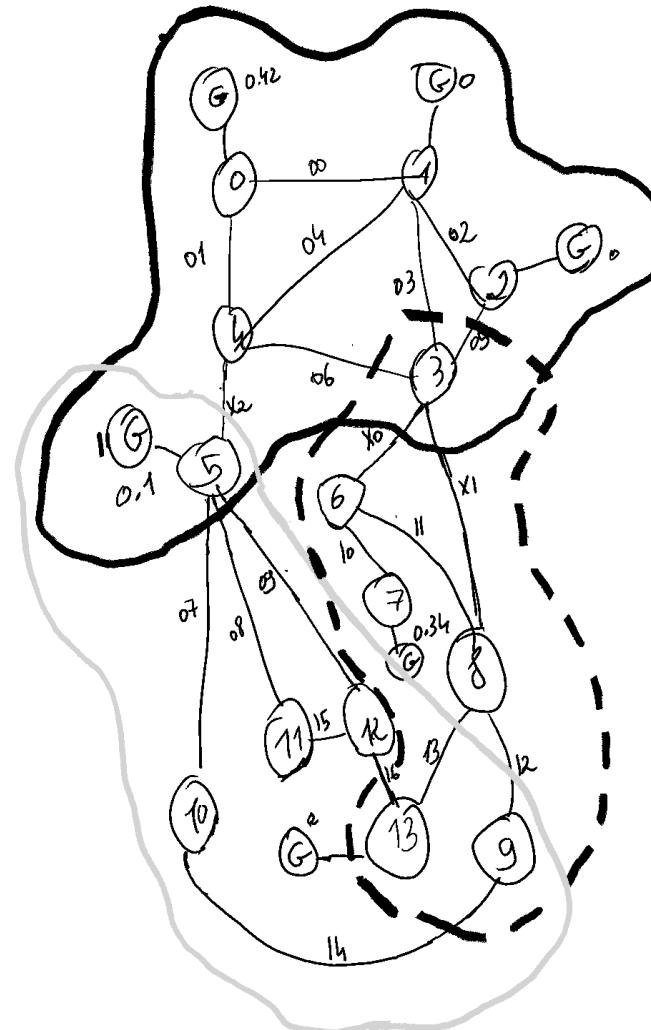
I) Spatial Decomposition



C3SON00014

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

