SAND2017-0426C

Power Grid Interdiction Using Pyomo

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January 14, 2017

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Overview

- Research Objective: Scaling and adapting power grid interdiction algorithms to work with a real power grid.
- Teamed with a real utility company.
- Utilized Pyomo & Python to create meaningful results.

Exact Interdiction Model

- As a baseline, used model from "A Mixed-Integer LP Procedure for the Analysis of Electric Grid Security Under Disruptive Threat" by Motto, Arroyo, and Galiana.

$$\max_{\substack{\delta^{Gen},\delta^{Line},\delta^{Bus},\\ \delta^{Sub},b,v}} \gamma(\delta^{Gen},\delta^{Line},\delta^{Bus},\delta^{Sub},b,v) \quad (1)$$

subject to

$$\sum_g M_g^{Gen}\delta_g^{Gen} + \sum_\ell M_\ell^{Line}\delta_\ell^{Line} + \sum_i M_i^{Bus}\delta_i^{Bus} + \sum_s M_s^{Sub}\delta_s^{Sub} \le M \quad (2)$$

$$v_\ell = (1-\delta_\ell^{Line})(1-\delta_{o(\ell)}^{Bus})(1-\delta_{d(\ell)}^{Bus}) \prod_{s|\ell\in L_s^{Sub}} (1-\delta_s^{Sub}) \prod_{\ell'|\ell'\in L_\ell^{Par}} (1-\delta_{\ell'}^{Line}), \forall \ell \quad (3a)$$

$$v_\ell \in \{0,1\},\ \forall \ell \quad (3b)$$

$$b_g = (1-\delta_{i(g)}^{Bus})(1-\delta_g^{Gen}),\ \forall g \quad (4a)$$

$$b_g \in \{0,1\},\ \forall g \quad (4b)$$

$$\delta_g^{Gen} \in \{0,1\},\ \forall g \quad (5)$$

$$\delta_\ell^{Line} \in \{0,1\},\ \forall \ell \quad (6)$$

$$\delta_i^{Bus} \in \{0,1\},\ \forall i \quad (7)$$

$$\delta_s^{Sub} \in \{0,1\},\ \forall s \in S \quad (8)$$

$$\gamma(\delta^{Gen},\delta^{Line},\delta^{Bus},\delta^{Sub},b,v) = \min_{P^{Gen},P^{Line},S,\theta} \left(\sum_g h_g P_g^{Gen} + \sum_c f_c S_c\right) \quad (9)$$

subject to

$$P_\ell^{Line} = B_\ell v_\ell(\theta_{o(\ell)} - \theta_{d(\ell)}),\ \forall \ell \quad (10)$$

$$\sum_{g\in G_i} P_g^{Gen} + \sum_{c\in C_i} S_c - \sum_{\ell|o(\ell)=i} P_\ell^{Line} + \sum_{\ell|d(\ell)=i} P_\ell^{Line} = \sum_{c\in C_i} d_c,\ \forall i \quad (11)$$

$$-\overline{P}_\ell^{Line} \le P_\ell^{Line} \le \overline{P}_\ell^{Line},\ \forall \ell \quad (12)$$

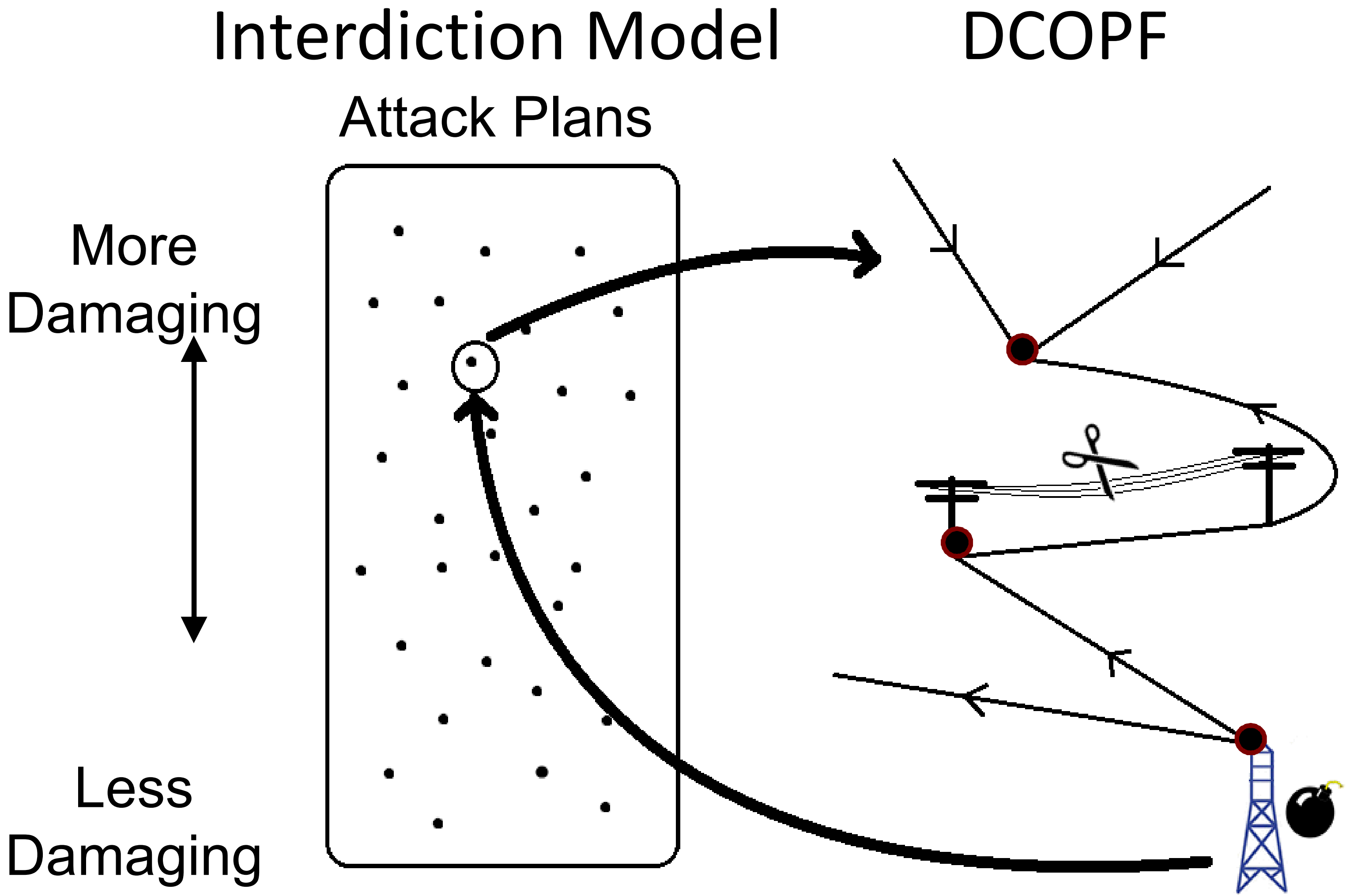
$$-\overline{\theta} \le \theta_i \le \overline{\theta},\ \forall i \quad (13)$$

$$0 \le P_g^{Gen} \le b_g \overline{P}_g^{Gen},\ \forall g \quad (14)$$

$$0 \le S_c \le d_c,\ \forall c. \quad (15)$$

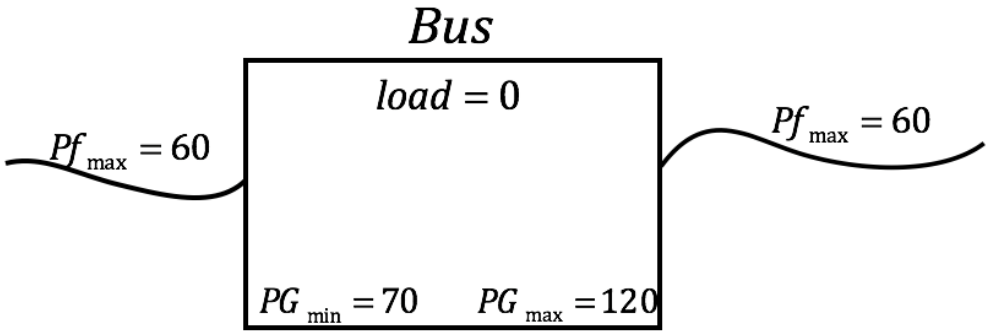
Interdiction Heuristic

- "Analysis of Electric Grid Security Under Terrorist Threat", Salmeron, Wood, Baldick.

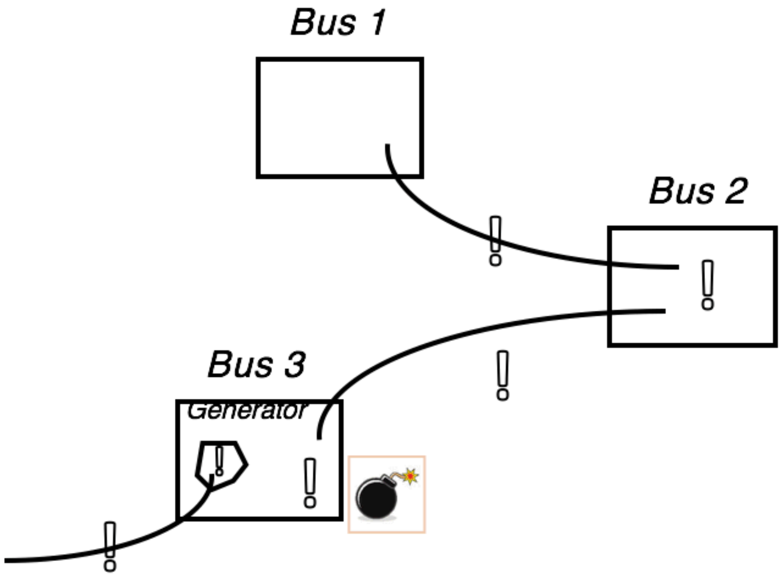


Model Adaptations

- Numerically problematic susceptance values.
- Nonnegative generator dispatch lower bound



- Existence of contingencies



Development through Pyomo

- Step 1: Baseline model and heuristic implementation
  - Need trustworthy models and heuristic implementation before adaptations can be made.
  - Compare results to results in papers to ensure heuristic was interpreted correctly.

- Step 2: Connect exact model and heuristic to real power grid data and watch both of them crash

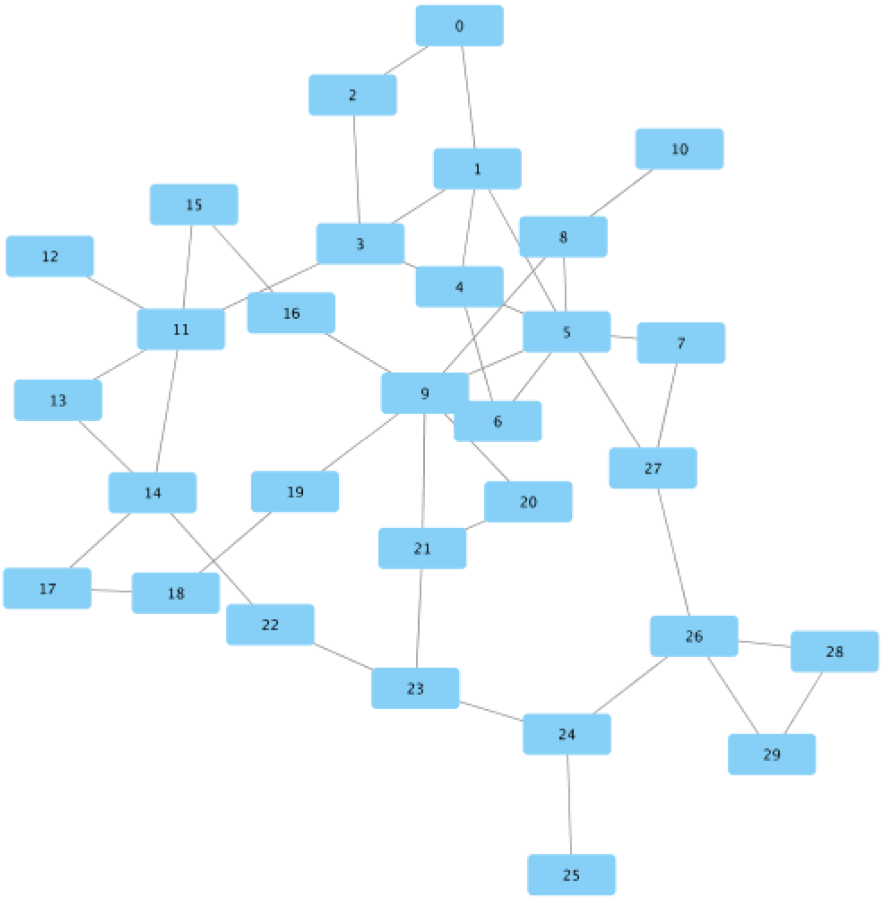
Experiment Development Architecture

```
Interdiction
├─ common
│  ├─ models
│  │  ├─ test models
│  │  └─ real models
│  ├─ data
│  │  ├─ grid data
│  │  └─ contingency data
│  ├─ utils
│  │  ├─ heuristics
│  │  ├─ instantiate
│  │  ├─ model modification
│  │  ├─ interdiction
│  │  └─ data parse
│  └─ results
└─ experiments
   ├─ exact test
   ├─ heuristic test
   ├─ exact utility base experiment
   ├─ heuristic utility base experiment
   ├─ heuristic utility hardening experiment
   └─ exact utility hardening experiment
```

Troubleshooting

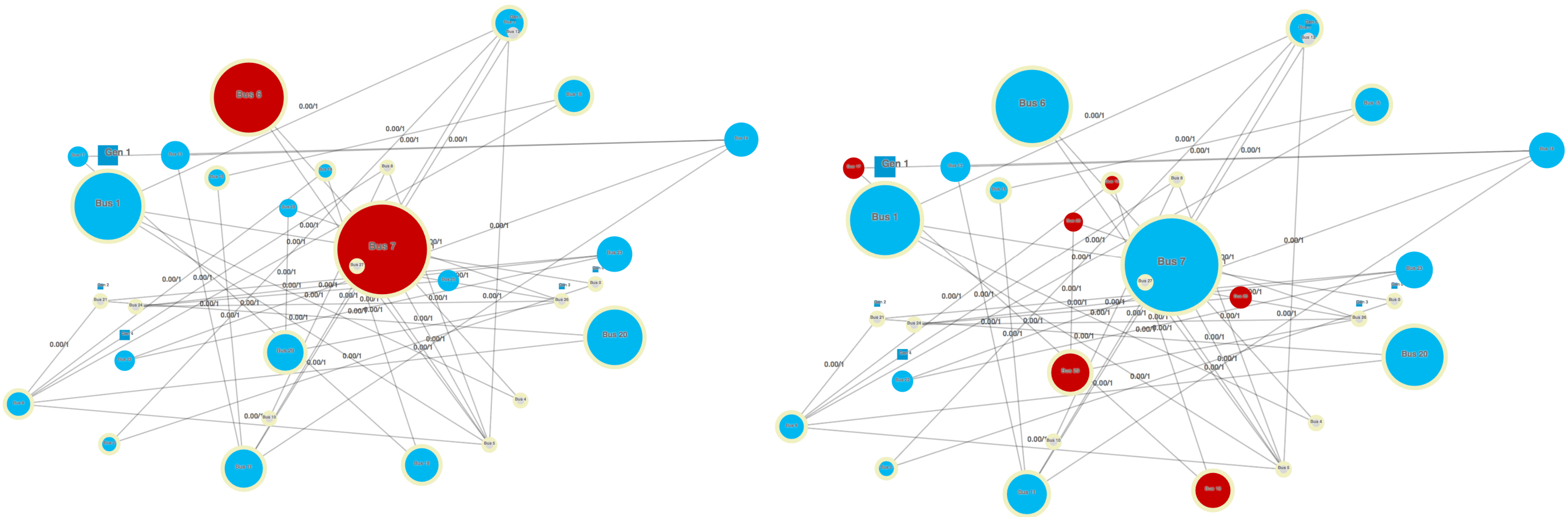
- Use NetworkX to generate a graphml file in order to see grid networks.

- Graph visual together with model inspection before and after solve is effective for resolving issues.



Hardening

- After hardening, components cost more resources to attack, so attacker will make different choices.



Load Shed

Load

Results

- Generate results data file which includes interdiction results as well ad DCOPF data. Use R to plot results on a map for presentation to customer.

- Customer can identify components
  - Make sense of our results
  - Identify any issues

- Reiterate experiments to resolve issues.

Future Work

- Contingencies are even more complicated than what we expected.
- Work with full power grid rather than reduced version.
- Further develop component hardening technique.

Thank you!

Any questions?