Security Gaps Arising Due to Large Infrastructures Coupled with Energy Delivery Sub-systems

Gas and Electric Grid Unit Commitment with Coordinated N-1 Generator Contingency

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GOALS

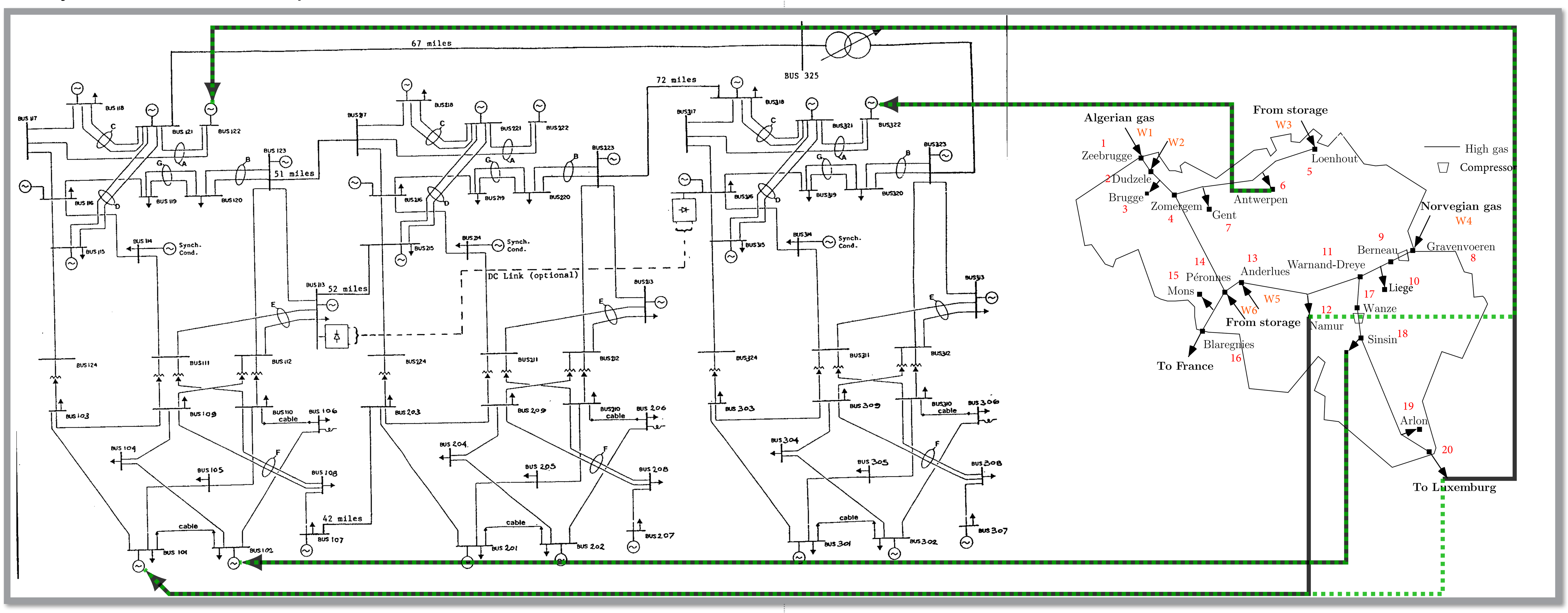
- Operate both the gas and electric systems optimally, while respecting N-1 generator contingency requirements

FUNDAMENTAL QUESTIONS/CHALLENGES

- Critical infrastructures like the gas and electric systems are coupled.
- How does the operation technology (OT) of one affect the other?
- Could security breaches in one "spill-over" to the other?

EXPERIMENT SETUP

- Gas Grid: modified Belgium high-calorific gas grid†
- Electric Grid: RTS-96 test case with 73 buses‡
- The following generators are supplied by nodes in the gas grid:
  - *Coordinated UC (black):* Node 12: G1 and G2, Node 18: G5 and G6. Node 20: G25 and G26, Node 6: G93, G94, and G95
  - *Coordinated UC with Contingencies (green):* Node 20: G1 and G2, Node 18: G5 and G6. Node 12: G25, G26 and G27, Node 6: G93, G94, and G95

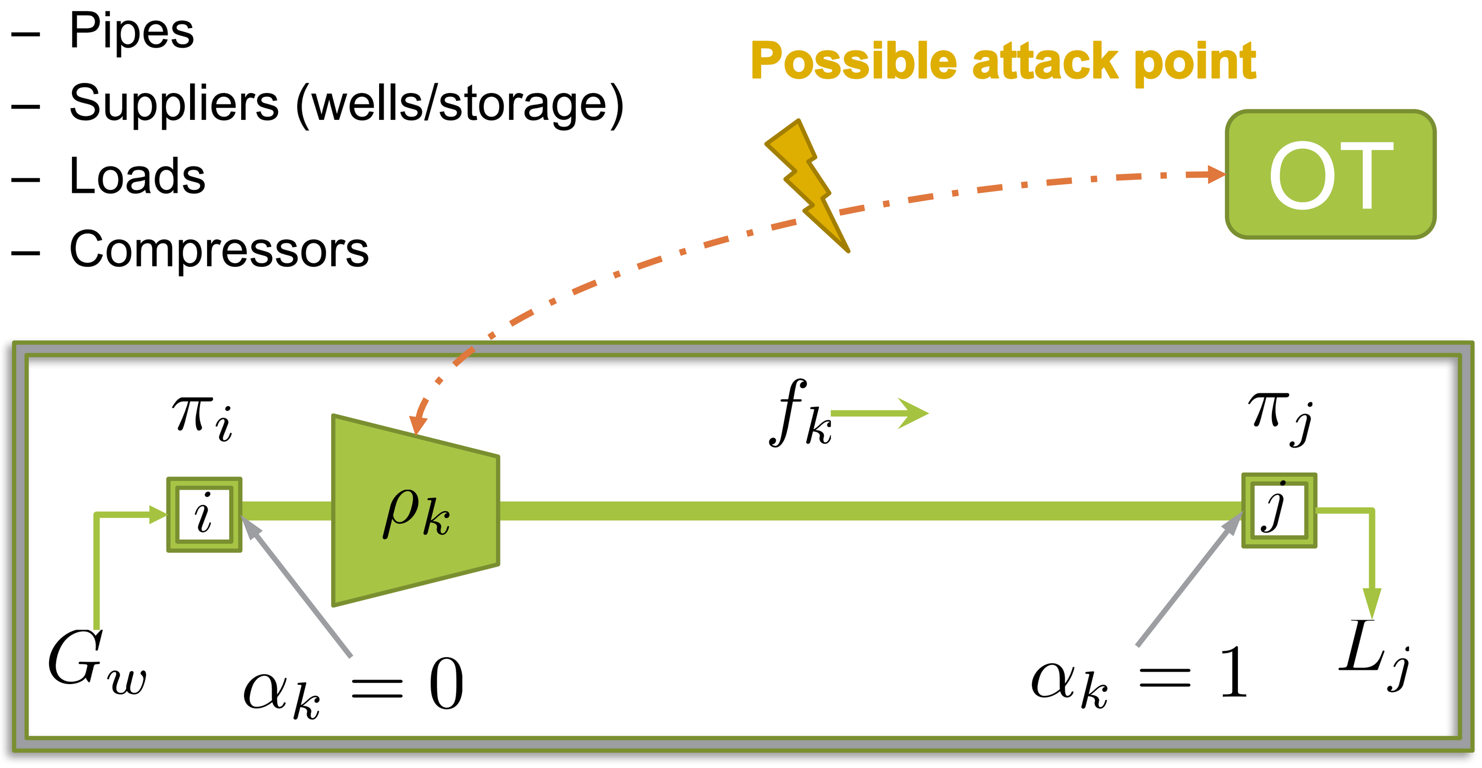


†D. De Wolf and Y. Smeers, "The gas transmission problem solved by an extension of the simplex algorithm," *Management Science*, vol. 46, no. 11, pp. 1454-1465, 2000.

‡R. T. Force, "The IEEE reliability test system-1996," *IEEE Trans. Power Sys.* Vol. 14, no. 3, pp. 1010-1020, 1999.

GAS GRID MODEL

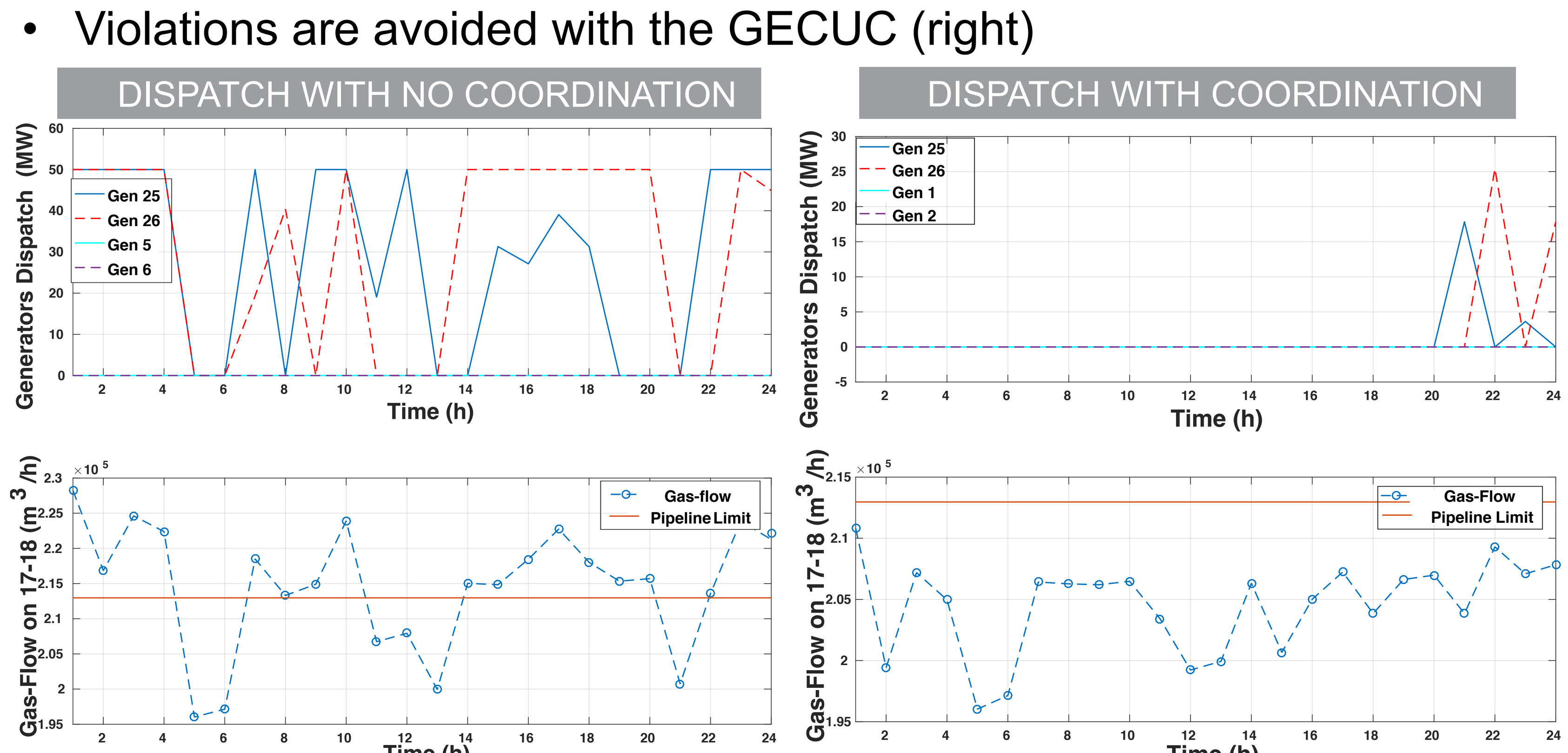
- The Gas grid is modeled with the following elements:
  - Pipes
  - Suppliers (wells/storage)
  - Loads
  - Compressors



$$\rho_k = \left(\frac{\pi_j^2 + (1-\alpha_k) h_k f_k^2 \cdot \mathrm{sgn}(f_k)}{\pi_i^2 - \alpha_k h_k f_k^2 \cdot \mathrm{sgn}(f_k)} \right)^{\mathrm{sgn}(f_k)}$$

RESULTS: NO COORDINATION VS. COORDINATION

- Solving the gas and electric systems separately (left) pressure violations occur.
  - This has also been shown in other works§
- Violations are avoided with the GECUC (right)



§A. Zlotnik, L. Roald, S. Backhaus, M. Chertkov, and G. Andersson, "Coordinated scheduling for interdependent electric power and natural gas infrastructures," IEEE TPS, 2016.

COORDINATED GAS & ELECTRIC UNIT COMMITMENT

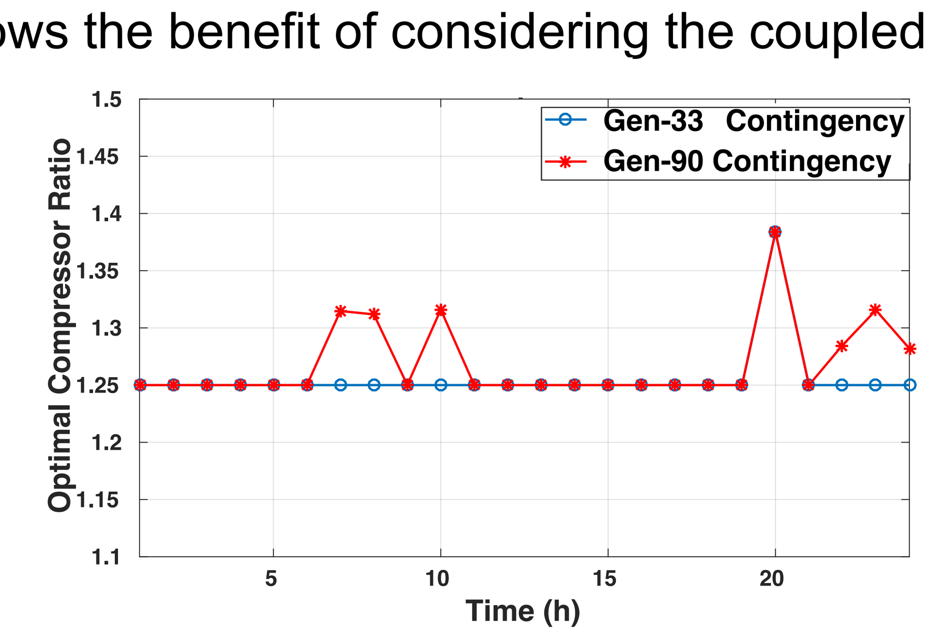
- The Gas and Electric Coordinated Unit Commitment (GECUC) is formulated by combining the two separate problems along with a coupling constraint.

$$\begin{aligned}
\textbf{Minimize} \quad & \sum_t c(G_w) + c(P_g) \\
\textbf{Subject to} \quad & \text{Gas Constraints} \\
& \text{Electric Constraints} \\
& \quad \text{(including commitment and reserves)} \\
& \sum_{w \in \mathcal{W}(i)} G_w(t) + \sum_{k \in \mathcal{T}_i} f_k(t) \\
& - \sum_{k \in \mathcal{F}_i} f_k(t) - \sum_{g \in \mathcal{S}(i)} P_g(t) \eta_g = L_i(t) \quad \forall t, i
\end{aligned}$$

- Coupling constraint converts electric power production at a gas-fired power plant to a load on the gas grid.
- the relationship between f_k and ρ_k is linearized in the gas constraints by introducing binary variables that "select" constraints based on the direction of flow.

RESULTS: GENERATOR CONTINGENCY

- MILP formulation enables easy integration with N-1 contingency formulations.
- Compressor ratio is allowed to increase.
  - The fact that it does shows the benefit of considering the coupled problem
  - Certain cases could also cause infeasibility



FUTURE EFFORTS

- Example case demonstrating contingency infeasibility if compressors are not handled correctly.
- Develop ways to decompose the optimization problem.

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