Interdependence between Electric Power and Natural Gas Networks

Gas Available Transfer Capability, Loadability, and A Fast Computational Tool for Feasibility Screening

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Electricity generation will be more dependent on natural gas in the near future.

How to ensure security and resilience of interdependent networks?
Couplings between Gas and Electricity Networks

Power Grid Reliance on Gas
• Gas-fired Power Plant

Gas System Reliance on Electricity
• Communication
• Compressor
  1, gas fueled
  2, electric-driven

Wellhead Processors and Extraction Motors
  1, diesel (offshore drilling)
  2, gas fueled
  3, electric-driven

2018 US ELECTRICITY GENERATION ALL SECTORS

Assume no gas production, full load demand, 50% compressors are gas fueled and evenly distributed, no LNG import, and electric utilities using gas, the natural gas system can sustain between 13 and 67 days [1].

Currently, natural gas networks are very resilient to the local, short term power outages!

Challenges of Interconnected Systems

Reliability and resilience of natural gas systems are primarily from:

- Slow dynamics of natural gas;
- Distributed large LNG storages;
- Self-sustainable designs of the critical components;
- Very restricted contracts on gas withdrawal rate.

Challenges:

- Deep interdependence increases risks of cascading failures.
- Local electricity failure can migrate to the natural gas network.
- Do not have an appropriate model to mimic this loop in different time scales.
- Coupling complex systems makes it more difficult.
- Disturbances from flexible contracts can jeopardize pipeline operations.
- Migrate disturbance from electric power grid to the natural gas network.
- Need to consider gas security as well.

More electric-driven components:
1. Cheaper to install and maintain
2. Emission requirements

More flexible contracts:
1. Gas sector in power generation becomes a major gas load
2. Power grids are seeking for more flexible contracts
Preserving Reliability and Resilience under Flexible Contracts

A Possible Solution: Co-optimization formulation
- Combine natural gas model and electric power model together
- Chance constrained formulation
- Security constrained formulation
- Differential model, etc

Fundamental Challenges:
- No authority can co-optimize and coordinate both systems
  1. Who will do the co-optimization? How to weight the costs for both systems?
  2. Who is going to coordinate both systems? etc
- Largely increase problem complexity
  1. Power system is complex. Gas system is complex. Now put them together…
  2. Compromise accuracy for speed? Can you trust these models in extreme cases?
- Different time scales
Preserving Reliability and Resilience under Flexible Contracts

Another Possible Solution: Not combine together, but exchange critical information between two systems.

- From power grid side, how much extra gas flow can be withdrawn from some spot to a designated gas-fired power plant without violating gas network constraints?

Gas Available Transfer Capability

If more than one gas-fired power plant... High dimensional available transfer capability? Not the direct product of each individual one.

Gas Loadability Region
Gas Loadability Region

The set of gas load profile that admits feasible pressure solutions within required engineering limits.

Weymouth model

Mass flow conservation

Ideal compressors

Pressure limits

Under the following conditions, the gas loadability region is convex \([2]\):

1. Tree structure network;
2. Fixed branch flow direction;
3. Either pressure upper bounds are identical or lower bounds are identical.

\[ \lambda_{i,j} (\pi_i^2 - \pi_j^2) = \psi_{i,j} |\psi_{i,j}| \]

\[ \sum_{i \rightarrow k} \psi_{i,k} + \phi_{k,in} = \sum_{j \rightarrow k} \psi_{k,j} - \phi_{k,out} \]

\[ P_j = K_{i,j} P_i \]

\[ K_{i,j} \geq 1 \]

\[ -K_{i,j} \geq -K_{i,j,\text{max}} \]

\[ P \geq P_{\text{min}} \]

\[ -P \geq -P_{\text{max}} \]

Estimating Convex Loadability Region

Fundamental idea: Using a polytope to approximate a convex set from inside

Design: Monotone inner polytope sequence

Advantages:

1. Polytopes are easy to construct → Cheap construction
2. Sequence approaching real convex set → Controlled conservativeness
3. Polytopes are easy to check → Cheap feasibility verification

Converting nonlinear-defined convex set into a simpler linear inequality defined set!
Numerical Example

Revised Belgium gas network \(^{[3]}\)

The 3\(^{rd}\) polytope occupies 96.4\% of the real loadability region.

Numerical Example

4-D illustration

The 3rd polytope occupies 99% of the real loadability region.
Summary

• Natural gas network is resilient to local, short term power outages.
• Interdependence of gas and electricity systems will become deeper in the near future with the increase of electric-driven apparatus in the gas system and more flexible contracts.
• To prevent cascading failures for both interconnected systems, critical information should be exchanged.
• Gas available transfer capability and loadability region provide important limits for reliable operations of gas system and power system scheduling.
• Under certain conditions the gas loadability region is convex, which can be estimated by polytopes.
• A special sequence of monotone inner polytope can be constructed with the advantages of fast computation and controlled conservativeness.
Thank you!

Questions?
Natural Gas Network Operations and Markets

Wellhead
- Processor

Production
- Compressor
- Storage

Transmission
- Regulator

Distribution
- Customer

Pipeline Company
- Gas Utility, LDC

Primary Market
- Long term contract, yrs, regulated rate

Secondary Market
- Short term contract, hrs to 1 yr, interruptible

Spot Market
- Short term contract, interruptible, deliver to specific node

Independent marketer

Gas fired power plant