Technical University of Denmark

Stochastic Integrated Market for Electric Power and Natural Gas Systems

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Introduction

Decision making models in energy markets → Uncertainty introduced by renewable energy sources (RES) → Optimization models that account for uncertainty

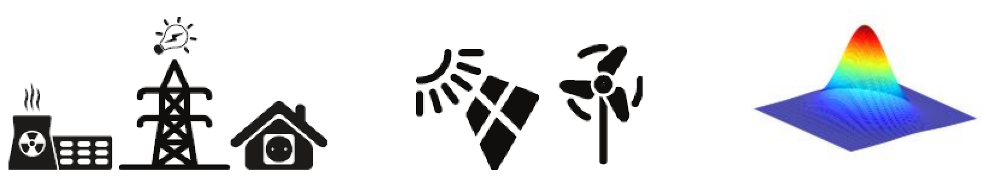
Market clearing based on stochastic programming → Capture uncertainty in a flexible and intuitive manner → Stochastic market clearing with uncertain wind production

Energy System Integration

Aim

- Efficiently align existing synergies towards the optimal operation of energy systems.
- Propose **new market structures** to provide adequate incentives to all market participants.
- Manage high **uncertainty** on both supply and demand sides.

Decision-making in energy markets + Sources of uncertainty in energy systems → Optimization under uncertainty

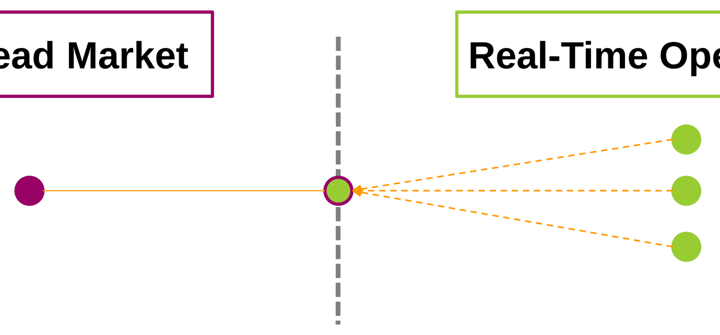


Electricity and Natural Gas

Strong link between the electricity and natural gas systems is increased by integration of **renewable energy sources** and the need for flexible reserves provided by GFPPs.

Market Clearing Approaches

Day-Ahead Market | Real-Time Operation

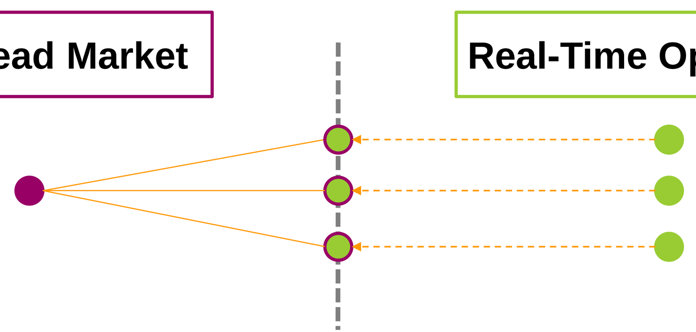


Conventional market clearing

Sequential clearing of two trading floors:

1) Day-ahead market is cleared based on deterministic description of uncertain wind power production.
2) A balancing market is cleared for real-time operation.

Day-Ahead Market | Real-Time Operation



Stochastic market clearing

Co-optimization of two trading floors:

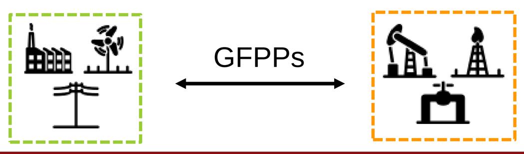
1) Day-ahead dispatch is determined by co-optimizing day-ahead and real-time dispatch, where wind power uncertainty is probabilistically described.
2) A balancing market is cleared for real-time operation.

GFPPs: Gas-fired power plants
NG: Natural gas
LMP: Locational marginal price

Electricity and Natural Gas Markets

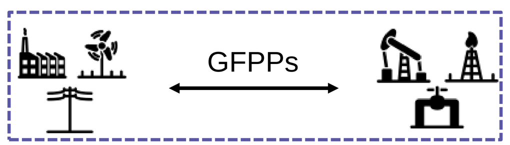
Decoupled Approach

1) Economic dispatch of electricity system is solved and the NG consumption of GFPPs in determined.
2) Economic dispatch of natural gas system is solved.



Integrated Approach

Simultaneously solve the economic dispatch of electricity and natural gas systems.



Optimization Models

The following models are used to determine the day-ahead dispatch of the electricity and natural gas systems.

Conventional – Decoupled

Minimize
Day-ahead electricity cost.

Subject to
- Day-ahead operating constraints of electricity system.
- Wind power is constrained by its expected value.

GFPPs NG consumption is determined.

Minimize
Day-ahead natural gas cost.

Subject to
- Day-ahead operating constraints of natural gas system.

Conventional – Integrated

Minimize
Day-ahead electricity and natural gas cost.

Subject to
- Day-ahead operating constraints of electricity and natural gas systems.
- Wind power is constrained by its expected value.

Stochastic – Integrated

Minimize
Day-ahead electricity and natural gas cost + expected electricity and natural gas balancing cost.

Subject to
- Day-ahead operating constraints of electricity and natural gas systems.
- Real-time operating constraints of electricity and natural gas systems.
- Wind power uncertainty is characterized by wind power scenarios.

The following model represents real-time operation. It is solved for a specific realization of wind power production.

Balancing

Minimize
Balancing electricity and natural gas cost.

Subject to
- Real-time operating constraints of electricity and natural gas systems.
- Wind power production is considered known.

Model details

1) The optimization models recast as MILP problems.
2) Balancing actions are provided only by GFPPs.
3) Power flow is modelled by DC approximation.
4) A Taylor series expansion is used to linearize the constraints related to the natural gas network.
5) A dynamic gas system with line pack is considered.

Application Results

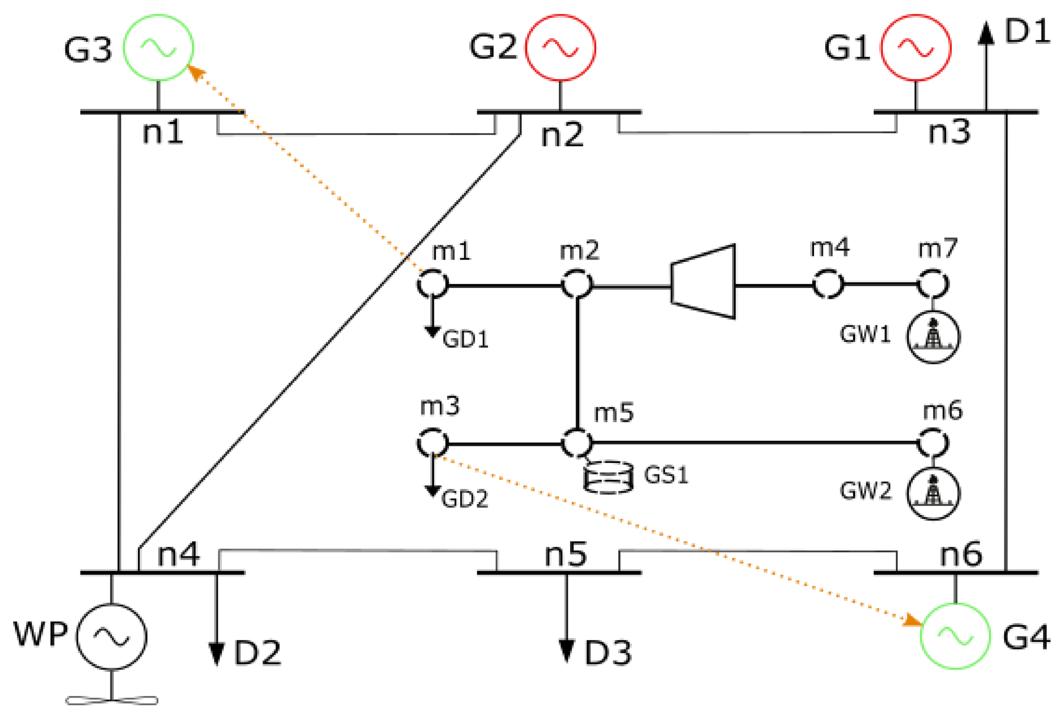


Fig. 1: Power and natural gas systems.

	P_{max} (MW)	$R^{(+/-)}$ (MW)	η (km³/MW)	C ($/MWh)
G1	100	0	-	20
G2	80	0	-	35
G3	60	60	0.205	-
G4	60	60	0.264	-
WP	200	-	-	0
	G_{max} (km³)	Initial storage level (km³)	Max in/outflow rate (km³/h)	C ($/km³)
GW1	150	-	-	184
GW2	170	-	-	110
GS1	150	75	50	147
Max Electricity Load	280 MW	Max NG Load		192 km³

Table 1: Technical and economic data of generating units, natural gas suppliers and natural gas storage unit.

Solution procedure

1) Day-ahead dispatch of power and natural gas systems is determined. Models **Conv-Dec, Conv-Int** and **Stoch-Int** are solved and 10 wind power scenarios are given as input.
2) In **Conv-Dec**, we introduce parameter k that helps us define the electricity marginal cost of GFPPs ($C = k \cdot LMP_{gas} \cdot \eta$). The LMP_{gas} is determined from **Conv-Int** model.
3) Given the day-ahead dispatch from (1), **balancing** model is evaluated for 30 different wind power realizations to determine the total operating cost.

Optimization model	Total cost ($)	Relative to Stoch-Int (%)
Stoch-Int	558 726	-
Conv-Int	588 836	5.38
Conv-Dec (k=1)	588 836	5.38
Conv-Dec (k=1.1)	589 292	5.47
Conv-Dec (k=0.9)	591 815	5.92

Table 2: Total operating cost.

Conclusions and Future Plans

- Integrating the operation of power and natural gas systems under stochastic market clearing results in a significant reduction of daily operating cost.
- The case of k=1 reflects the case when GFPPs have perfectly foreseen the ideal natural gas price (i.e., the one stemming from Conv-Int model).
- It is noticed that the total operating cost further increases in the cases of k≠1.
- In future work, the introduction of CHP plants to cover heat demand will be examined, as well as power-to-gas technology.

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