Locational-based Coupling of Electricity Markets:
Benefits from Coordinating Unit Commitment & Balancing Markets

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Overview

1. **What** are we estimating?
2. **How**?
   a) Modelling framework
   b) Numerical application
3. What are the **results** in a “base case”?
4. How do these results depend on various parameters (**sensitivity**)?
5. What can we **conclude**?
1. What are we estimating?

Potential Benefits of LMP:

- Short-run improvements
  - within-country dispatch
  - international dispatch/trade
  - unit commitment
  - demand response
  - avoiding inc-dec-games

- Long-run improvements
  - siting of investment
  - mix of investment
  - less transmission investment needed

This study (in a simple network + sensitivities)
2a. How? Model framework

- **Three models** calculating expected cost (EC) of commitment & dispatch
  1) LMP: commit s.t. full network (lowest cost!)
  2) NTC-ID: commit s.t. NTC, followed by international redispatch
     • “Net Transfer Capability” = Total MW limit between countries
     • This is an approximation to true network constraints → cost increase
  3) NTC-NID: commit s.t. NTC, only domestic redispatch

- Calculate **unit commitment benefits**: $EC[\text{NTC-ID}] - EC[\text{LMP}]$
  Quantified for two NTC cases:
  1) Optimal NTC (minimize expected costs) → through search over NTCs
  2) Arbitrary (fixed) NTC

- Calculate **benefits of international redispatch**:
  $EC[\text{NTC-NID}] - EC[\text{NTC-ID}]$

- **Sensitivity** analysis to network parameters
Model LMP

Net load realised

Day-ahead unit commitment & scheduling
subject to full network constraints

Redispatch
Model NTC-ID

TSO sets NTC

Day-ahead unit commitment
  subject to NTC

Net load realised

Real-time international redispach
  subject to network constraints
Model NTC-NID

Net load realised

TSO sets NTC

Day-ahead unit commitment subject to NTC

Real-time redispatch only within country (international MW flow fixed)
2b. How? Numerical application

Transmission: Equal reactance, line limits = 1000 MW

- Hence: \(1000 \text{ MW} \leq \text{NTC} \leq 2000 \text{ MW}\): search over this interval

Generation: 12 generators (based on Bard, 1988)

- Baseloaded plants ignored
- Day-ahead unit commitment for 24 hours (grouped into 3 time periods)
3. What are the results in a ‘base case’?

NID: 14.25%

NTC 1700MW: Optimal NTC: 1.27%  0.51%
4. Sensitivity: generator size

(min run, max run, start-up costs, fixed costs multiplied)

Non-monotonic

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4. Sensitivity: generator lumpiness

Keeping aggregate system capacity constant

NTC [MW]

Benefit [% of LMP costs]

- Intl. Redispatch
  - size=s
  - size=s/2
  - LP

- No IR
  - size=s
  - size=s/2
  - LP

Benefit [% of LMP costs]

1000 1200 1400 1600 1800 2000

10% 8% 6% 4% 2% 0%

15,6% 15,2% 14,8% 14,4% 14,0% 13,6%

1000 1200 1400 1600 1800 2000

14,0% 14,8%

NTC [MW]
4. Sensitivity: Load levels
Load at all nodes scaled up & down

![Graph showing sensitivity to load levels](image-url)

- ID - Optimal NTC
- ID - NTC 85%
- NID - Optimal NTC

**Non-monotonic**

Load multiplier

Benefit [% of LMP costs]
5. What can we conclude?

- LMP can significantly improve unit commitment decisions (saving 0-1% of fuel costs of non-baseload plants)
- Intl balancing can provide significant benefits even if unit commitment decisions consider only NTC constraints
- Magnitudes greatly depend on exact characteristics of the electricity market
- Cf. other studies
  - 0.1% Unit commitment benefits in EU (R. Barth et al., Load-Flow Based Market Coupling with Large Scale Wind Power in Europe. 8th Workshop on Large-Scale Integration of Wind Power in Power Systems, 2009)
  - 0.38 €/MWh Intl. redispatch benefits in F-Be-NL-G example (Oggioni & Smeers, Degrees of Coordination in Market Coupling and Counter-Trading, UCL, 2009)
5. What can we conclude?

- **Intl Redispatch:**
  
  \[\downarrow \text{generator size}, \uparrow \text{min run levels} \]
  
  \[\uparrow \text{load symmetry}, \uparrow \text{load correlation} \]

- **NIR:** \[\downarrow \text{generator size}, \uparrow \text{min run levels} \]
  
  \[\uparrow \text{transmission capacity}, \downarrow \text{load level} \]
  
  \[\uparrow \text{load symmetry} \uparrow \text{load correlation} \]

\[\uparrow \text{benefits} \]

- continuous approximations of binary commitment variables can significantly overstate UC benefits for small systems.
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Appendices
UC model

\[
\min_{\{s_{it}, z_{it}, p_{ijt}\}} \sum_{t \in T} \left[ \sum_{i \in I} (S_{U_i}s_{it} + H_iFC_i z_{it}) + \sum_{j \in J} PR_j H_i \sum_{i \in I} MC_i p_{ijt} \right]
\]

s.t.

\[
P_{i_{\text{min}}} z_{it} \leq p_{ijt} \leq P_{i_{\text{max}}} z_{it}
\]

\[
z_{it} - z_{i,t-1} \leq s_{it}
\]

and for NTC:

\[
\sum_{i \in I^A} p_{ijt} + \sum_{i \in I^B} p_{ijt} \leq NTC
\]

\[
\sum_{i \in I^A} p_{ijt} + \sum_{i \in I^B} p_{ijt} \leq NTC
\]

and for LMP:

\[
\sum_{h \in H} PTDF_{hk} \left( \sum_{i \in I^h} p_{ijt} - Q_{hjt} \right) \leq T_k
\]
Dispatch model

\[
\min_{\{p_{ijt}, l_{jt}\}} \sum_t H_t \left( \sum_{i \in I} MC_i \bar{p}_{ijt} + l_{jt} CL \right)
\]

s.t.:

\[
P_i^{\text{min}} z_{it} \leq \bar{p}_{ijt} \leq P_i^{\text{max}} z_{it}
\]

\[
\sum_{h \in H} PTDF_{hk} \left( \sum_{i \in I^h} \bar{p}_{ijt} - Q_{hjt} \right) \leq T_k
\]

and for NID:

\[
\sum_{i \in I^A} \bar{p}_{ijt} + \sum_{i \in I^B} \bar{p}_{ijt} + l_{jt} = \sum_{i \in I^A} \bar{p}_{ijt} + \sum_{i \in I^B} \bar{p}_{ijt}
\]

\[
l_{jt} \geq 0
\]
Benefit calculation

• Costs for each model:

\[ E[TC] = \sum_{t \in T} \left[ \sum_{i \in I} SU_i s_{it}^* + H_i FC_i z_{it}^* + \sum_{j \in J} PR_j H_i \sum_{i \in I} (MC_i \bar{p}_{ijt} + l_{jt} CL) \right] \]

• Benefit = \( E[TC_{NTC}] - E[TC_{LMP}] \)