An integrated approach to model redispatch and assess potential benefits from Market Splitting in Germany

Katrin Schmitz*, Michael Bucksteeg, Christoph Weber
Enerday in Dresden, 19/04/2013
Overview

1. Introduction

2. Model Framework

3. Case study: Redispatch and Impacts of Market Splitting in Germany

4. Findings and Conclusion
1. Introduction

Motivation

- Increasing RES-feed-in, grid extension not keeping pace with RES, accelerated nuclear phase-out and increasing international trading activities are challenging the transmission grids
1. Introduction

Motivation

• Increasing RES-feed-in, grid extension not keeping pace with RES, accelerated nuclear phase-out and increasing international trading activities are challenging the transmission grids

• **Increasing difficulties for TSOs in daily grid operation**
  - Congestion management and redispatch
  - Stability and security concerns

• First-best answer for congestion management according to textbook economic theory: Market Splitting through Nodal Pricing
  - Timely implementation is unrealistic, German-/ European-wide TSO needed

• **Alternative: Market Splitting through Zonal Pricing (?)**
  - Implications for congestion and redispatch?
  - Implications for Security of Supply (SoS)?
1. Introduction

Congestion Management in Germany:
Day-ahead market “copperplate” + Redispatch

Redispatch = remove transmission congestion by changing generator output levels to reduce congestion and keep up system security

- We assume: 500 MW congestion between Remptendorf and Redwitz
- Redispatch measure:
  - Down-regulating of power plant in front of the bottleneck (Negative redispatch)
    - How much MW have to be down-regulated depends on the effectiveness of the power plant on the specific congested line
  - Up-regulating of power plant behind the bottleneck (Positive redispatch)
    - According to energy amount that has be down-regulated „in front of the“ bottleneck

Source: ENTSOE (2012)
1. Introduction

Research issues

[1.] Redispatch
- Development of an adequate model approach for redispatch
- Redispatch development in future? Drivers?

[2.] Market Splitting
- Impacts of market splitting on redispatch amount?
- Specific design of bidding zones?
- How much zonal (transfer) capacity is given to the Day-ahead market?
- How much redispatch is still necessary – despite of the introduction of market splitting?
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Modelling Redispatch: Conflicting requirements → Usage of 2 model variants

• **Detailed** modelling of power plant dispatch, electricity flows between regions and **redispatch**
  → Need for unit-wise (MIP) modelling

• Impact of **varying production of RES** and conventional power plants on **German imports and exports** and therefore also on **redispatch**
  → Need for modelling of the whole ENTSO-E grid

→ European-wide MIP-model computationally too demanding
  – Huge model size: MIP-modelling of EACH European power plant

→ **Solution:**

  **LP-Model Europe**
  • Imports and exports
  • Electricity produced in subordinated grids

  **MIP-Model Germany**
2. Model Framework

Basic Characteristics of the Dispatch Model: Joint Market Model (I)

- Objective function minimizes variable generation costs

- Detailed hourly optimisation of power plant dispatch for 8760 hours
  - Linear respectively mixed-integer optimisation
  - Rolling planning approach
  - Planning horizon up to 36 h with hourly optimisation

- Consideration of arrival of new information („wait-and-see“ decision-making structure),
  - 1\textsuperscript{st} step: Optimisation of power plant dispatch from a day-ahead perspective
  - 2\textsuperscript{nd} step: Readjustment of power plant dispatch based on new intraday information (e.g. modified wind production, grid restrictions) = redispacht
Basic Characteristics of the Dispatch Model: Joint Market Model (II)

- Detailed formulation of technical restrictions
  - start up-costs, part-load efficiency losses, CHP plants, pumped storages, reserves, ...

- Load flow approximation:
  - European 50-node-model: thereby Germany in 21 nodes
  - Germany: PTDF and regional NTCs, both from German load flow model (600+ buses, transmission grid)
  - Outside Germany: NTCs from ENTSO-E, ex-post PTDF

- Development within the EU-projects WILMAR and SUPWIND, used in several studies e.g. EWIS or TSO studies (redispatch, evaluation of concrete grid extension projects, market design issues), used from several research institutes (Universities of Essen/ Stuttgart/ Denmark/ Dublin) and also in industry

2. Model Framework

Model Coupling: how to consider Europe?

- Imports and Exports
- Electricity produced in subordinated grid (for determination of vertical load)

LP-Model Europe → Coupling of models → MIP-Model Germany

JMM Europe (DE in 21 buses)

Source regional model: TSO websites
2. Model Framework

1st Challenge: Definition of market zones

Model results 2015:
- **Main bottlenecks:**
  - **Amp2-Amp4** *(new coal-fired power plants, partly compensation by decommissioning of old lignite-fired units)*
  - **Te5-50Hz3** *(already now most congested line „Thüringer Waldleitung“, wind-driven)*

(Effective) congestion management requires:
- Zonal border should run along the main bottlenecks to manage congestion already day-ahead
2. Model Framework

2\textsuperscript{nd} Challenge: Definition of zonal day-ahead capacity

- Trade-Off: System security vs. market liquidity

- The lower the zonal transfer capacity given to the day-ahead market
  - The higher is the system security
  - The lower is the market liquidity (less trading between market zones possible)

→ Comprehensible and transparent approach:

→ **NTC calculation between market zones according to Entso-E**
  1. Determination of base case exchange between market zones [BCE]
  2. Determination of maximal additional transmission capacity between zones by increasing exchange (until constraints are binding) [delta_Emax]
  3. Calculation of Transmission Reliability Margin [TRM]
  4. NTC = BCE + delta_Emax - TRM
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Key Assumptions 2015

- **Load**: 2008 (Profile and total amount)
- **Fuel and CO₂-Prices**: Future prices for 2015
- **Power plants 2015**: EWL-Datenbank & Bundesnetzagentur (2011)
- **Grid 2015**: “Realistic”
  - Europe: No consideration of NorGer, NordLink, Cobra Cable...
  - Germany: Consideration of Görris-Krümmel, Lauchstädt-Vieselbach, Hamburg/Nord-Dollern and phase shifter Diele
    → But no full consideration of all Enlag projects
- **RES-production**:
3. Case study Germany - Results

Development of Congestion 2015

Congestion amount = amount of energy not transmitted due to congestion

Top 10 constrained regional borders

<table>
<thead>
<tr>
<th>Regional border</th>
<th>Congestion amount (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP2_AMP4</td>
<td>2,559</td>
</tr>
<tr>
<td>Te5_50Hz3</td>
<td>2,322</td>
</tr>
<tr>
<td>AMP4_AMP5</td>
<td>887</td>
</tr>
<tr>
<td>Te5_TrBW1</td>
<td>1,754</td>
</tr>
<tr>
<td>Te2_AMP1</td>
<td>955</td>
</tr>
<tr>
<td>TrBW2_AMP6</td>
<td>243</td>
</tr>
<tr>
<td>Te1_Te2</td>
<td>0</td>
</tr>
<tr>
<td>Te3_Te4</td>
<td>199</td>
</tr>
<tr>
<td>TrBW1_AMP5</td>
<td>201</td>
</tr>
<tr>
<td>Te4_Te5</td>
<td>69</td>
</tr>
</tbody>
</table>

Source regional model: TSO websites
3. Case study Germany - Results

Development of Redispatch until 2015

Main drivers:
- Increasing RES-production (far from load centers)
- Resulting export and import flows
- Grid extension not keeping pace with RES-increase


GWh

<table>
<thead>
<tr>
<th>Year</th>
<th>Redispatch</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008 (BNetzA)</td>
<td>3,500</td>
</tr>
<tr>
<td>2009 (BNetzA)</td>
<td>2,200</td>
</tr>
<tr>
<td>2010 (BNetzA)</td>
<td>2,000</td>
</tr>
<tr>
<td>2011 (BNetzA)</td>
<td>3,750</td>
</tr>
<tr>
<td>2015 (JMM model results, Without Market Splitting)</td>
<td>7,314</td>
</tr>
</tbody>
</table>

+95%
3. Case study Germany - Results

Impacts of MSpl on Congestion and (negative) Redispatch 2015

<table>
<thead>
<tr>
<th></th>
<th>Reduction in total</th>
<th>Reduction at zonal border</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion 2015 (JMM, Without Market Splitting)</td>
<td>72%</td>
<td>73%</td>
</tr>
<tr>
<td>Congestion 2015 (JMM, With 2 zones)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redispatch 2015 (JMM, Without Market Splitting)</td>
<td>59%</td>
<td></td>
</tr>
<tr>
<td>Redispatch 2015 (JMM, With 2 zones)</td>
<td>61%</td>
<td>23%</td>
</tr>
</tbody>
</table>

GWh Reduction

- Reduction in total: 72%
- Reduction at zonal border: 73%
3. Case study Germany - Results

**Congestion 2015 – without MSpl**

*Congestion amount = amount of energy not transmitted due to congestion*

### Top 10 constrained regional borders

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*Source regional model: TSO websites*
3. Case study Germany - Results

Congestion 2015 – with MSpl (2 zones)

**Congestion amount** = amount of energy not transmitted due to congestion

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<tr>
<td>AMP2_AMP4</td>
<td>509</td>
</tr>
<tr>
<td>Te5_50Hz3</td>
<td>668</td>
</tr>
<tr>
<td>AMP4_AMP5</td>
<td>10</td>
</tr>
<tr>
<td>Te5_TrBW1</td>
<td>241</td>
</tr>
<tr>
<td>Te2_AMP1</td>
<td>201</td>
</tr>
<tr>
<td>TrBW2_AMP6</td>
<td>89</td>
</tr>
<tr>
<td>Te1_Te2</td>
<td>0</td>
</tr>
<tr>
<td>Te3_Te4</td>
<td>10</td>
</tr>
<tr>
<td>TrBW1_AMP5</td>
<td>53</td>
</tr>
<tr>
<td>Te4_Te5</td>
<td>0</td>
</tr>
</tbody>
</table>

Source regional model: TSO websites
### 3. Case study Germany - Results

**(Negative) Redispatch 2015 – without MSpl**

**(Negative) redispatch quantity* = re-distributed amount of energy due to congestion**

#### Source regional model: TSO websites

<table>
<thead>
<tr>
<th>Region</th>
<th>Redispatch quantity (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP2</td>
<td>3,262</td>
</tr>
<tr>
<td>50Hz3</td>
<td>1,688</td>
</tr>
<tr>
<td>50Hz4</td>
<td>936</td>
</tr>
<tr>
<td>Te2</td>
<td>459</td>
</tr>
<tr>
<td>Te3</td>
<td>224</td>
</tr>
<tr>
<td>Te5</td>
<td>119</td>
</tr>
<tr>
<td>Te1</td>
<td>114</td>
</tr>
<tr>
<td>TrBW1</td>
<td>103</td>
</tr>
<tr>
<td>50Hz2</td>
<td>99</td>
</tr>
<tr>
<td>Te6</td>
<td>82</td>
</tr>
</tbody>
</table>

*not equal to congestion amount due to system stability requirements and spatial deviation of congestion and generating facilities*
3. Case study Germany - Results

(Negative) Redispatch 2015 – with MSpl (2 zones)

(Negative) redispatch quantity* = redispached amount of energy due to congestion

Top 10 constrained regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Redispatch quantity (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP2</td>
<td>714</td>
</tr>
<tr>
<td>50Hz3</td>
<td>944</td>
</tr>
<tr>
<td>50Hz4</td>
<td>502</td>
</tr>
<tr>
<td>Te2</td>
<td>115</td>
</tr>
<tr>
<td>Te3</td>
<td>174</td>
</tr>
<tr>
<td>Te5</td>
<td>80</td>
</tr>
<tr>
<td>Te1</td>
<td>103</td>
</tr>
<tr>
<td>TrBW1</td>
<td>100</td>
</tr>
<tr>
<td>50Hz2</td>
<td>66</td>
</tr>
<tr>
<td>Te6</td>
<td>90</td>
</tr>
</tbody>
</table>

*not equal to congestion amount due to system stability requirements and spatial deviation of congestion and generating facilities
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1. Introduction/ Motivation/ Congestion Management in Germany

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4. Findings and Conclusion
Concerning Redispatch

- Increase in redispatch quantities by 95% until 2015 (compared to 2011)
- Main drivers:
  - Increasing RES-production (far away from load centers)
  - Resulting export and import flows
  - Grid extension not keeping pace with RES-increase (delays?)
  - *Nuclear phase-out (Atommoratorium)*
- Main bottlenecks: Thüringer Waldleitung (Te5-50Hz3) and Amp2-Amp4
  - Assumption of grid extension Hamburg-Nord/Dollern decreases Bottleneck Te1-Te2
  - Huge loop flows from North of Germany over CZ and PL to South of Germany
3. Findings and Conclusion

Concerning Market Splitting

- MSpl can reduce redispatch quantities very substantially
  - Complete avoidance of redispatch is yet not feasible (plant outages, forecast errors...)

- Beneficial effects of MSpl for the SoS in DE depend strongly on a 'good design', in particular:

  (1) Appropriate design of day-ahead market zones
      - Zonal borders should run along the main bottlenecks
      - Changing flow patterns will require regular checks and adaptations

  (2) Appropriate determination of zonal transfer capacity
3. Findings and Conclusion

Concerning Market Splitting

- MSpl can have a very significant reducing effect on redispatch
  - Complete avoidance of redispatch is yet not feasible (plant outages, forecast errors...)

- Beneficial effects of MSpl for the SoS in DE depend strongly on a ‘well design’, in particular:

  (1) Appropriate design of day-ahead market zones:
  (2) Appropriate determination of zonal transfer capacity:
    - Tradeoff: Market liquidity vs. efficient congestion management
      - Leads to reduction of efficiency
      - Leads to reduction of liquidity

Too high ?
Too low?
Concerning Market Splitting

- MSpl can have a very significant reducing effect on redispatch
  - Complete avoidance of redispatch is yet not feasible (plant outages, forecast errors...)

- Beneficial effects of MSpl for the SoS in DE depend strongly on a 'well design':
  1. Appropriate design of day-ahead market zones:
  2. Appropriate determination of zonal transfer capacity:

  - MSpl cannot be expected to be the 'one and only' solution.
    - Need for differentiated assessment between market splitting and grid extension to mitigate SoS risks
    - Also TSO measures like flow-controlling devices have to be taken into account

  - MSpl can be an adequate way to manage congestion in times of „grid delays“ and as alternative to grid extension within less congested areas
Thank you for your attention!

Any questions, remarks or comments?

Contact: Dipl.-Kffr. Katrin Schmitz
E-Mail: katrin.schmitz@uni-due.de
Phone.: +49 201/183-2634
• Bundesnetzagentur (2012): Beschluss der Beschlusskammer 8 zur Festlegung von Kriterien für die Bestimmung einer angemessenen Vergütung bei strombedingten Redispatchmaßnahmen und bei spannungsbedingten Anpassungen der Wirkleistungseinspeisung, Aktenzeichen BK8-12-019


Conventional power plants 2015

- Consideration of commisioning and decommissioning of power plants as far as known/expected, including:

  - Commisioning Germany:
    - Wilhelmshaven (Coal, ca. 750 MW, Te2)
    - Moorburg 1 + 2 (Coal, 2 x 755 MW, 50Hz2)
    - Grevenbroich-Neurath BoA 1 + 2 (Lignite, 2 x 1,050 MW, AMP2)
    - Datteln 4 (Coal, ca. 1,000 MW, AMP2)
    - Hamm 1 + 2 (Coal, 2 x ca. 750 MW, AMP3)
    - ...

  - Decommissioning Germany:
    - Partly Frimmersdorf (Lignite, ca. 1,200 MW, AMP2)
    - Partly Niederaussem (Lignite, ca. 550 MW, AMP2)
    - ...

- Based on power plant list as published by Bundesnetzagentur
Load Flow Model

Load Flow Approximation by PTDF

- **Power Transfer Distribution Factor (PTDF):**
  - Relative change in power flow on a particular line due to a change in injection and corresponding withdrawal at a pair of busses

- **Net Transfer Capacity (NTC):**
  - Maximum commercial exchange program between two interconnected market zones
    - without compromising system security
    - and taking into account uncertainties on future network conditions

- **BCE:** Base Case Exchange
- **ΔE:** Maximum additional exchange between two buses
- **TRM:** Transmission Reliability Margin

**Equations**

\[ \text{NTC1} \to 2 = \text{BCE} + \Delta E - \text{TRM} \]
\[ = 100 \text{ MW} + (100 \text{ MW} - 60 \text{ MW}) / 60 \% - \text{TRM} \]
\[ = 166,67 \text{ MW} - \text{TRM} \]

**Diagram:**

- PTDF1 \to 2 = 60 \%
- PTDF1 \to 3 = 40 \%
- PTDF2 \to 3 = -40 \%
Load Flow Model

2015
Load Flow Model

Brief description

• Focus on German transmission grid: 220 kV and 380 kV
• 601 buses (454 regular and 147 auxiliary buses)
• Including
  – all generators with an installed capacity greater than 100 MW
  – offshore and onshore wind generation
  – locational residual load levels (load minus photovoltaic feed-in)
• Surrounding countries are represented by country nodes
• Dispatch per unit and the load flows are obtained by running a DC Security Constrained Optimal Power Flow (SCOPF) in PowerWorld Simulator
Further Results

3. Case study Germany - Results

Impacts of MSpl on (mean) DA prices in Germany

<table>
<thead>
<tr>
<th></th>
<th>Without Market Splitting</th>
<th>2 Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours with Market Splitting</td>
<td>(unique price)</td>
<td>2.736 hours</td>
</tr>
<tr>
<td>(mean) Price in DE-North</td>
<td>47.58 €/MWh</td>
<td>46.48 €/MWh</td>
</tr>
<tr>
<td>(mean) Price in DE-South</td>
<td></td>
<td>48.78 €/MWh</td>
</tr>
<tr>
<td>(mean) Price difference</td>
<td>(unique price)</td>
<td>-2.31 €/MWh</td>
</tr>
</tbody>
</table>

- In general: The more Market Splitting, the higher is the price difference between market zones
  - Depends on marginal costs of power plants

- In general: The lower the zonal NTC, the more hours with market splitting
  - No linear relationship! Depends on network topology