Value of Demand Response
Reduction of system OPEX
Value of demand response

Outline

- Future energy transition
- DR reduces system OPEX
- Problem definition
  - Model the performance of DR in a unit commitment model
- Example
  - Scenarios for Germany 2015 and 2040
- Conclusions

- ABB Corporate Research project “Future Utility” investigating alternatives scenarios of electric power sector transition and assessing potential of different technologies to support these changes
- We see demand response role will grow with a need to have more flexible grids in light of growing amount of variable RES
Future energy transition scenarios
Anticipated trajectories 2015-2040

Plausible scenarios:
- V-RES < 15%
- Distributed-ness < 15%
Future energy transition scenarios
Anticipated trajectories 2015-2040

Plausible scenarios:
- V-RES < 15%
- Distributed-ness <15%

More ambitious scenarios:
- V-RES < 25%
- Distributed-ness <25%

Radical scenarios:
- V-RES < 45%
- Distributed-ness <35%

Germany shows exceptional progress on V-RES but as part of ENTSO-E the global European figures are at the same levels as above
Future energy transition scenarios
Growing need for system flexibility

Wind and solar supply in 2014:
- up to 15% of load feed-in for half of the time
- >50% of load feed-in was reached 1.6% of the time (140 hours)
- record maximum of 71% of load feed-in was reached once on Sunday, May 11th at 2 pm, when the demand was 52 GW
- 1.8% of load feed-in at the highest demand, 79 GW, was on December 3rd at 6 pm

In the future the V-RES in-feed share will grow and create a need for more system flexibility

Despite the 74 GW of installed capacity, wind and solar do not present challenges yet due to low feed-in
Demand Response (DR) is defined as the change in the electricity use in response to the electricity price changes or the system operator’s control signal.

- **Energy time shift**: a percentage of demand can be anticipated or postponed within a given time delay.

- **Ancillary services** (e.g. frequency regulation): a percentage of demand can be changed by the system operator in case of contingency.

- We focus on OPEX (production cost) savings: avoided fuel, startups, shutdowns, ramping, CO2 emission cost, etc.
**Integration of demand response to unit commitment**

**Mathematical formulation for energy time shift**

\[ P_t = P_t^0 - P_t^- + \sum_{\tau} P_{t,\tau}^+ \]  
change in demand

- \( P_t \): modified demand after demand response.
- \( P_t^0 \): initial demand
- \( P_t^- \): reduction of demand
- \( P_{t,\tau}^+ \): compensation of reduced demand

\[ P_t^- = \sum_{\tau} P_{t,\tau}^+ \]  
reduced demand should be compensated within time delay

\[ P_t^- \leq u_t X\% \]  
limit for change of demand

\( u_t \in \{0,1\} \): deciding between the reduction of demand (\( u_t = 1 \)) and its compensation (\( u_t = 0 \))

\( X\% \): percentage of demand participating in demand response

\[ \sum_{\tau} P_{t,\tau}^+ \leq (1 - u_t) X\% K \]  
compensation is allowed if there is no demand reduction

\( K \): sufficiently big number

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**Table:**

<table>
<thead>
<tr>
<th>( P_t^- )</th>
<th>( P_t^+ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1^- )</td>
<td>( P_2^+ )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( P_r^- )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( P_{r-1}^- )</td>
<td>( P_T^- )</td>
</tr>
</tbody>
</table>

**Diagram:**

- \( P_t^- \): initial demand
- \( P_t^+ \): modified demand after demand response
- \( P_{t,\tau}^+ \): compensation of reduced demand
- \( u_t \in \{0,1\} \): deciding between the reduction of demand (\( u_t = 1 \)) and its compensation (\( u_t = 0 \))

**Legend:**

- \( X\% \): percentage of demand participating in demand response
- \( K \): sufficiently big number

**Notes:**

- Change in demand: \( P_t = P_t^0 - P_t^- + \sum_{\tau} P_{t,\tau}^+ \)
- Initial demand: \( P_t^0 \)
- Reduction of demand: \( P_t^- \)
- Compensation of reduced demand: \( P_{t,\tau}^+ \)
- Decision: \( u_t \in \{0,1\} \)
- Percentage participating: \( X\% \)
- Limit for change of demand: \( P_t^- \leq u_t X\% \)
- Compensation allowed: \( \sum_{\tau} P_{t,\tau}^+ \leq (1 - u_t) X\% K \)
Unit commitment analysis
Germany: regional installed capacity 2014

Germany is divided in 2 zones: north is dominated by wind, the south is by solar power.

70.7 GW

100.0 GW

Source: Velocity Suite, Bundesnetzagentur
Unit commitment analysis
Germany: regional installed capacity 2014 & 2040

The capacity of RES increases, nuclear phase-out, and coal capacity decreases

Source: Energiewende, Fraunhofer
Unit commitment analysis
Germany: results for a week in December 2014

Maximum 10% DR and 8 hour delay is allowed

Base case: no DR
OPEX: 167.47 M€
CO₂: 0.34 tonne/MWh

With DR
OPEX: 161.29 M€
CO₂: 0.31 tonne/MWh
A maximum DR of 10% is activated about 40% of time and values between 0-10% are activated for another 20% of time.

40% of time the disconnected demand is compensated (compensation can be above 10%).

With DR

OPEX: 161.29 M€
CO₂: 0.31 tonne/MWh

Maximum 10% DR and 8 hour delay is allowed
Congestion relief and RES curtailment reduction
Germany: results for a week in December 2014

**Base case: no DR**

![Inter-area power flow graph](image)

**With DR**

![Inter-area power flow graph](image)

\[
\begin{align*}
P_{W\text{curtail}} &= 36.76 \text{ GWh} \\
P_{S\text{curtail}} &= 0.01 \text{ GWh}
\end{align*}
\]

\[
\begin{align*}
P_{W\text{curtail}} &= 16.34 \text{ GWh} \\
P_{S\text{curtail}} &= 0 \text{ GWh}
\end{align*}
\]

Maximum 10% DR and 8 hour delay is allowed
Dividing 388.4 M€ in production cost savings by the peak DR capacity enabled, 7.7 GW, yields a value of **50.6 €/kW-y**

Dividing 388.4 M€ in production cost savings by the total energy DR provided to the system, 34'810.3 GWh, yields a value of **0.01 €/kWh**

In order to estimate profit we need to include the cost of enabling a demand response service

For any given conditions OPEX savings are always saturated when percentage of DR and compensation delay are increased
Unit commitment analysis
Germany: results for 2014

<table>
<thead>
<tr>
<th>Cost, M€</th>
<th>Base case</th>
<th>DR 10%, 8 h</th>
<th>Savings, M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel &amp; VOM</td>
<td>11650.3</td>
<td>11330.7</td>
<td>319.6</td>
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<tr>
<td>CO2</td>
<td>1500.3</td>
<td>1451.3</td>
<td>49.0</td>
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<tr>
<td>Start/stop</td>
<td>18.7</td>
<td>4.2</td>
<td>14.5</td>
</tr>
<tr>
<td>Reserve</td>
<td>256.4</td>
<td>251.1</td>
<td>5.3</td>
</tr>
<tr>
<td>Total cost</td>
<td>13425.7</td>
<td>13037.3</td>
<td>388.4</td>
</tr>
</tbody>
</table>

- Dividing 388.4 M€ in production cost savings by the peak DR capacity enabled, 7.7 GW, yields a value of **50.6 €/kW-y**
- Dividing 388.4 M€ in production cost savings by the total energy DR provided to the system, 34’810.3 GWh, yields a value of **0.01 €/kWh**
- In order to estimate profit we need to include the cost of enabling a demand response service

For any given conditions OPEX savings are always saturated when percentage of DR and compensation delay are increased.
Unit commitment analysis
Germany: results for 2040 and comparison with 2014

**Dividing 823.4 M€ in production cost savings by the peak DR capacity enabled, 7.7 GW, yields a value of 107 €/kW-y**

**Dividing 823.4 M€ in production cost savings by the total energy DR provided to the system, 30'960.6 GWh, yields a value of 0.026 €/kWh**

**The absolute growth is mainly due to increase in fuel and CO2 emission costs**

**Start/stop and reserve cost savings grow significantly**

<table>
<thead>
<tr>
<th>Cost, M€</th>
<th>Base case</th>
<th>DR 10%, 8 h</th>
<th>Savings, M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel &amp; VOM</td>
<td>16513.1</td>
<td>15905.6</td>
<td>607.5</td>
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<tr>
<td>CO2</td>
<td>6185.7</td>
<td>6021.7</td>
<td>164.0</td>
</tr>
<tr>
<td>Start/stop</td>
<td>144.2</td>
<td>104.5</td>
<td>39.7</td>
</tr>
<tr>
<td>Reserve</td>
<td>537.1</td>
<td>524.9</td>
<td>12.2</td>
</tr>
<tr>
<td>Total cost</td>
<td>23380.1</td>
<td>22556.7</td>
<td>823.4</td>
</tr>
</tbody>
</table>

For any given conditions OPEX savings are always saturated when percentage of DR and compensation delay are increased
Value of demand response

Recap

A Future power systems with a significant amount of variable RES will create a need for more flexible operation

A Demand response is one of key technologies which can provide this flexibility

A Use of demand response results in production cost savings

A Sensitivity analysis across different sizes shows that for each set of system conditions there are optimal parameters of demand response

A With increase in variable RES feed-in a higher percentage of demand response will be economic

A We have to include costs of enabling demand response to estimate a profit
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