Flexibility Auctions: A Framework for Managing Imbalance Risk

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FERC Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency Through Improved Software
Agenda

Introduction

Flexibility auction

Numerical example

Conclusions
An Electric Sector in Transition

- Wind and solar photovoltaics are anticipated to contribute >50% of future electricity.
- System operators and flexible resources must manage challenging imbalances.

Key milestones in the pathway to net zero

By 2050, almost 70% of electricity generation globally from solar PV and wind.


Net load imbalances at California ISO

Operators and participants could hedge system supply-demand and own imbalance risk.

Supply curves for operational flexibility become steeper as lead time reduces...

Day-ahead
Hour-ahead
Minutes-ahead
Real-time

Graph adapted from ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E) U.S. DEPARTMENT OF ENERGY PERFORMANCE-BASED ENERGY RESOURCE FEEDBACK, OPTIMIZATION, AND RISK MANAGEMENT (PERFORM) Funding Opportunity No. DE-FOA-0002171 CFDA Number 81.135

One aspect of operational flexibility

With respect to generation decreases as lead time reduces...

Data for generators included in EIA-860A/860B 2019 and have data for time from cold shutdown to full load.

Source: EPRI
Designing a Framework for Imbalance Risk

Two Settlement System
- Day-ahead market considering imbalance risk
- Real-time market

Marginal Pricing
- Imbalance risk pricing
- Co-optimization of products traded (opportunity costs)

Independent System Operator
Cost-effective and reliable outcomes considering imbalance risk

Bid-Based Market
- Supply bids for flexibility
- Demand bids for flexibility

“Easy to do badly and difficult to do well.”

FLEXIBILITY AUCTION: Participants

- Initial focus on participants with physical assets
- Extension: financial participants

**SELLERS OF FLEXIBILITY OPTIONS**

- Flexibility
- Power plants
- Storage
- Electric vehicles
- Water heaters
- Smart heating/cooling
- Distributed Energy Resources

**BUYERS OF FLEXIBILITY OPTIONS**

- Uncertainty
- Solar plants
- Wind plants
- Electricity consumption
- Probabilistic forecasts

Identifies cost-effective physical hedging options
FLEXIBILITY AUCTION: Preliminary Product Definition

A contract issuing rights to its purchaser to buy or sell energy imbalances during a market interval at a strike price.
FLEXIBILITY AUCTION: Preliminary Product Definition

A contract issuing rights to its purchaser to buy or sell energy *imbalances* during a market interval at a strike price.

- **Negative imbalance**
  - “Call” option to purchase up to \( x \) MW at strike price.
  - Can be exercised only when imbalance is negative.

- **Positive imbalance**
  - “Put” option to sell up to \( x \) MW at strike price.
  - Can be exercised only when imbalance is positive.

- **Day-ahead energy award**
- **Real-time physical availability**
FLEXIBILITY AUCTION: Preliminary Product Definition

A contract issuing rights to its purchaser to buy or sell energy *imbalances* during a market interval at a strike price.

- **Negative imbalance**
  - **Upward option**
    - “Call” option to purchase up to $x$ MW at strike price.
    - Can be exercised only when imbalance is negative.

- **Positive imbalance**
  - **Downward option**
    - “Put” option to sell up to $x$ MW at strike price.
    - Can be exercised only when imbalance is positive.

Option “tier” indicates the frequency at which the option can be exercised.
### Flexibility Auction: Trading and Pricing

#### Parameters
- Pairs of quantities & strike prices for flexibility suppliers
- Pairs of quantities & probabilities/tiers of deployment for flexibility buyers

#### Objective function
- Additional term: costs of flexibility, weighted by probability of deployment (minimization)

#### Constraints
- Operational flexibility constraints for suppliers
- Upper operating limit for buyer can depend on amount bought of flexibility option
- Flexibility demand-supply balance per tier

#### Results
- Flexibility option awards
- Shadow prices of balance constraints

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**FLEXIBILITY AUCTION**

**Offers**

**Auction Formulation**

**Auction Awards and Prices**

**Day-ahead**  
**Hour-ahead**  
**Minutes-ahead**  
**Real-time operations**
FLEXIBILITY AUCTION: Settlements

Two-settlement system:
A. Option pricing in day-ahead
B. Option pay-off in real-time

SIMPLIFIED FORMULATION FOR FLEXIBILITY UP

MW = flexibility option award = imbalance
Flexibility up supplier = supplier in real-time market

Buyer

A

− { “flex up price”
   − prob-weighted avg strike price} × MW

B

− RT energy price × MW
+ max(0, {RT energy price − avg strike price}) × MW

Seller

A

+ { “flex up price”
   − prob-weighted strike price} × MW

B

− Max(0, {RT energy price − Strike price}) × MW
+ RT energy price × MW

‡ Megawatt-weighted average over all suppliers
Introduction

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Conclusions
Simple Example for One Interval

**Flexibility buyers**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Probability</th>
<th>Renewable 1</th>
<th>Renewable 2</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>20%</td>
<td>67</td>
<td>64</td>
<td>131</td>
</tr>
<tr>
<td>S2</td>
<td>20%</td>
<td>74</td>
<td>67</td>
<td>141</td>
</tr>
<tr>
<td>S3</td>
<td>20%</td>
<td>83</td>
<td>72</td>
<td>155</td>
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<tr>
<td>S4</td>
<td>20%</td>
<td>90</td>
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</tr>
<tr>
<td>S5</td>
<td>20%</td>
<td>95</td>
<td>77</td>
<td>172</td>
</tr>
</tbody>
</table>

Correlation of R1 & R2: ~1

**Flexibility suppliers**

<table>
<thead>
<tr>
<th>Variable cost ($/MWh)</th>
<th>Max capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST 1</td>
<td>20</td>
</tr>
<tr>
<td>CT 2</td>
<td>35</td>
</tr>
<tr>
<td>CT 3</td>
<td>50</td>
</tr>
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<td>60</td>
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</table>

Strike price = Variable Cost
Ramp Rate = Capacity

**Energy-only participants**

Load: 200 MW

**DISCLAIMER:** Simple example:

1) excludes “surprises” (assumes uncertainty perfectly quantified & revealed by flexibility buyers);
2) assumes perfectly correlated uncertainties among flexibility buyers.
Observation 1: Price signals for imbalance risk

Endogenous consideration of imbalance costs for renewable energy [1]

<table>
<thead>
<tr>
<th>MW Schedule</th>
<th>DA Energy</th>
<th>T1 FLEX</th>
<th>T2 FLEX</th>
<th>T3 FLEX</th>
<th>T4 FLEX</th>
<th>T1 FLEX</th>
<th>T2 FLEX</th>
<th>T3 FLEX</th>
<th>T4 FLEX</th>
</tr>
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<tbody>
<tr>
<td>RE 1</td>
<td>83</td>
<td>-7</td>
<td>-9</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>RE 2</td>
<td>67</td>
<td>-3</td>
<td></td>
<td>-5</td>
<td>-3</td>
<td>-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST 1</td>
<td>50</td>
<td></td>
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<td>10</td>
<td>7</td>
</tr>
<tr>
<td>CT 2</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
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<table>
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<th>Shadow price, $/MWh</th>
<th>T1 FLEX</th>
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<th>T4 FLEX</th>
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<td>-4</td>
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DA energy price = Expected RT energy price

If no flexibility auction, degeneracy for DA energy price in [20,35]. Assuming ε MW of virtual supply at 29$/MWh, same DA energy price ($29/MWh).
Observation 2: Mutually beneficial imbalance risk sharing

- Overall $E(\text{profits})$ remain the same
- Win-win: Both suppliers and buyers experience lower profit variability after trading flexibility options

**Expected day-ahead and real-time profits** same between two cases: RE1 (2260), RE2 (2005), ST1 (450), CT2 (30)

**Standard deviation of day-ahead and real-time profits**
### Simple Example [Modified: Unit Commitment]

**Flexibility buyers**

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**Flexibility suppliers**

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<tr>
<td>ST1 (DA start)</td>
<td>44</td>
<td>20</td>
<td>50</td>
</tr>
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<td>ST2 (DA start)</td>
<td>25</td>
<td>22</td>
<td>50</td>
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**Energy-only participants**

Load: 200 MW

- Business as usual case would have committed ST1 unaware of flexibility needs.
- With flexibility auction, ST2 should be committed.
Observation 3: Cost-effective power system operations

Introducing a flexibility auction might reduce perfect forecast gap (extent is system-dependent)

Elimination of perfect forecast gap due to simple example assumptions – not generalizable result!
Introduction
Flexibility auction
Numerical example
Conclusions

Agenda
Conclusions

- Preliminary design of flexibility auction proposed
- Simple examples show price signals for imbalance risk
- Simple examples show improved hedging for suppliers & buyers of flexibility options
- Simple examples show increased market surplus
Ongoing Work

Comparison with other hedging instruments

Implementation in FESTIV*

Simulations with ARPA-E PERFORM Texas system to analyze value of the auction

Three-year Project

Detailed formulation with additional considerations—such as network constraints, multi-interval markets, and market monitoring functions etc.—will be released along with results on value analysis.

Additional focus on flexibility by DERs.

ONGOING (ARPA-E FUNDED)

Simulate Texas ERCOT power system:

• To verify design of flexibility auction and DER scores
• To estimate economic and reliability benefits for power system, generators, load, and DER portfolio managers

IMPACT ANALYSIS
(2020–2023)

PILOT
(2023–2024)

WIDE-SCALE USE
(2025–…)

PARTNERS NEEDED

Pilot framework for delivery risk

FUTURE PLANS

• Facilitate use of DER scores at national scale
• Assist energy markets to implement flexibility auctions

1

NREL: E. Spyrou; M. Cai; Y. Liu; Y. Zhang

2

Johns Hopkins University: B. Hobbs; H. Geman; M. AlAshery; Y. Ma

3

Electric Power Research Institute: R. Hytowitz; E. Ela

Packetized Energy: P. Hines; M. Almassalkhi

kWh Analytics: J. Kaminsky
Thank you

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