Storage & Variable Generation in Capacity Auctions

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Special thanks to National Grid
Work supported by RCUK Energy Programme
Definition of risk indices

• Evolution of margin through peak season
  \[ Z_t = X_t + Y_t - D_t \]
  - \((X_t, Y_t)\) available (conventional, VG) – interconnection/storage?
  - \(D_t\) demand, \(\Delta\) time resolution
  - \(t\) ranges over future season under study
  - Indicator \(I_t\): 1 if \(Z_t < 0\); 0 otherwise

• Standard adequacy risk indices (what is adequacy?)
  - Loss of Load Expectation (duration of shortfall) – expected (mean) total duration of shortfall over all possible realised peak seasons
    \[ [\text{LOLE}] = \Delta \cdot E \left[ \sum_t I_t \right] = \Delta \sum_t P(Z_t < 0) \]
  - Expected Energy Unserved (energy not supplied) – expected (mean) energy unserved over all possible realised peak seasons
    \[ [\text{EEU}] = \Delta \cdot E \left[ \sum_t \max(-Z_t, 0) \right] \]
CONTRIBUTION OF STORAGE
What’s different about storage

• Different from what?

• Differs from all the above in that…
  – There is a relevant control action (when to use finite energy)

• Differs from conventional but not wind in that…
  – It’s not just about mechanical availability
Why does difference matter? (1)

- Choice of risk index
  - Suppose index/target is duration of shortfall
    - Shape over time of shortfall
    - Energy limited storage minimises duration of shortfall by doing this
    - Minimises maximum shortfall depth by doing this

- Conventional plant makes greater contribution
  - But gives same reduction in shortfall duration

- Energy unserved not duration gives fair comparison
  - Capacity mechanism – uses energy index for storage EFC
• Conv units – adding one unit to ~250 shifts distribution
  – Work with mean available capacity as additive commodity
• Wind and storage – not so simple
  – Wind (dependence between units), storage (energy limit)
  – Not straightforward to run auction without additive commodity
• Possible resolution
  – Main topic of this talk
RISK METRICS AND EQUIVALENT FIRM CAPACITY
Definitions and assumptions...

- Risk indices
  \[
  \text{LOLE} = \sum_{t=1}^{n} P(Z_t < 0),
  \]
  \[
  \text{EEU} = \sum_{t=1}^{n} E(\max(-Z_t, 0)) = \sum_{t=1}^{n} \int_{-\infty}^{0} P(Z_t < z) \, dz,
  \]

- Assumptions and definitions
  - Demand process \( D_t \) given, i.e. specific scenario (important for capacity market)
  - \( \rho(R) \) is risk level with set \( R \) of resources
  - Continuity: \( \rho \) may be varied continuously
  - Smoothness: \( \rho(R) - \rho(R \cup \{i\}) \) approx. constant wrt \( R \)

- ‘Derivative’ with respect to firm capacity \( y \)
  \[
  \rho(R + y) = \rho(R) + \rho'(R)y,
  \]

- Equivalent Firm Capacity definition
  \[
  \rho(R \cup \{i\}) = \rho(R + efc_R(i))
  \]
  \[
  \Rightarrow \quad \rho(R \cup \{i\}) = \rho(R) + \rho'(R)efc_R(i)
  \]
... And some consequences

- Alternative calculation for small $i$
  \[ ef_{c_R}(i) = \frac{\rho(R \cup \{i\}) - \rho(R)}{\rho'(R)} \]

- Derivative of EEU wrt firm cap (only gen, no storage)
  \[ EEU'(R) = -\text{LOLE}(R) \]

- When there is storage
  - Assuming storage recharged overnight…
  - … and any current shortfall prioritised…
  - … optimal strategy (see ST / SZ / JC etc)…
  - … $S_e$: stores empty at end of day (uncertain ex ante)
    \[ EEU'(R) = -\text{LOLE}(R \setminus S_e) \]
  - Firm capacity contributes more when added to portfolio including storage resources
CAPACITY MARKETS
Capacity markets – risk target

• Minimise procurement cost subject to
  \[ \rho(R) \leq k \]
  – Add in units in order of value for money
  – Identify price \( p \) and set of units \( R \) such that
    \[ c_i \leq p \times ef_{c_R}(i), \quad i \in R \]
    \[ c_i > p \times ef_{c_R}(i), \quad i \notin R \]

• If marginal EFCs known ex ante…
  – Rank units by \( c_i/ef_{c_R}(i) \)
  – Add in merit order until EEU target hit

• But they are not…
  – Initial estimate of EFCs (e.g. by adding to guess at auction result)
  – Create merit order, add units until EEU target hit, recalculate EFCs
  – Iterate until convergence
Capacity markets - economic

• Minimise

\[ \text{VOLL} \times \text{EEU}(R) + c(R) \]

– If all resource is firm capacity

\[ \text{VOLL} \times \text{EEU}'(R) + c'(R) = 0 \]

– If \( c'(R) \) is written CONE:

\[ \text{LOLE}(R) = \frac{\text{CONE}}{\text{VOLL}} \]

– Economic condition ‘pivots’ onto LOLE constraint

• If VG or storage…

– Holds with VG if VG capacity small, or diurnal variation / statistical association with demand process weak

– Does not hold for storage – have to work directly with EEU constraint or economic optimisation [remember shortcoming of LOLE]
# Capacity markets - example

<table>
<thead>
<tr>
<th>Iteration</th>
<th>Cost (£)</th>
<th>Clearing price (£)</th>
<th>LOLE (hrs/year)</th>
<th>EEU (MWh)</th>
<th>Storage EFC (MW)</th>
<th>Sum of store EFCs (MW)</th>
<th>Firm capacity (MW)</th>
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<tbody>
<tr>
<td>Initial</td>
<td>71,224,647</td>
<td>26,098</td>
<td>3.04</td>
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Table 1: Summary of results for the iterative procedure used to estimate the lowest cost resource set $R$ that meets the reliability criteria.
Conclusions

• Proposal for running a capacity market
  – Motivated by inclusion of storage
  – Allows any technology to be included on a common basis
  – Auction commodity is not additive – any alternatives?
  – No schemes (?) for including VG and storage in auctions
    in a way which (a) properly reflects system risk profile,
    and (b) maintains an additive commodity

• Pre-print https://arxiv.org/abs/1907.05973