WP7 Scaling up and replication

T7.3 Methodology for optimal design of BESS

June 18th, 2020 | Webinar
Benoît RICHARD | CEA
Agenda

1. Introduction to the OSMOSE project
2. Presentation of the work on BESS optimal sizing methodology
3. Q&A session
Webinar process

- Use the chat box to write your questions
- The moderator will synthesise all questions and introduce them after the presentation
- The deliverable associated to the work presented today and the slides are available on OSMOSE website: www.osmose-h2020.eu/deliverables
- The webinar is recorded and will be published in OSMOSE website
Remember to mute your microphone

Display CHATTER

Specify slide number if possible in your question
Combining new needs and solutions

**OSMOSE PROJECT**

**HOLISTIC APPROACH OF FLEXIBILITY**

**FLEXIBILITY SOURCES**

**FLEXIBILITY NEEDS**

- Balance offer-demand
- System services
- Control of grid flows
The consortium

✓ H2020 EU funded
✓ 28M€ budget
✓ 33 partners
✓ Leaders: RTE, REE, TERNA, ELES, CEA, TUB
✓ 2018 – 2021
OSMOSE PROJECT

Overview

Methods and simulations

Optimal mix of flexibilities (WP1)

Market designs and regulations (WP2)

Scaling-up & replication (WP7)

Demonstrators

Grid forming by multi-services hybrid storage (WP3)

Multi-services by different storage and FACTS devices (WP4)

Multi-services by coordinated grid devices, large demand-response and RES (WP5)

Near real-time cross-border energy market (WP6)

Rte

RED ELECTRICA DE ESPAÑA

Terna Group

ELES
Sub-Task 7.3.1 Battery Energy Storage Systems (BESS) optimal sizing methodology
BESS optimal sizing methodology

Agenda

1. General problem of BESS sizing
2. Optimal sizing method implemented
3. Illustrative BESS use cases
4. Sensitivity analysis
5. Conclusion
BESS optimal sizing methodology

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General problem of BESS sizing

**UNDERSIZED**
- Service not correctly achieved
- Battery to replace sooner than expected due to intense cycling

**OVERSIZED**
- Higher CAPEX / OPEX budget than necessary
- Financial brake on investment

**OPTIMAL SIZE?**
- Energy / power application needs?
- BESS efficiency?
- Battery ageing?
- Project lifetime?
- EMS control?
- Forecast errors?
- Solicitation profiles?
- Generation costs?
- Utilities prices?

**IN MOST CASES**
- Sizing on « worst case » scenario

**FOSTER THE COMPETITIVENESS OF BESS AS FLEXIBILITY SOURCE**
What are the most influencing factors to consider in a BESS sizing procedure?

1. Implementation of an optimal sizing method
   - Deterministic method using numerical simulation

2. Sensitivity analysis
   - Identify the key drivers for BESS optimal size determination
   - Battery ageing
   - BESS efficiency
   - EMS control
   - Forecast errors
   - Solicitation profiles

   - Quantify their impact on sizing results
   - Strong impact?
   - Low impact?
BESS optimal sizing methodology

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1. General problem of BESS sizing

2. Optimal sizing method implemented

3. Illustrative BESS use cases

4. Sensitivity analysis

5. Conclusion
Optimal sizing method implemented

Synoptic of the simulation-based method implemented

- **Input data time series**
  - e.g. weather forecast, PV production, load profile, ...

- **Simulation of operation scenario**
  - Matlab / Simulink platform
  - + interface with GAMS software when predictive control strategies are implementing some optimization problems

- **Output time series results**
  - e.g. power outputs of each component, BESS SOC profile, component states, ...

- **Control algorithms**

- **Component models**

- **Model parameters** (including BESS size)

- **Set of economic assumptions**

- **Economic performance on whole project lifetime**
  - BESS optimal sizing criteria
  - e.g. LCOE, NPV, IRR, ...

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**Optimal sizing indicator**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Formula</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Levelized Cost of Energy</strong></td>
<td>$LCOE = \frac{\sum_{n=0}^{N} (CAPEX_n + OPEX_n)}{\sum_{n=0}^{N} \frac{E_n}{(1+r)^n}}$</td>
<td>$CAPEX_n$: Investment costs of year $n$ $OPEX_n$: O&amp;M costs of year $n$ $E_n$: total electrical energy generated in the year $n$ $r$: discount rate $N$: project lifetime</td>
</tr>
<tr>
<td><strong>Net Present Value</strong></td>
<td>$NPV = \sum_{n=0}^{N} \frac{CF_n}{(1+r)^n}$</td>
<td>$CF_n$: cash flow of year $n$ $r$: discount rate $N$: project lifetime</td>
</tr>
<tr>
<td><strong>Internal Rate of Return</strong></td>
<td>$\sum_{n=0}^{N} \frac{CF_n}{(1 + IRR)^n} = 0$</td>
<td>$CF_n$: cash flow of year $n$ $IRR$: internal rate of return $N$: project lifetime</td>
</tr>
</tbody>
</table>

**LCOE ($/MWh$)**

- 360 (Optimum)
- 519
- 421
- 376
- 369
- 386
- 405
- 425
- 448
- 472

$LCOE = f(Battery Size)$
Agenda

1. General problem of BESS sizing
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5. Conclusion
Illustrative BESS use cases

2 illustrative BESS application cases have been used for optimal sizing analysis

- **PV smoothing and peak shaving**
  
  (Call for tenders – French Energy Regulatory Commission)

- **Hybrid microgrid**

  **BESS optimal size is obtained when benefits are maximum over the project lifetime**

  Sizing Criteria = NPV (Net Present Value)

  **BESS optimal size is obtained when load can be fed at minimum cost of energy produced**

  Sizing Criteria = LCOE (Levelized Cost Of Energy)
BESS optimal sizing methodology

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## Factors investigated through sensitivity analysis

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Influence of BESS efficiency precision

<table>
<thead>
<tr>
<th>Precision of the BESS efficiency</th>
<th>Baseline</th>
<th>BESS model parameters include tables of precise efficiency values varying according to temperature, current and SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative</td>
<td></td>
<td>BESS efficiency is set up as a constant value (average efficiency)</td>
</tr>
</tbody>
</table>

Baseline - variable efficiency

Comparative - constant efficiency

A variable efficiency behavior can be approximated by an average efficiency single value without any impact on optimal sizing.

LCOE = f(Battery Size)

Same optimal sizing results (average deviation on LCOE value: 0.25%)

Optimum
Influence of BESS efficiency precision

How precisely must be set the average constant efficiency value?

The average efficiency value must be set precisely since the sizing indicator is strongly affected by this parameter.

An error on BESS efficiency value causes an error bordering on the same magnitude on the sizing indicator.

The sizing indicator is very sensitive to the constant efficiency value set for the BESS.

An approximation of 5% on the efficiency leads to an error on the LCOE value of 4%.

LCOE = f(Battery Size)
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**Influence of ageing**

### Degradation of battery capacity due to ageing

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<th>Baseline</th>
<th>Comparative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BESS model parameters include ageing data / battery capacity degradation is continuously computed over time</td>
<td>Battery capacity remains constant over time</td>
</tr>
</tbody>
</table>

**Baseline (with aging)**

- Battery size (kWh)
- LCOE (€/MWh)
- Fuel costs significantly increase when BESS capacity degrades

**Comparative (without capacity degradation)**

- Baseline scenario - Ageing taken into account
- Comparative scenario - Without capacity degradation

<table>
<thead>
<tr>
<th>BESS size (kWh)</th>
<th>LCOE (€/MWh) Baseline</th>
<th>LCOE (€/MWh) Comparative</th>
<th>Relative error</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>519</td>
<td>487</td>
<td>6.17%</td>
</tr>
<tr>
<td>222</td>
<td>421</td>
<td>388</td>
<td>7.84%</td>
</tr>
<tr>
<td>333</td>
<td>376</td>
<td>352</td>
<td>6.38%</td>
</tr>
<tr>
<td>444</td>
<td>360</td>
<td>344</td>
<td>4.44%</td>
</tr>
<tr>
<td>555</td>
<td>369</td>
<td>361</td>
<td>2.17%</td>
</tr>
<tr>
<td>666</td>
<td>386</td>
<td>379</td>
<td>1.81%</td>
</tr>
<tr>
<td>777</td>
<td>405</td>
<td>399</td>
<td>1.48%</td>
</tr>
<tr>
<td>888</td>
<td>425</td>
<td>424</td>
<td>0.24%</td>
</tr>
<tr>
<td>999</td>
<td>448</td>
<td>446</td>
<td>0.45%</td>
</tr>
<tr>
<td>1110</td>
<td>472</td>
<td>470</td>
<td>0.42%</td>
</tr>
</tbody>
</table>

**Mean error** 3.14%

**Strong impact when LCOE is mainly composed of OPEX generation costs**

⇒ **BESS capacity degradation must be taken into account in optimal sizing**
Comparison of different methods to estimate ageing

<table>
<thead>
<tr>
<th>Aging estimation method</th>
<th>SOH computation integrated into BESS model: capacity degradation calculated at each time-step</th>
<th>Simulation with constant but moderately degraded battery capacity over project lifetime</th>
<th>Yearly estimates of performances degradation use of macro ageing data in post-processing calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td>• Results are the most precise</td>
<td>• Ease of implementation</td>
<td>• Rough ageing estimates more easy to obtain</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td>• In-depth ageing parameter values difficult to collect</td>
<td>• It may be difficult to find the appropriate average constant degraded capacity value</td>
<td>• Possible loss of precision on sizing indicator results</td>
</tr>
</tbody>
</table>

LCOE (€/MWh) = f(Battery Size)

1. Baseline (with aging)
2. Constant capacity 100%
3. Constant capacity 85%
4. Constant capacity 90%

But difficult to estimate the average degradation in regards to the application and battery specificities

Mean absolute deviation on LCOE is only 1%
Computation time is divided by 20

Appropriate confidence levels can be obtained through approximation when detailed ageing lab-extracted data are not available
### Factors investigated through sensitivity analysis

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<td>Forecast quality</td>
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</tbody>
</table>
Influence of degree of technical modelling

**Baseline**

In-depth performances battery modelling based on equivalent-circuit equations (EC_model)

*OCV + resistance detailed tables / precise SOH computation module*

**Comparative**

Simplified modelling of the energy/power behavior of the BESS (E/P_model)

*BESS global efficiency constant value / SOH not computed during simulation*

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**Optimal sizing does not require a high degree of technical modelling**

Using a simplified BESS model leads to similar results while saving significant computation time
## Sensitivity analysis

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The influence of the simulation time-step strongly depends on the application time constants related to the events impacting the operation costs or incomes. With PV fluctuation or fuel generator operation a time-step of 10mn is acceptable.
## Sensitivity analysis

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</table>
Influence of control strategy

<table>
<thead>
<tr>
<th>Degree of complexity of control algorithms</th>
<th>Baseline: Basic control algorithms</th>
<th>Comparative: Advanced control algorithms (including optimization)</th>
</tr>
</thead>
</table>

Strong impact: different control strategies may lead to a different optimal BESS size.

It is therefore recommended to clearly define the control strategy before determining the optimal size.

![LCOE vs Battery Size diagram](image)

<table>
<thead>
<tr>
<th>BESS size (kWh)</th>
<th>Baseline LCOE (€/MWh)</th>
<th>Comparative LCOE (€/MWh)</th>
<th>LCOE variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>528</td>
<td>407</td>
<td>-22.92%</td>
</tr>
<tr>
<td>222</td>
<td>417</td>
<td>381</td>
<td>-8.63%</td>
</tr>
<tr>
<td>333</td>
<td>370</td>
<td>344</td>
<td>-7.03%</td>
</tr>
<tr>
<td>444</td>
<td>357</td>
<td>350</td>
<td>-1.96%</td>
</tr>
<tr>
<td>555</td>
<td>371</td>
<td>368</td>
<td>-0.81%</td>
</tr>
<tr>
<td>666</td>
<td>388</td>
<td>390</td>
<td>0.52%</td>
</tr>
<tr>
<td>777</td>
<td>408</td>
<td>413</td>
<td>1.23%</td>
</tr>
<tr>
<td>888</td>
<td>432</td>
<td>436</td>
<td>0.93%</td>
</tr>
<tr>
<td>999</td>
<td>454</td>
<td>459</td>
<td>1.10%</td>
</tr>
<tr>
<td>1110</td>
<td>477</td>
<td>485</td>
<td>1.68%</td>
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Optimal LCOE variation between the 2 scenarios: -3.64%
## Sensitivity analysis

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Influence of forecast quality

Highly depends on the application purpose: if the main function of BESS is to compensate for forecasting errors in the RE sources, forecast quality is of the highest importance for optimal sizing.

| Forecast quality when predictive control is facing forecast errors | Baseline | PV: standard day-1 forecast / Load: persistence day+7 |
| | Comparative #1 | PV: perfect forecast (actual PV production) / Load: perfect forecast (actual consumption) |
| | Comparative #2 | PV / Load: enhanced forecast with 50% fewer errors |

**NPV = f(Battery Size)**

- **Baseline - standard PV forecast**
- **50% enhanced PV forecast**

**LCOE = f(Battery Size)**

- **Baseline - PV forecast D-1 LOAD persistent**
- **PV perfect LOAD perfect (actual profiles)**
- **PV 50% enhanced LOAD 50% enhanced**

**Application #1: High impact**
50% fewer errors improves performance by 15%

**Application #2: Moderate impact**
50% fewer errors improves performance by 2%

NPV increases by 15%
BESS optimal sizing methodology

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## Conclusion

### Sensitivity study conclusions

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<tbody>
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<td>Precision of the BESS efficiency</td>
<td>Variable efficiency can be approximated by an average efficiency single value</td>
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<td>Degradation of battery capacity due to ageing</td>
<td>Ageing must be taken into account in optimal sizing</td>
</tr>
<tr>
<td></td>
<td>Appropriate confidence levels can be obtained through approximation</td>
</tr>
<tr>
<td>Degree of technical modelling</td>
<td>Optimal sizing does not require a high degree of technical modelling</td>
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<tr>
<td>Simulation time-step</td>
<td>Impact depends on the application time constants</td>
</tr>
<tr>
<td></td>
<td>For PV or fuel generator operation, time-step of 10mn is suitable</td>
</tr>
<tr>
<td>Control strategy</td>
<td>Strong impact</td>
</tr>
<tr>
<td>Forecast quality</td>
<td>Highly depends on the application purpose</td>
</tr>
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<td></td>
<td>Significant impact when the main function of the BESS is to compensate for forecasting errors</td>
</tr>
</tbody>
</table>

These conclusions help to:

- concentrate the effort on the crucial factors
- identify where computation time can be saved without degrading the accuracy of the result
Conclusive approximation ➔ trade-off between accuracy of the result and calculation time

By putting into practice the study sensitivity study conclusions, calculation time can be divided by 840 with an average error below 2% compared to the baseline (most precise) scenario.
Potential method improvements

The very deterministic simulation-based method used for optimal sizing:

- was well suited for the sensitivity analysis purposes
- has some weaknesses
  - Requires to collect a large amount of data
  - Doesn’t take into account uncertainties
  - Needs large number of simulations to reach the optimum

- could be combined with other techniques such as:
  - Probabilistic / stochastic methods,
  - Direct search algorithms:
    - Mathematical optimisation
    - Heuristic approaches

Model parameters (including BESS size)

Input data time series

Control algorithms

Component models

Simulation of operation scenario

Matlab / Simulink platform

Output time series results

E.g. power outputs of each component, BESS SOC profile, component states, ...

Intermediate useful indicators

E.g. revenues from injected energy, annual O&M costs, BESS cycles number, ...

Economic performance on whole project lifetime

E.g. LCOE, NPV, IRR, ...

Set of economic assumptions

Requires less input data

Handles uncertainties

Reduces calculation time

Automatically converges to optimum

Hybrid method?
Thank you!