Le réseau
de transport
d'électricité

The Economic Potential of Battery Storage in Grid Expansion Planning for Renewables Integration

18th IAEE European Conference
25th July, 2023

Author & Presenter : Adrienne de Bazelaire – CentraleSupélec, Université Paris Saclay & RTE
email : adrienne.de-bazelaire@centralesupelec.fr

Summary

1. Context & Research question
2. Method & Network definition
3. Preliminary results

1 Context and research question

1.1 Context

- Growing **penetration of solar and wind** in the energy system
- **Saturation of the availabe connection capacity** on lower voltage grids
- Increasing wind and solar connection & upstream **reinforcement needs on medium-voltage** (MV) grid
- **Battery storage** can manage **marginal congestions** on the grid
- Battery storage can **complement** or **substitute** to grid expansion

1.2 Research question

- Research question :
  - **How valuable is battery storage** for medium-voltage **grid expansion planning** under high **wind and solar penetration** ?

- Aim of the presentation :
  - **Creating an expansion planning model** for both **storage** and medium-voltage **grid**
  - Impact of using a **discretized grid** in expansion planning on storage economic space
  - Assessing the model sensibility to various exogenous parameters

2 Method and network definition

2.1 Method

- Modelisation of a **co-optimisation** of **grid** expansion, **storage** expansion and **dispatching**
  - Using **Pypsa** package
  - Minimisation of the total system cost (CAPEX and OPEX of lines, generators and storage units)

- Implementation of an iterative process **to turn line capacities continuous variables into discrete parameters**
  - rounding **number of parallel lines to an integer number**
  - allows a **more realistic grid representation**
  - increase storage economic space by **revealing residual congestions** that can be managed by battery storage

- (Sensibility analyses to assess the model sensibility to various parameters on a test case)

2.2 Definition of the test network

- Pypsa v0.23
- Three nodes network, 63kV
- One week hours, based on July 2015
  - All CAPEX are annualized and weighted according to the simulation horizon
- Date sources :
  - Storage costs from *RTE Futurs énergétiques 2050*, round trip efficiency 0.95
  - Solar production factortime serie from *NUTS2* Occitanie
  - Lines costs and parameters (impedance, nominal current) based on experts knowledge
  - Load factor from *OpenData Réseaux Energie*
  - Load shedding cost from *ENTSO-e* value 20k€/MWh

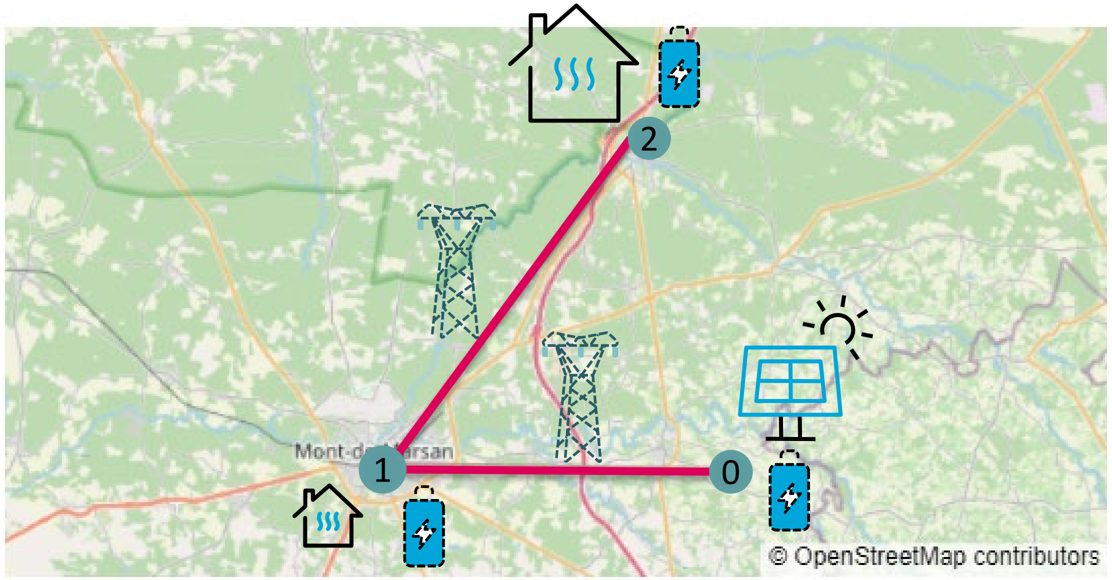
Lines
- voltage : 63 kV
- length : ~20 km
- nominal frequency : 50 Hz
- impedance : 0,401 Ohm/km
- nominal current : 567 A
- cost : 91 k€/MVA
- **Optimised capacity for apparent power : 0 MVA, extendable***

Storage (1 hour)
- **installed capacity : 0 MW, extendable***
- **dispatched and stored power : committable***
- efficiency : 0.9
- cost : 255 k€/MW

Load
- load time series

Load shedding
- marginal cost : 20 k€/MWh
- **committable***

Solar
- wind factor time series
- nominal capacity installed (fixed)
- marginal cost : 0 €/MWh
- **curtailment : downward commitment only***



2.3 Discretization of the grid

Initial network, with continuous line capacities
- Lines :
  - Extendable
  - Continuous capacities s_{nom}
- Storages :
  - Extendable
  - Commitable

Pypsa optimization function (ilopf)

Optimized network
- Lines :
  - Optimal capacities $\mathbf{s_{nom,opt}}$
  - Reactance $\mathbf{X_n}$
- Storages :
  - Optimal capacities p_{nom}
  - Optimal dispatch $p_{dispatch}$, p_{store}

Lines Capacities Discretization

$s_{nom,min} = s_{nom,max} = base_{s\_nom}$ *
- ➢ Up : roundup($s_{nom,opt}/base_{s\_nom}$)
- ➢ Down : $s_{nom,opt}$ // $base_{s\_nom}$)

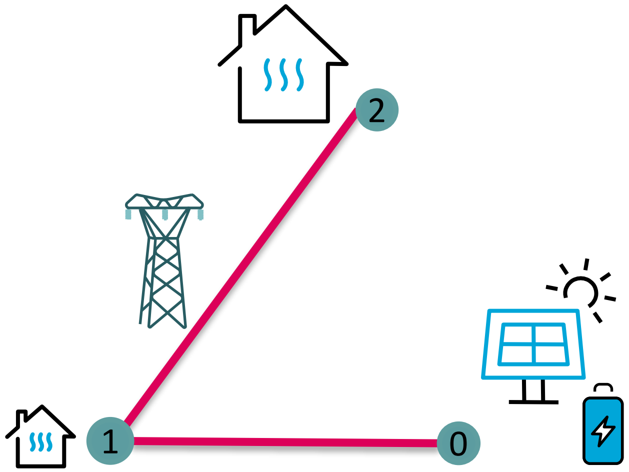
1st optimisation network, with discrete line capacities
- Lines :
  - non-extendable
  - Discretized $s_{nom,opt}$, updated X_n
- Storages :
  - Extendable
  - Commitable

Pypsa optimization function (lopf)

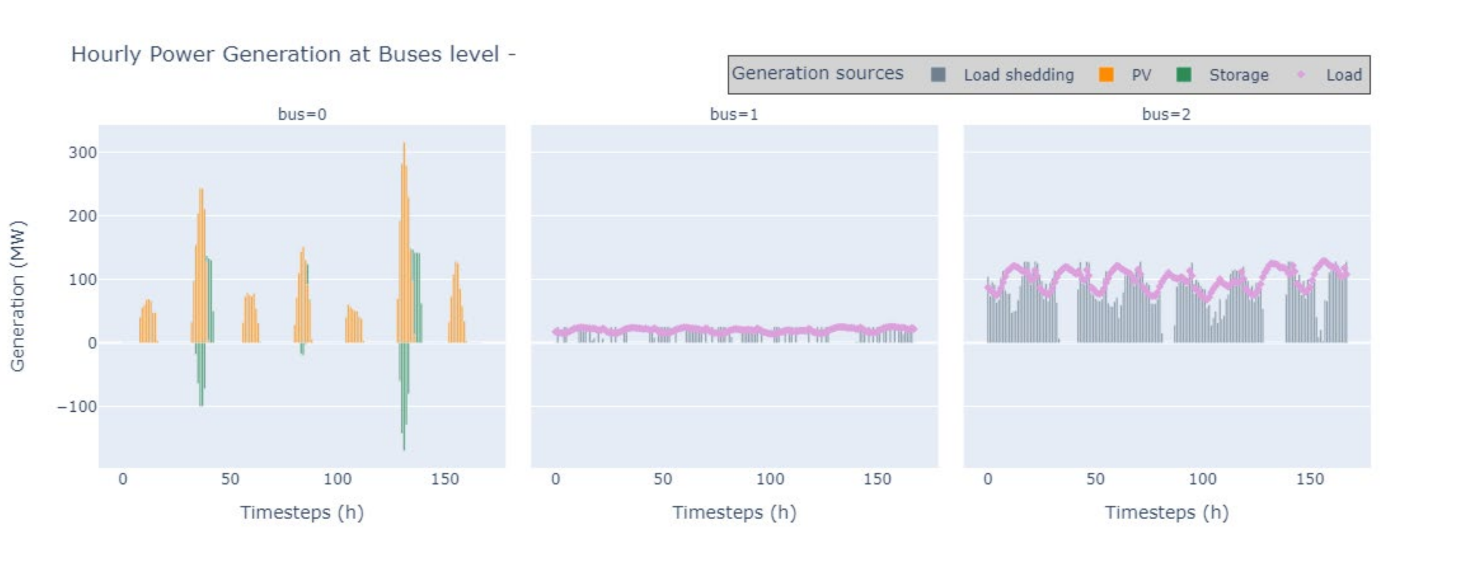
2nd optimisation network
- Lines :
  - *not changes in $s_{nom,opt}$ with 1st*
- Storages :
  - **Optimal capacities $\mathbf{p_{nom}}$**
  - **Optimal dispatch $\mathbf{p_{dispatch}}$, $\mathbf{p_{store}}$**

3 Results (preliminary)

3.1 Results of an optimization – test case



Network	Continuous
PV installed (MW)	600
PV Pmax (MW)	316
Line Cost (k€/km)	267
Storage Cost (€/kWh)	500
Line 01 s_nom_opt	150
Line 12 s_nom_opt	125
Storage 0 p_nom_opt	145
Storage 1 p_nom_opt	0
Storage 2 p_nom_opt	0
Objective Function Total Cost	**290 257 369**
Line cost	51
Storage cost	490 049
Dispatch cost	289 767 319



3.2 Impact of Line discretization

Network	PV installed (MW)	PV Pmax (MW)	Line Cost (k€/km)	Storage Cost (€/kWh)		Line 01 s_nom_opt	Line 12 s_nom_opt	Storage 0 p_nom_opt	Storage 1 p_nom_opt	Storage 2 p_nom_opt		Objective Function Total Cost	Line cost	Storage cost	Dispatch cost
Continuous	600	316	267	500		150	125	145	0	0		290 257 369	51	490 049	289 767 319
Discrete – round up grid	600	316	267	500		186	186	26	0	119		290 257 438	68	490 049	289 767 319
Discrete – round down grid	600	316	267	500		124	124	235	0	0		290 812 526	46	593 424	290 219 055

- Observation of the line capacities rounding

Impacts on the results :

- Total cost increase with grid discretization
- Rounding up :
  - same storage capacities installed & allows storage installation on nodes other than the PV one
  - small cost increased due to line additional capacities
- Rounding down :
  - increased storage capacities (235 MW versus 145 MW previously) & limits storage instalation on the PV node

3.3 Sensibility analysis

[-75%,-50%,+50%,+75%] on Installed PV, Line cost, Storage cost, Load shedding cost

Network	PV installed (MW)	Line Cost (k€/km)	Storage Cost (€/kWh)	Load shedding Cost (€/MWh)	Variation of Total Cost	Variation of Total Line Cost	Variation of Total Storage Cost	Variation of Total Load shedding cost
Reference case	*600*	*267*	*200*	*20000*				
PV -75%	150	267	200	20000	29%	-48%	-100%	29%
PV -50%	300	267	200	20000	19%	-15%	-98%	19%
PV +50%	900	267	200	20000	-19%	0%	124%	-19%
PV +75%	1050	267	200	20000	-28%	0%	191%	-28%
Storage cost -75%	600	267	50	20000	-0.05%	0%	-75%	0%
Storage cost -50%	600	267	100	20000	-0.03%	0%	-50%	0%
Storage cost +50%	600	267	300	20000	0.03%	0%	50%	0%
Storage cost +75%	600	267	350	20000	0.05%	0%	75%	0%
Line cost -75%	600	66.75	200	20000	-0.00002%	-75%	0%	0%
Line cost -50%	600	133.5	200	20000	-0.00001%	-50%	0%	0%
Line cost +50%	600	400.5	200	20000	0.00001%	50%	0%	0%
Line cost +75%	600	467.25	200	20000	0.00002%	75%	0%	0%
Load shedding cost -75%	600	267	200	5000	-75%	0%	0%	-75%
Load shedding cost -50%	600	267	200	10000	-50%	0%	0%	-50%
Load shedding cost +50%	600	267	200	30000	50%	0%	0%	50%
Load shedding cost +75%	600	267	200	35000	75%	0%	0%	75%

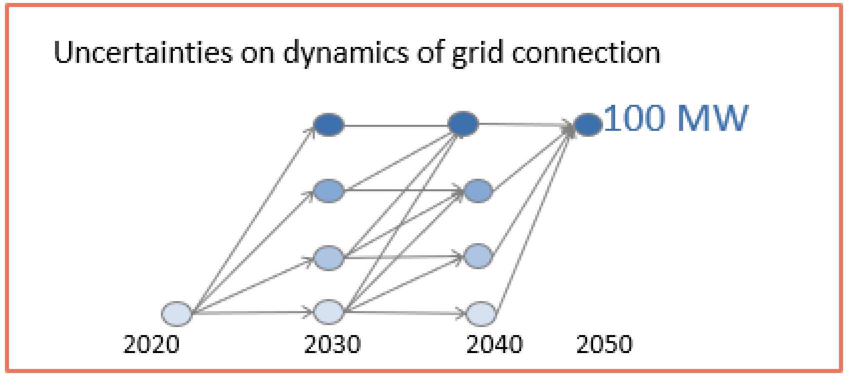
Observations

- Higher PV reduces system costs :
  - Opportunity for more storage
  - Decreasing load shedding
- Storage cost sensibility does not influence the line investments → to further investigate
- Line cost being a super small part of total system cost, its sensibility is neglectable
- Load shedding price heavily influences the total system cost
- Sensibility shown depends on the reference case

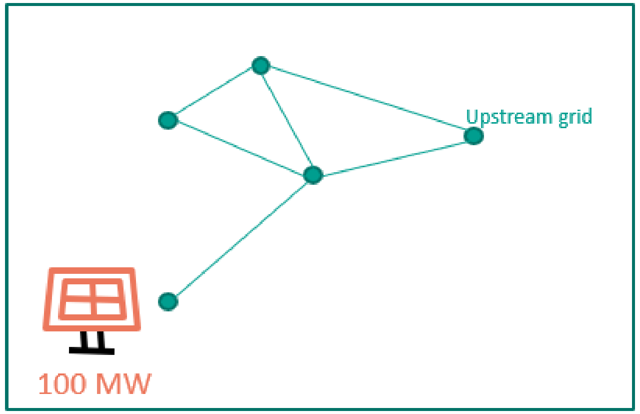
3.4 Future works

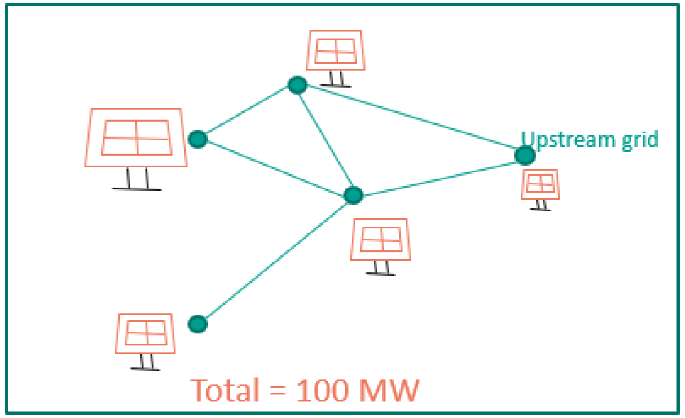
- Assess the model sensibility to different parameters (battery storage E/P size, load amount) & wider range or try more relevant reference points
- Expan time horizon and the network

- Shift from static to multi horizon planning :
  - Include construction time constraints, lifespan and economic lifetime considerations
  - Combine trajectories to create uncertainty on the rythm of RES deployement



- Study the location spread of RES :
  - widespread RES could increase the value of storage relative to line reinforcement





Annexes

.1 Litterature overview on storage value for grid expansion

- Studies on transmission and storage expansion
  - [1] C. Bustos, E. Sauma, S. Torre, J. A. Aguado, J. Contreras, and D. Pozo, ‘Energy storage and transmission expansion planning: substitutes or complements?’, Apr. 2018
  - [2] S. Wogrin and D. F. Gayme, ‘Optimizing Storage Siting, Sizing, and Technology Portfolios in Transmission-Constrained Networks’, Nov. 2015
  - [3] I.-C. Gonzalez-Romero, S. Wogrin, and T. Gomez, ‘Proactive transmission expansion planning with storage considerations’, Apr. 2019
  - [4] A. Manocha, N. Patankar, and J. D. Jenkins, ‘Reducing transmission expansion by co-optimizing sizing of wind, solar, storage and grid connection capacity’, Mar. 21, 2023
  - [5] G. Migliavacca et al., ‘The Innovative FlexPlan Grid-Planning Methodology: How Storage and Flexible Resources Could Help in De-Bottlenecking the European System’, Feb. 2021
- Studies on distribution and storage expansion
  - [6] N. Astier, R. Rajagopal, and F. A. Wolak, ‘What kinds of distributed generation technologies defer network expansions? Evidence from France’, May 2021
  - [7] O. Laribi and K. Rudion, ‘Optimized Planning of Distribution Grids Considering Grid Expansion, Battery Systems and Dynamic Curtailment’, Aug. 2021
  - [8] J. A. Schachter, P. Mancarella, J. Moriarty, and R. Shaw, ‘Flexible investment under uncertainty in smart distribution networks with demand side response: Assessment framework and practical implementation’, Oct. 2016
  - [9] J. N. Fidalgo, M. Couto, and L. Fournié, ‘The worth of network upgrade deferral in distribution systems – Truism or myth?’, Aug. 2016

➢ Transmission Expansion Planning (TEP) studies power flow between regions or countries : **the network used is based on the real transmission lines aggregation**. Line capacities are represented as **continuous variable**

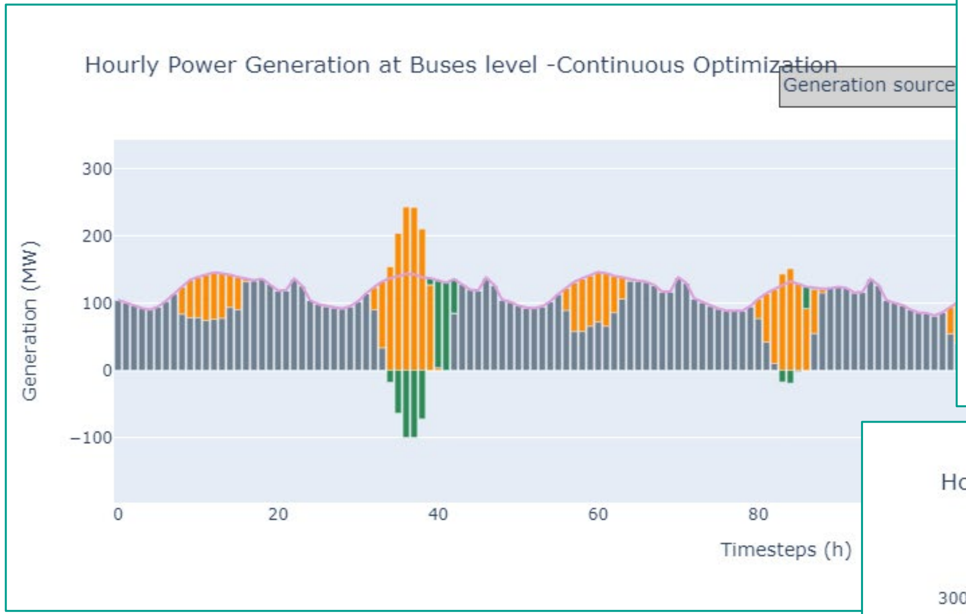
➢ Studies on distribution grid and local flexibilities (domestic storage, demand side response, electric vehicules) mostly use a **radial grid** representation. They focus on **lower voltage flexibilities**.

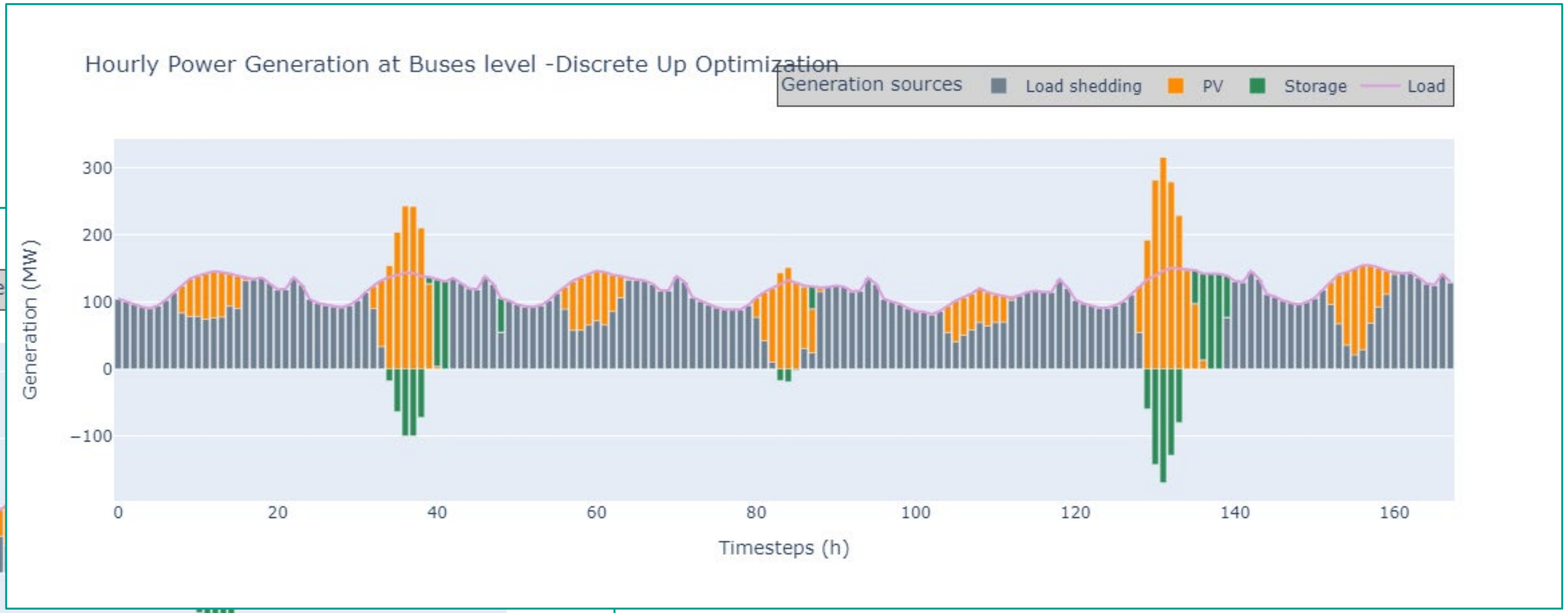
➢ The MV grid is meshed. Representing line capacities with continuous variable is not realistic. Moreover, storage can be best valorised for the grid on residual line congestion.

.2 Comparison Continuous Discrete for 2 Storage cost

Network	PV installed (MW)	PV Pmax (MW)	Line Cost (k€/km)	Storage Cost (€/kWh)	Line 01 s_nom_opt	Line 12 s_nom_opt	Storage 0 p_nom_opt	Storage 1 p_nom_opt	Storage 2 p_nom_opt	Objective Function Total Cost	Line cost	Storage cost	Dispatch cost
Continuous	600	316	267	500	150	125	145	0	0	290 257 369	51	490 049	289 767 319
Discrete – round up grid	600	316	267	500	186	186	26	0	119	290 257 438	68	490 049	289 767 319
Discrete – round down grid	600	316	267	500	124	124	235	0	0	290 812 526	46	593 424	290 219 055
Continuous	600	316	267	200	150	125	552	0	0	289 963 340	51	196 020	289 767 319
Discrete – round up grid	600	316	267	200	186	186	352	200	0	289 963 408	68	196 020	289 767 319
Discrete – round down grid	600	316	267	200	124	124	669	0	0	290 456 472	46	237 370	290 219 055

.3 Influence on the dispatching





.4 Storage costs & Line characteristics

Consultation publique sur le cadrage et les hypothèses du Bilan prévisionnel à l'horizon 2050

Coût du stockage par batterie

Pour les batteries stationnaires dédiées au système électrique, RTE propose de retenir trois hypothèses de coût. Ces hypothèses s'appuient sur une revue de littérature des coûts des projets de stockage stationnaire par batterie Li-ion, pour des batteries de 1h ou 4h (NREL, Bloomberg NEF, JRC, Lazard, Navigant, PEPS4, littérature académique…). Les OPEX fixes annuels sont estimés à 3,5% des CAPEX initiaux. La durée de vie estimée est de 15 ans.

	batteries 1 h			batteries 4 h		
€2019/kWh	2020	2035	2050	2020	2035	2050
CAPEX bas	370	190	175	260	130	115
CAPEX moyen	435	275	255	300	185	150
CAPEX haut	500	360	335	340	240	185

Tableau 8 : Hypothèses de coûts unitaires des batteries stationnaires

Tension (kV)	Section (mm²)	Nominal current - summer (A)	Nominal current - Winter (A)	Impedance resistance – R/km	Impedance reactance – X/km	Rebuilding cost (k€/km)
63-90	228	567	673	0.147	0.401	267

Le réseau
de transport
d'électricité

Thank you for your attention !
Any questions ?

adrienne.de-bazelaire@centralesupelec.fr