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Battery energy storage for optimal renewable power trading

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CSEM has developed a battery model for LTO cells that is suitable for energy simulation purposes to analyze battery usage for optimization of wind park operation. The project challenge has been to find a correct compromise between the model complexity - its capability to represents the non-linear electrochemical behaviors – and the computational effort required for the simulations. The model is of semi-empirical type, based on a simplification of standard electrical circuit models (ECM). The battery model developed at CSEM has been included into a wind park optimization process, which measures the added value in terms of imbalance penalty reduction and the financial return from selling the renewable power into the market. Out of the six outlined optimization strategies, two showed promising results whereby a storage owner can increase the financial return of the wind park.

The general objective of the project BESTRADE (battery energy storage for optimal renewable power trading) was to expand the knowledge about the impact of battery energy storage onto the power grid. This objective is achieved by investigating the opportunity to alleviate the financial impact of renewable energy production intermittency via the use of batteries. The specific objectives were: (i) to model the real-time behavior of a specific battery chemistry and (ii) to assess the financial value that such battery storage can bring when used in the dispatch of a wind park. For this purpose, CSEM and implementation partners Samawatt SA and Lechanché SA shared their knowledge: Leclanchè as provider of LTO (lithium-titanate chemistry) cells, CSEM as producer of the battery model and SAMAWATT as the user of the model to run optimization strategies. As regards of the first objective, CSEM faced the challenge to develop a computationally effective model to be used for long-lasting energy simulation purposes (i.e., wind park optimization analyses), without sacrificing the capability of the model itself to represent the non-linear behaviors of any battery cell. The modelling approach used for the purpose was a semi-empirical model based on a simplification of standard ECM. Specifically, a two-element ECM was chosen that includes:

- A voltage source to model the energy capabilities of the cell and to compute/update the state of charge (SoC);
- A polarization resistance to model the power capabilities and to estimate the cell overpotential in regime conditions.

Moreover, capacity fade and power fade mechanisms were also included to account for State-of-Health (SoH, i.e., capacity decrease) and State-of-Resistance (SoR, i.e., resistance increase).

The model was based on an extensive battery testing campaign carried out in two different laboratories: the energy system lab at CSEM in Neuchâtel and the Energy Storage Research Center (ESReC) in Biel (Fig.1-left).

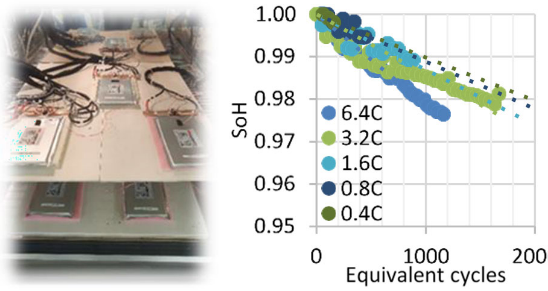


Figure 1: LTO cells under tests, and aging tests results.

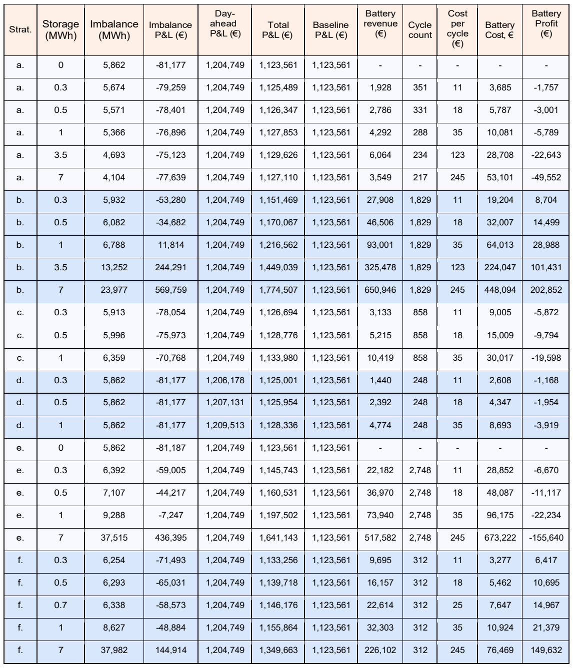
Different testing protocols have been developed to determine the model parameters. Specifically: (i) the OCV characterization.

tests to derive look-up table which links the open circuit voltage with the SoC; (ii) the efficiency characterization tests to derive the polarization resistance parameters as function of the current rate and SoC; and (iii) aging tests to determine the parameters of the SoH model (Fig.1-right) and SoR model a as function of the equivalent cycles and current rates.

The developed cell model has been scaled-up to a system level by using a per-unit approach (i.e., the power/energy ratio is preserved), implemented into Matlab script and used to run simulations. The model performance was respecting the limitation of execution time below 4s for a 24h scenario evaluation set at the beginning of the project.

As regards of the second objective, a portfolio of wind parks with a capacity of 30MW has been used as reference scenario with an imbalance account of about 20 % of the total parks capacity for a given hour. Several dispatching strategies (i.e., the battery charging/discharging signals) have been tested, from simple ones to the proprietary ones (Figure 2). The results show that simple strategies such as deviation correction, or peak/off-peak arbitrage are not profitable unless the battery storage cost drops below €150/kWh. On the contrary, more sophisticated strategies, such as stochastic optimization, proved to have a competitive advantage and could lead to a profitable outcome in the current market conditions.

The BESTRADE outcomes open room for future improvements as enhancing the imbalance price prediction model and combining it with the stochastic optimization to extract higher financial value for the wind park and battery owner.



Strat.	Storage (MWh)	Imbalance (MWh)	Imbalance P&L (€)	Day-ahead P&L (€)	Total P&L (€)	Baseline P&L (€)	Battery revenue (€)	Cycle count	Cost per cycle (€)	Battery Cost, €	Battery Profit (€)
a.	0	5,862	-81,177	1,204,749	1,123,561	1,123,561	-	-	-	-	-
a.	0.3	5,674	-79,259	1,204,749	1,125,489	1,123,561	1,928	351	11	3,685	-1,757
a.	0.5	5,571	-78,401	1,204,749	1,126,347	1,123,561	2,786	331	18	5,787	-3,001
a.	1	5,366	-76,896	1,204,749	1,127,853	1,123,561	4,292	288	35	10,081	-5,789
a.	3.5	4,693	-75,123	1,204,749	1,129,626	1,123,561	6,064	234	123	28,708	-22,643
a.	7	4,104	-77,639	1,204,749	1,127,110	1,123,561	3,549	217	245	53,101	-49,552
b.	0.3	5,932	-53,280	1,204,749	1,151,469	1,123,561	27,908	1,829	11	19,204	8,704
b.	0.5	6,082	-34,682	1,204,749	1,170,067	1,123,561	46,506	1,829	18	32,007	14,499
b.	1	6,788	11,814	1,204,749	1,216,562	1,123,561	93,001	1,829	35	64,013	28,988
b.	3.5	13,252	244,291	1,204,749	1,449,039	1,123,561	325,478	1,829	123	224,047	101,431
b.	7	23,977	569,759	1,204,749	1,774,507	1,123,561	650,946	1,829	245	448,094	202,852
c.	0.3	5,913	-78,054	1,204,749	1,126,694	1,123,561	3,133	858	11	9,005	-5,872
c.	0.5	5,996	-75,973	1,204,749	1,128,776	1,123,561	5,215	858	18	15,009	-9,794
c.	1	6,359	-70,768	1,204,749	1,133,980	1,123,561	10,419	858	35	30,017	-19,598
d.	0.3	5,862	-81,177	1,206,178	1,125,001	1,123,561	1,440	248	11	2,608	-1,168
d.	0.5	5,862	-81,177	1,207,131	1,125,954	1,123,561	2,392	248	18	4,347	-1,954
d.	1	5,862	-81,177	1,209,513	1,128,336	1,123,561	4,774	248	35	8,693	-3,919
e.	0	5,862	-81,187	1,204,749	1,123,561	1,123,561	-	-	-	-	-
e.	0.3	6,392	-59,005	1,204,749	1,145,743	1,123,561	22,182	2,748	11	28,852	-6,670
e.	0.5	7,107	-44,217	1,204,749	1,160,531	1,123,561	36,970	2,748	18	48,087	-11,117
e.	1	9,288	-7,247	1,204,749	1,197,502	1,123,561	73,940	2,748	35	96,175	-22,234
e.	7	37,515	436,395	1,204,749	1,641,143	1,123,561	517,582	2,748	245	673,222	-155,640
f.	0.3	6,254	-71,493	1,204,749	1,133,256	1,123,561	9,695	312	11	3,277	6,417
f.	0.5	6,293	-65,031	1,204,749	1,139,718	1,123,561	16,157	312	18	5,462	10,695
f.	0.7	6,338	-58,573	1,204,749	1,146,176	1,123,561	22,614	312	25	7,647	14,967
f.	1	8,627	-48,884	1,204,749	1,155,864	1,123,561	32,303	312	35	10,924	21,379
f.	7	37,982	144,914	1,204,749	1,349,663	1,123,561	226,102	312	245	76,469	149,632

Figure 2: Wind park optimization strategies and results.

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