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Cost of out-of-balance conditions in utility-scale batteries

- Out-of-balance is largest cause of loss of revenue in utility-scale batteries.[1]
- Batteries can lose between 10% and 20% of available capacity due to out-of-balance.[2]
- In most utility-scale batteries, modules or strings need to be taken offline for balancing. When those modules/strings are offline, there is 100% loss of revenue from them.[3]
- Modules or strings can be offline for hours or days while rebalancing.[4]
- Loss of revenue due to out-of-balance batteries can cost between $10k to $40k/MW/year.[5]
    - For example, loss of revenue due to out-of-balance on a 200MW battery can be as much as $2M/year to $8M/year
- Two ways to address out-of-balance:
    1. Oversize the battery by anywhere from 5% to 33%.[6]
        - This increases CapEx significantly
        - On a battery with nominal power of 200MW, this can represent additional up-front CapEx cost of $4M to $27M.[7]
    2. Negotiate with the customer to accept derating at a faster rate
        - This reduces the revenue stream over the life of the battery. Batteries that derate faster generate less revenue.
- If battery capacity declines below the agreed-upon rate of derating, the battery operator must pay penalties to the utility.

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[1] Source: TWAICE webinar on cost of out-of-balance conditions in BESS
[2] Source: TWAICE and Modo Energy
[3] Source: TWAICE
[4] Source: Modo Energy
[5] Source: TWAICE slide deck
[6] Source: TWAICE
[7] Source: The battery model on the last two pages of this document

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Summary of out-of-balance costs to BESS operators:

1. Oversize the battery, which increases CapEx
2. Loss of revenue when modules or strings need to be taken offline for balancing
3. Reduced revenue due to lower capacity
4. Fines for derating faster than contracted

How True Balancing and Positive Balancing Can Help

- Our technologies can minimize or completely eliminate all four of these areas of cost.
- Positive Balancing (recommended for utility-scale batteries) adds about 1% to the total cost of the battery. This is about $625,000 for an 800MWh battery.[8]
- Potential savings in an 800MWh battery:
    - $4M to $25M reduction in initial CapEx
        - Battery doesn't need to be oversized, or the amount of oversize can be much less
    - $2M to $8M per year for every year of operation of the battery
        - Completely eliminate loss of revenue due to reduction in capacity caused by out-of-balance conditions
    - An additional $1M per year
        - Modules or strings never need to be taken offline for balancing
        - No fines for derating faster than contracted rate

Additional Benefit: Extends Battery Life

Out-of-balance conditions cause batteries to reach end-of-life prematurely. By completely eliminating out-of-balance conditions, Positive Balancing can extend battery life by 20% to 40%.

Extending battery life by 20% to 40% can significantly increase ROI. A battery that would normally need to be retired at 10 years could have a 12-to-14-year life.

[8] See BESS battery cost model on the last two pages of this document.

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Cell Impedance Data: Early Warning of Cells Going Bad

In addition to eliminating out-of-balance conditions, our technology can provide real-time data on impedance of every cell in the series stack in the battery. Impedances from 1kHz down to 20mHz can be calculated.

Impedance data can provide early warning of cells that are going bad. This allows you to schedule preventive maintenance at a time that will minimize loss of revenue. The battery can be repaired before critical or catastrophic failure occurs. Cost of critical/catastrophic failures varies widely, but the cost can range from millions of dollars for critical failures to hundreds of millions of dollars for battery fires.

Improved Battery Performance After Maintenance and Repairs

If a module needs to be replaced, a new module can be installed in series with the existing used modules. This will usually create an out-of-balance condition, because the used modules will have lower capacity than new module.

When a new module is connected to used modules, existing balancing technologies will have difficulty keeping such a battery balanced. They may be unable to keep the battery balanced and its remaining life could be very short.

If you replace a used module with a new module, either of our technologies can keep your battery balanced, giving it maximum available capacity and longest possible remaining life.

Reference battery for analyzing added-value of Positive Balancing to BESS

Table 1: Baseline Parameters

Item #	Baseline Parameters	Value	Units	Comments
1	Nominal power:	200	MW	Assume that these are the customer's requirements for total battery power and back-up duratio
2	Back-up duration at full power:	4	hours	
3	Cell chemistry:	LFP	n/a	LFP is the most common battery chemistry for large stationary BESS
4	Cost of cells per kWh:	$50	$	This is lowest available price from the largest Chinese cell manufacturers. This price does not include tariffs. Source: Volta Foundation 2024 Battery Report
5	Additional cost for "everything else":	38%	Percent	Source: Volta Foundation 2024 Battery Report; ultimate source is BloombergNEF
6	Nominal cell voltage:	3.2	V	
7	Pack voltage:	1,600	V	I chose 1600V because it's a reasonable voltage for grid connection, and with pack voltage of 1600V most of the derived values in Table 2 are integers
8	Individual cell capacity:	300	Ah	We assume 300Ah prismatic cells
9	Cells in series per module:	50	Cells	Each module has a 50S1P architecture
10	Cells in parallel per module:	1	Cells	
11	Number of channels per Positive Balancing board	25	Channels	"Channels" refers to balancing channel. The complete system will have one balancing channel for each cell in series in each string.
12	Maximum balancing current:	15	A	15A balancing current is ~0.05C for 300Ah modules. This should be sufficient to keep the battery balanced for its entire life if Positive Balancing is OEM equipment.
13	Cost per channel of Positive Balancing board	$0.75	$	This cost estimate assumes high-volume mass-production for a 15A Positive Balancing system

Table 2: Derived Parameters

Item #	Derived Parameters	Value	Units	Comments
1	Nominal energy:	800	MWh	200MW power x 4 hours of back-up
2	Total cells in series:	500	Cells	Pack voltage divided by cell voltage: 1600V ÷ 3.2V
3	Number of cells per module:	50	Cells	50S/1P architecture
4	Volts per module:	160	V	3.2V/cell x 50 cells in series
5	Number of modules in series:	10	Modules	Pack voltage divided by module voltage: 1600V ÷ 160V
6	Capacity of each module:	300	Ah	Cell capacity times number of cells in parallel: 300Ah x 1
7	Nominal energy of each module:	48,000.00	Wh	Module voltage x Ah capacity of each module: 160V x 300Ah
8	Minimum number of modules:	16,666.67	Modules	Nominal energy of battery ÷ nominal energy of each module: 2000MWh ÷ 48kWh
9	Number of modules to make complete strings of 10 in series	16,670	Modules	Rounded up to nearest 10
10	Nominal energy of battery as configured:	800.16	MWh	Nominal energy of each module x number of modules: 48kWh x 16,670 modules
11	Cost of bare battery:	$40,008,000	$	Nominal energy of battery x cost per kWh: 800.16MWh x $50/kWh
12	Cost of "everything else":	$15,203,040	$	Additional cost of "everything else" is 35% of cost of bare battery (from Table 1, Item 5))
13	Total battery cost:	$55,211,040	$	Sum of bare battery plus "everything else"
14	How much battery is oversized:	0.02%	Percent	Battery as configured is oversized by 0.022% over customer spec See note 1
15	Number of Positive Balancing boards/module:	2	Boards	25 channels per board; 50 cells in series per module.
16	Total number of 25-channel Positive Balancing boards:	33,340	Boards	2 boards/module x 16,670 modules
17	Total number of channels:	833,500	Channels	25 channels per board x 33,340 boards
18	Cost of balancing system:	$625,125	$	$0.75 per channel x 833,500 channels
19	Cost of balancing system as % of battery cost:	1.13%	Percent	

Note 1 *: For purpose of this value analysis, we start with the battery sized as closely as possible to the nominal requirement.*

Cost to oversize the battery by 5%: $2,760,552

Cost to oversize the battery by 33%: $18,219,643