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Energy storage price targets to enable energy arbitrage in CAISO

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Abstract – The potential annual revenue of a generic battery energy storage system (BESS) participating in the CAISO day-ahead energy market was analyzed for 2,145 nodes over a seven year period (2014-2020). This data was used to estimate the break-even capital cost for each node as well as the cost requirements for several internal rate of return (IRR) scenarios.

Revenue optimization formulation:

$$max \sum_{t=1}^{T} \left[(P_t - C_d) \cdot q_t^D - (P_t + C_r) \cdot q_t^R \right] \cdot e^{-r_o t}$$

$$S_t = \gamma_s \cdot S_{t-1} + \gamma_c \cdot q_t^R - q_t^D$$

where

- S_t is the state of charge at any time t,
- q_t^R is the quantity of energy recharged at time t,
- q_t^D is the quantity of energy discharged at time t,
- γ_s is the storage efficiency,
- γ_c is the conversion efficiency,
- P_t is the price of electricity (LMP) at time t,
- C_d is the cost of discharging at time t,
- C_r is the cost of recharging at time t, and
- r_o is the interest rate over one time period

$$0 \le S_t \le \bar{S}, \forall t \qquad 0 \le q_t^R \le \bar{q}^R, \forall t \qquad 0 \le q_t^D \le \bar{q}^D, \forall t$$

The break-even cost formulation for each node:

The break-even capital cost for each node is obtained by first setting the NPV of the total cost equal to the NPV of the revenue streams for T years for each LMP node.

$$\begin{aligned} \text{NPV}\{\text{revenue}\} &= \text{NPV}\{\text{total cost}\} \\ &= \text{CAP} + \text{NPV}\{\text{O\&M costs}\} \end{aligned}$$

The break-even capital cost for each node is:

$$\text{CAP} = \frac{\text{GAF}_{r,g}^{T} \times \text{REV}}{1 + k \times \text{AF}_r^T}$$

Where

$$\text{AF}_r^T = \frac{1}{r} \cdot \left(1 - \frac{1}{(1+r)^T}\right)$$

and

$$\text{GAF}_{r,g}^{T} = \frac{1}{r-g} \cdot \left[1 - \left(\frac{1+g}{1+r}\right)^T\right]$$

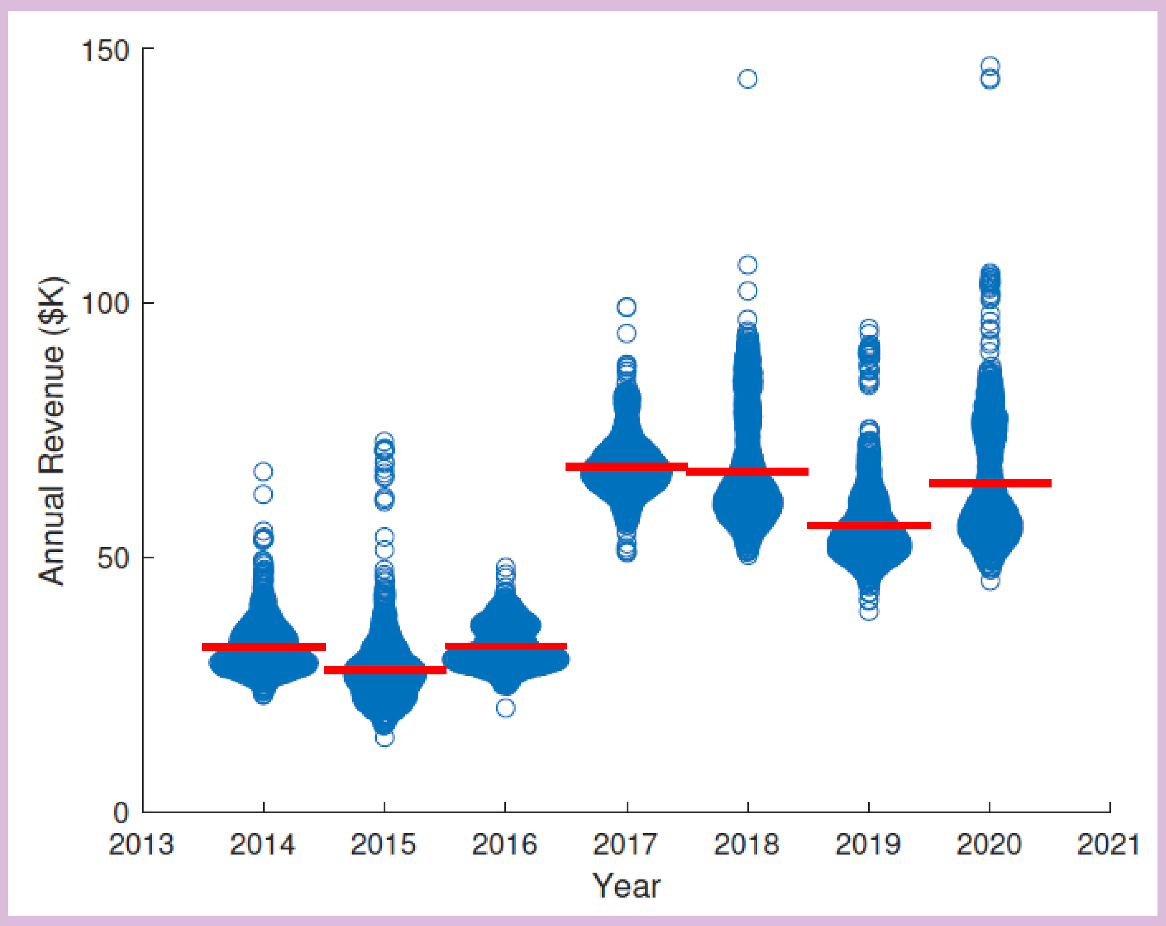
System parameters and case studies:

ENERGY STORAGE SYSTEM MODEL PARAMETERS

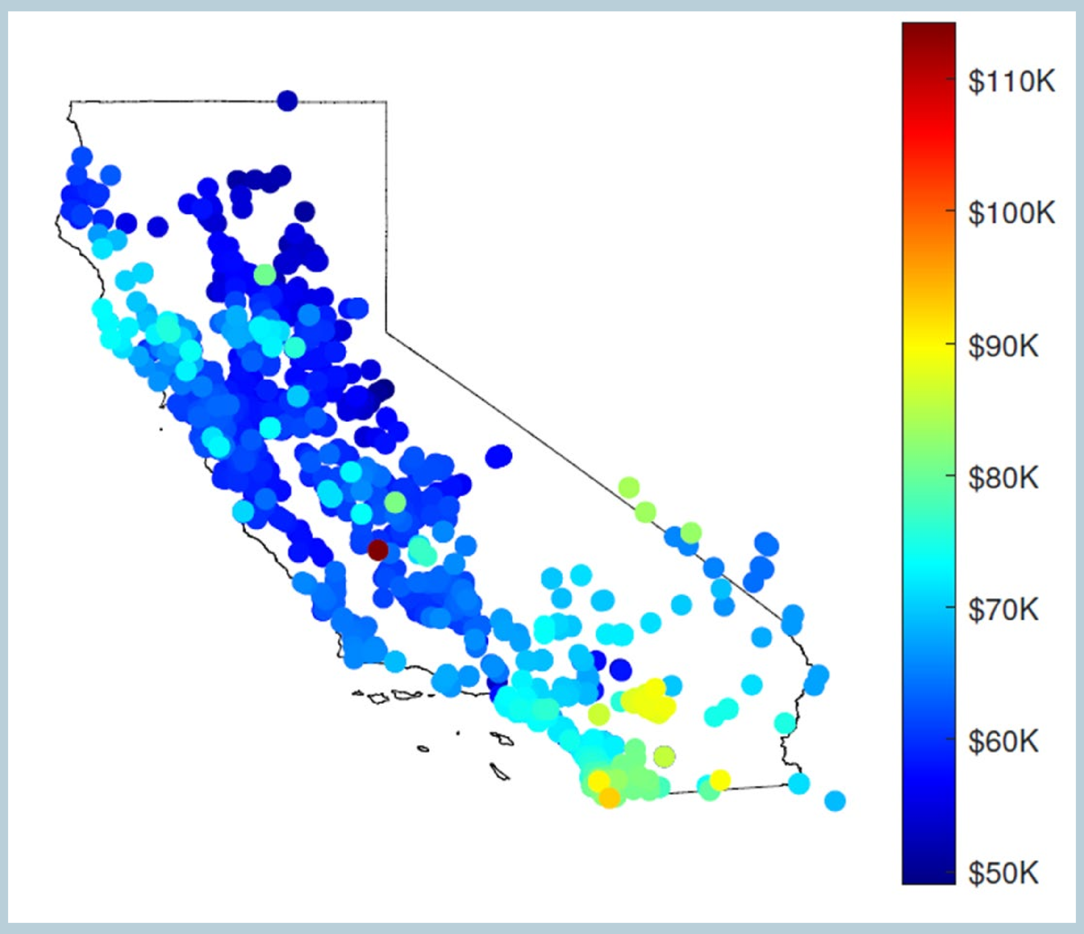
Value	Parameter
1	P_{max}, maximum power rating (MW)
4	$\bar{S}$, maximum state of charge (MWh)
1	$\bar{q}^R$ maximum quantity that can be bought/recharged in a period t (MWh)
1	$\bar{q}^D$ maximum quantity that can be sold/discharged in a period t (MWh)
1	Δt (hours)
1.0	γ_s, storage efficiency (fraction)
0.85	γ_c, conversion efficiency (fraction)
0	C_d, cost of discharging at time t (\$/MWh)
0	C_r, cost of recharging at time t, (\$/MWh)
0	r_o, interest rate over one time period (percent)

IRR = 2.5%, 5%, 7.5%, 10%
Annual revenue growth rates (g) = 0%, 3%, 6%
Project lifetimes (T) = 10 and 15 years
k = 2%

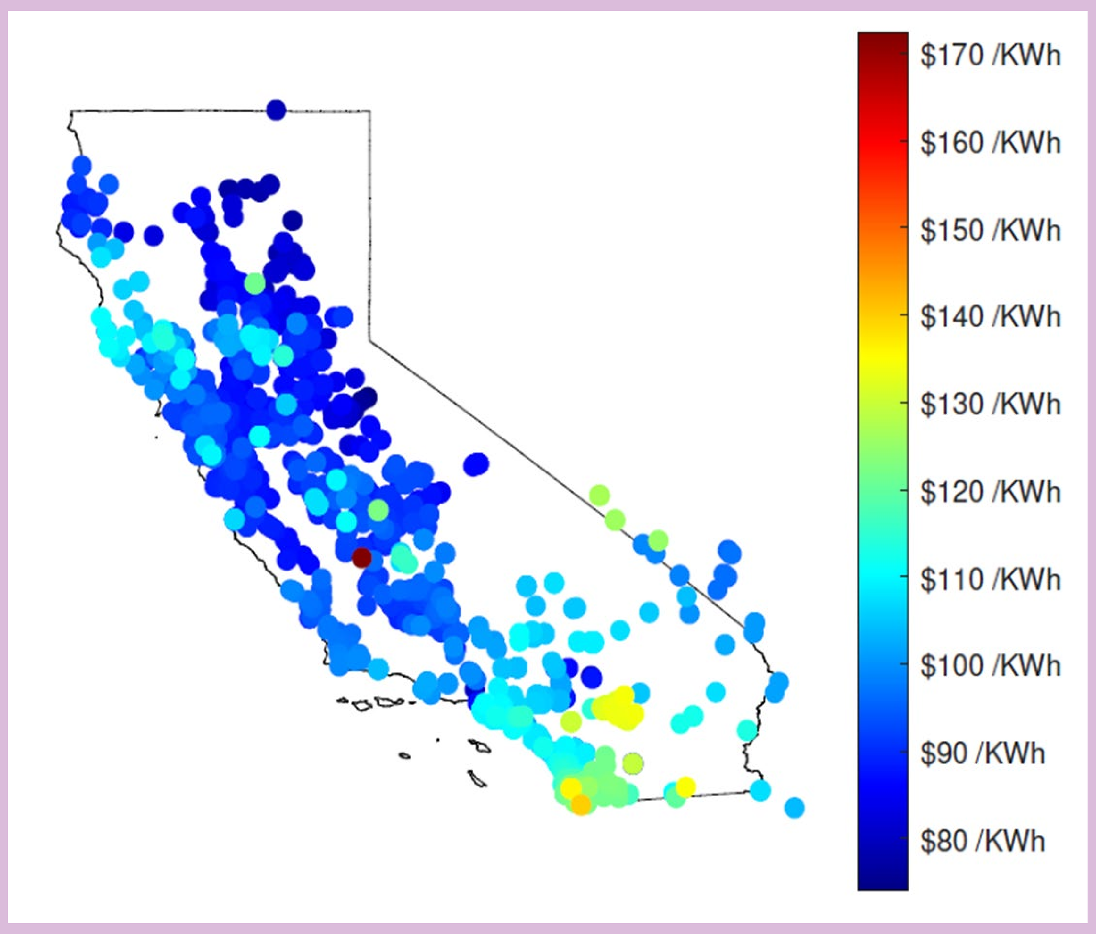
Distribution of average annual revenue for each of the 2,145 nodes. The red horizontal line indicates the average revenue for that year.



Average yearly revenue for 2,145 nodes in CAISO for the period 2017-2020 (thousands



Break-even cost distribution for 2,145 nodes in CAISO, IRR = 7.5%, 0% annual revenue growth, and T = 10 years.



Break-even capital cost statistics for different values of IRR. Project lifetime of 10 years, and average annual revenue growth at 0, 3, and 6%.

Rev Growth	\$/kWh	IRR (%) 2.5	5	7.5	10
0 %	median	113	101	92	83
	mean	119	107	96	87
	std. dev.	15	14	12	11
3 %	median	129	115	103	93
	mean	136	121	109	98
	std. dev.	17	15	14	12
6 %	median	147	131	117	105
	mean	155	138	123	110
	std. dev.	20	18	16	14

Break-even capital cost statistics for different values of IRR. Project lifetime of 15 years, and average annual revenue growth at 0, 3, and 6%.

Rev Growth	\$/kWh	IRR (%) 2.5	5	7.5	10
0 %	median	151	130	114	100
	mean	158	137	120	105
	std. dev.	20	18	15	13
3 %	median	184	157	136	118
	mean	194	166	143	124
	std. dev.	25	21	18	16
6 %	median	227	192	163	140
	mean	239	202	172	148
	std. dev.	31	26	22	19

Conclusion:

Using arbitrage as the only revenue stream for the BESS, capital costs need to be reduced by about 80% of the current cost for a battery system of the same type in order to make a reasonable rate of return.

Future work:

We are currently looking at additional revenue sources (i.e. frequency regulation, spinning and non-spinning reserves, as well as flexible ramping product) for the BESS in order to increase its revenue streams.

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