

Exceptional service in the national interest



Opportunities for Energy Storage in CAISO

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Goal: formulate the revenue maximization problem for energy storage participating in the CAISO day ahead for energy and frequency regulation and analyze three years of data.

The remuneration for providing frequency regulation in CAISO is given by:

Regulation payment = Capacity payment + Performance Payment + Net Energy Settlement

Energy Storage Model - Arbitrage

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

Energy Storage Model – Arbitrage + Regulation

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_{rd} q_t^{RD} - \gamma_{ru} q_t^{RU}$$

Where:

S_t : state of charge at time t (MWh)

γ_s : storage efficiency (%)

γ_c : conversion efficiency (%)

q_t^R : recharge quantity at time t (MWh)

q_t^D : discharge quantity at time t (MWh)

γ_{rd} : fraction of regulation down called upon (%)

γ_{ru} : fraction of regulation up called upon (%)

q_t^{RD} : capacity accepted for the regulation down market (MWh)

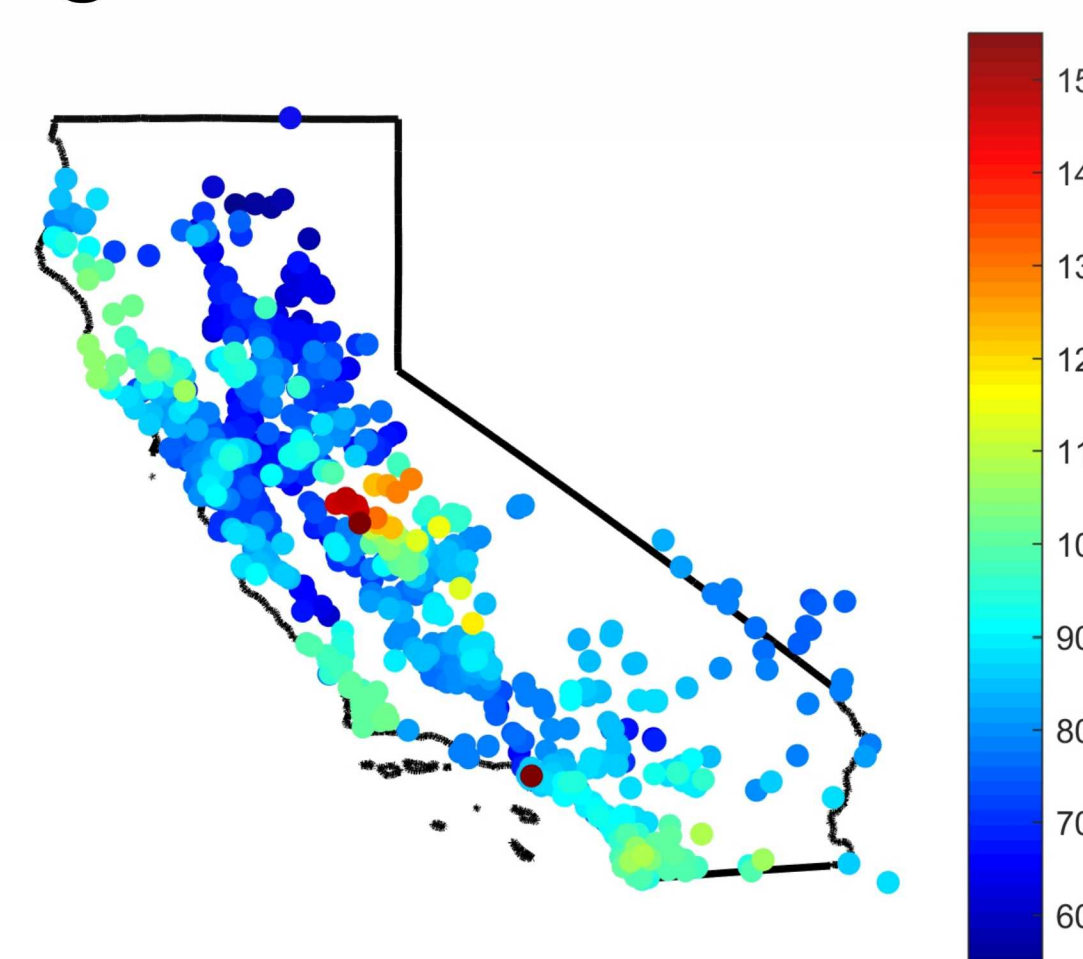
q_t^{RU} : capacity accepted for the regulation up market (MWh)

Cost function:

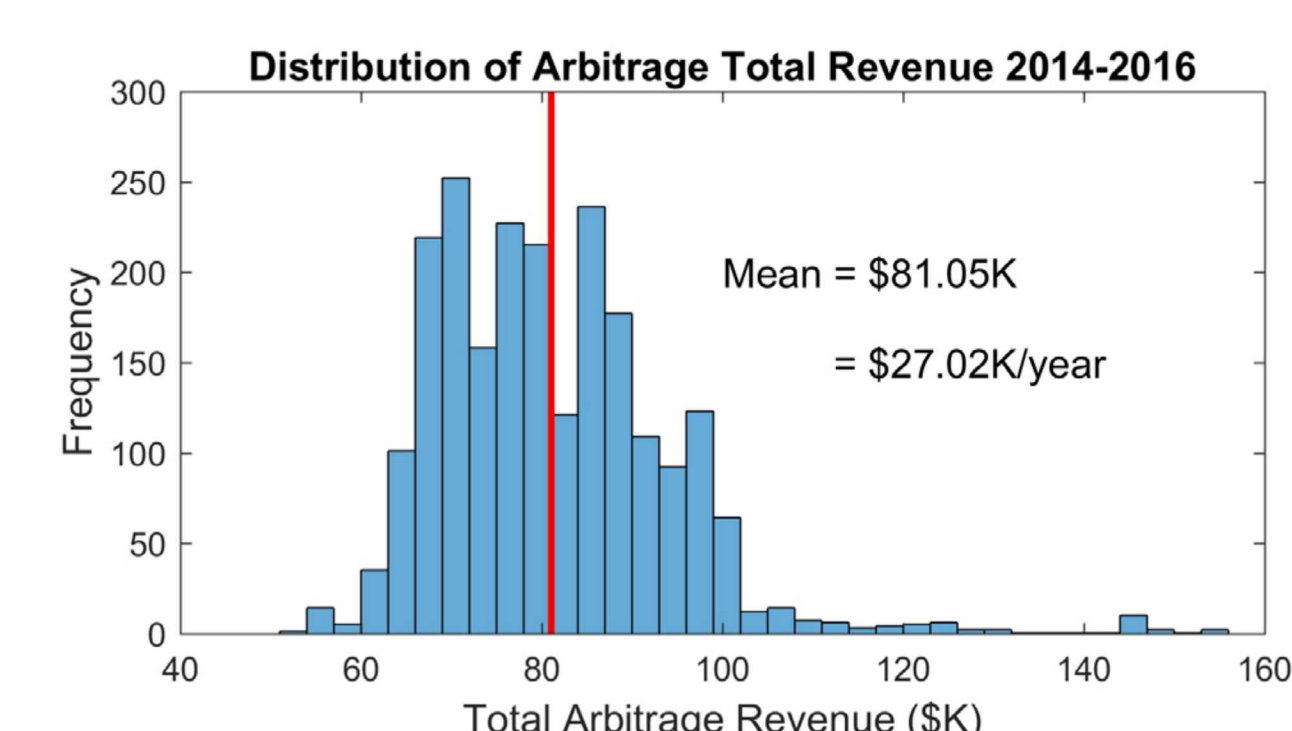
$$\max \sum_{t=1}^T [(P_t - C_d)(q_t^D + \gamma_{ru} q_t^{RU}) - (P_t + C_r)(q_t^R + \gamma_{rd} q_t^{RD}) + q_t^{RU} P_t^{RU} + q_t^{RD} P_t^{RD} + \beta_t^{RU} M_t^{AGC} P M_t^{RU} + \beta_t^{RD} M_t^{AGC} P M_t^{RD}] e^{-rt}$$

Results for three years of CAISO data (2014-2016)

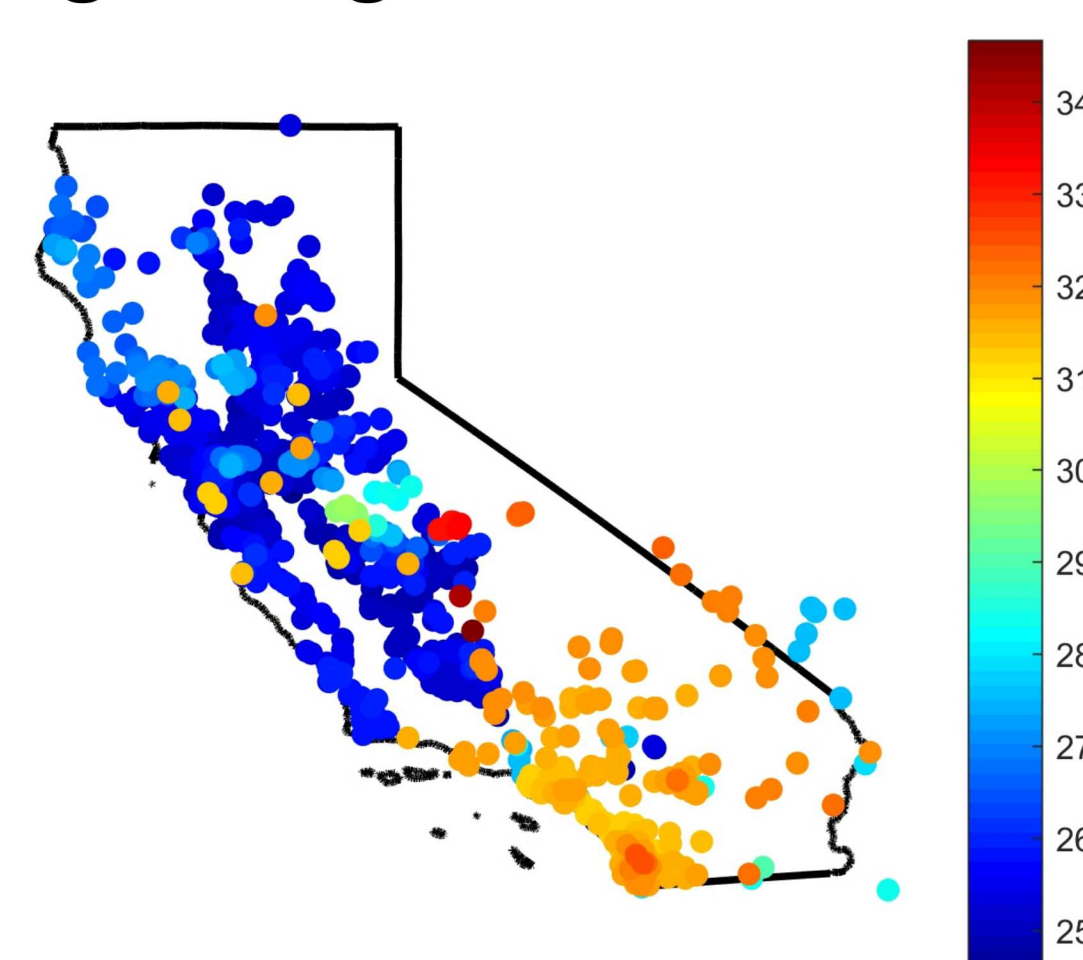
- 1MW, 4 MWh system, 85% efficiency
- Arbitrage Maximum Potential Revenue**



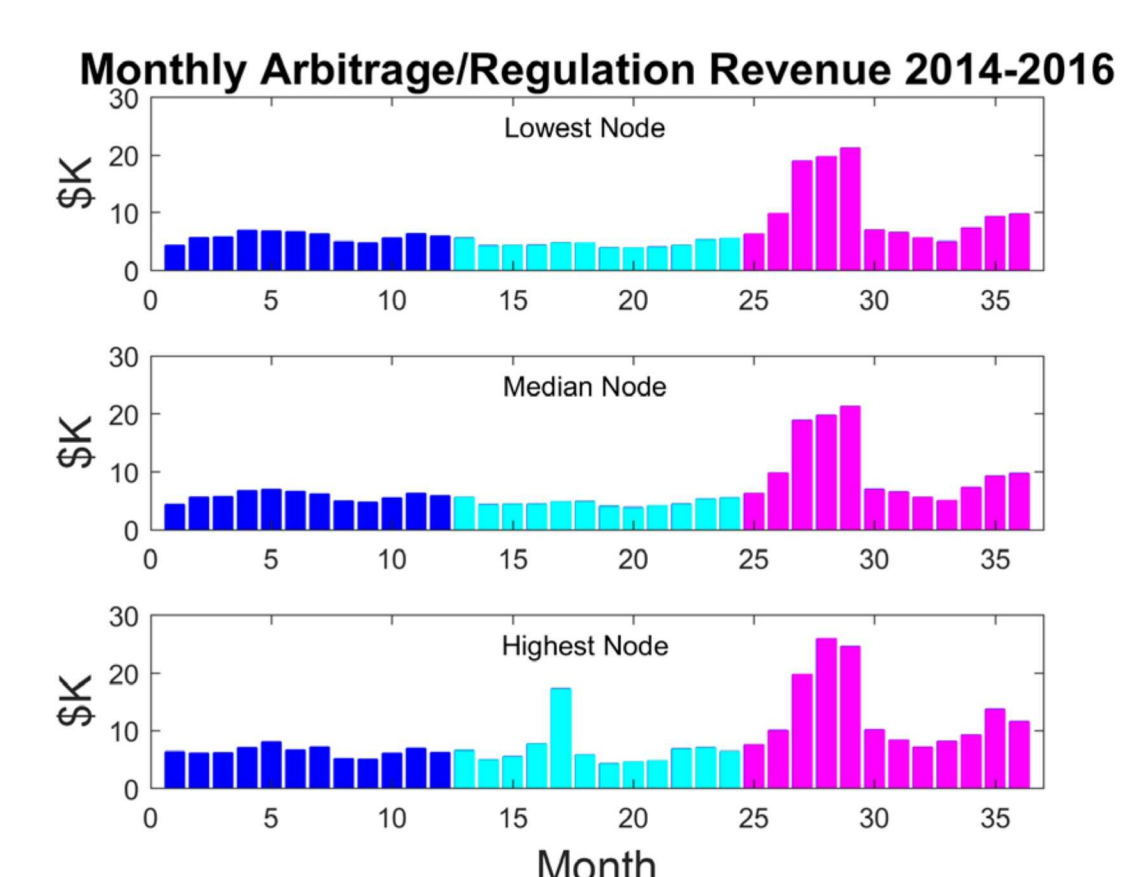
2014-2016 Total DAM Arbitrage Revenue (\$K)



Arbitrage + Regulation Maximum Potential Revenue



2014-2016 Total DAM Arbitrage plus Regulation Revenue (\$K)



Conclusions

- Arbitrage revenue is highly location dependent
- Regulation revenue is less location dependent
- Frequency regulation offers a significantly higher revenue opportunity