ESS Testing and Modeling of Stacked Application Duty Cycles

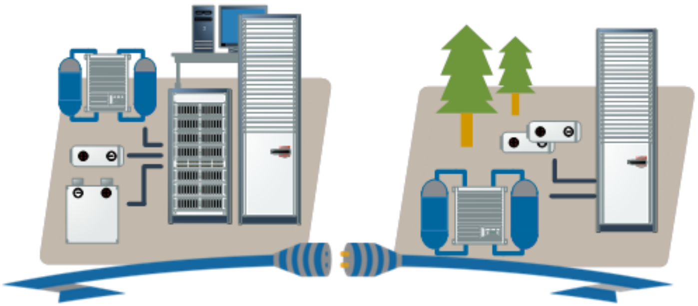
UC San Diego Energy Storage Research Webinar

11am Pacific Time, August 30th 2017

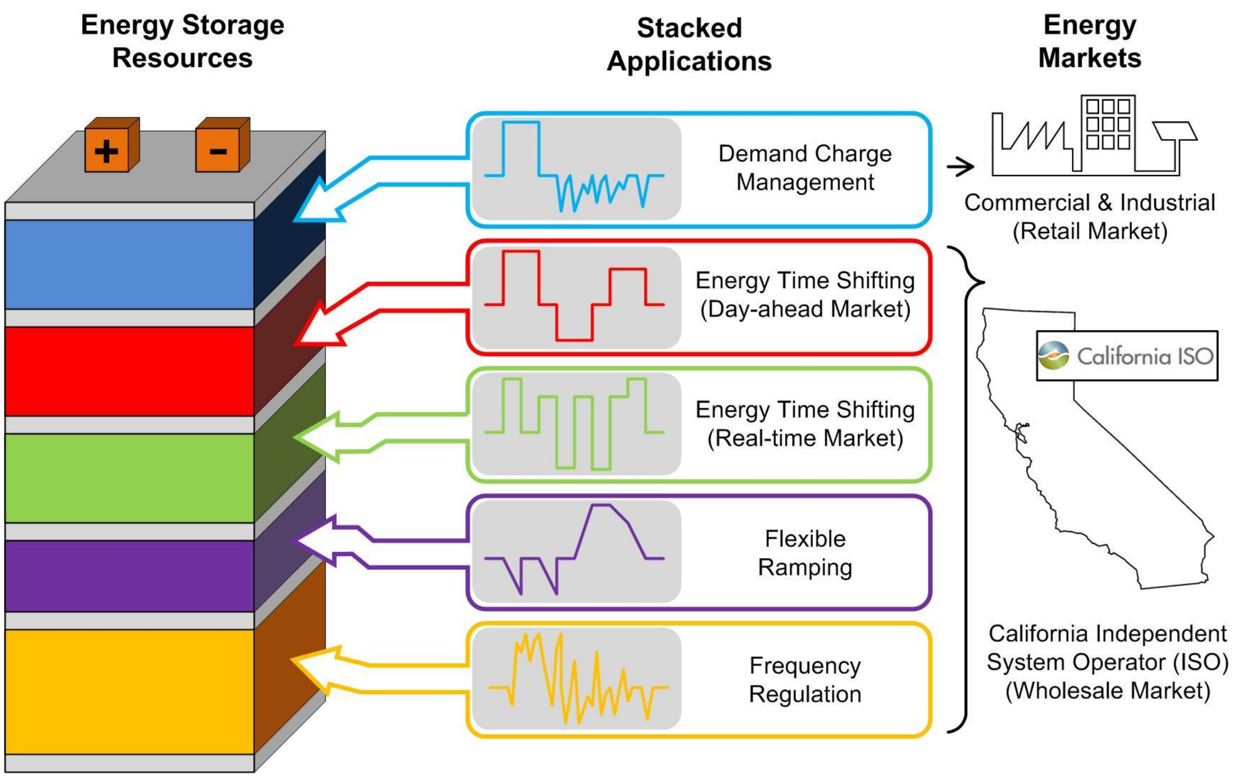
UC San Diego
Jacobs School of Engineering
Center for Energy Research

Overview

1. Economic Modeling Based Energy Storage Duty Cycle
2. Grid-integrated Energy Storage System Test Pads
3. Battery Cells and Modules Testing



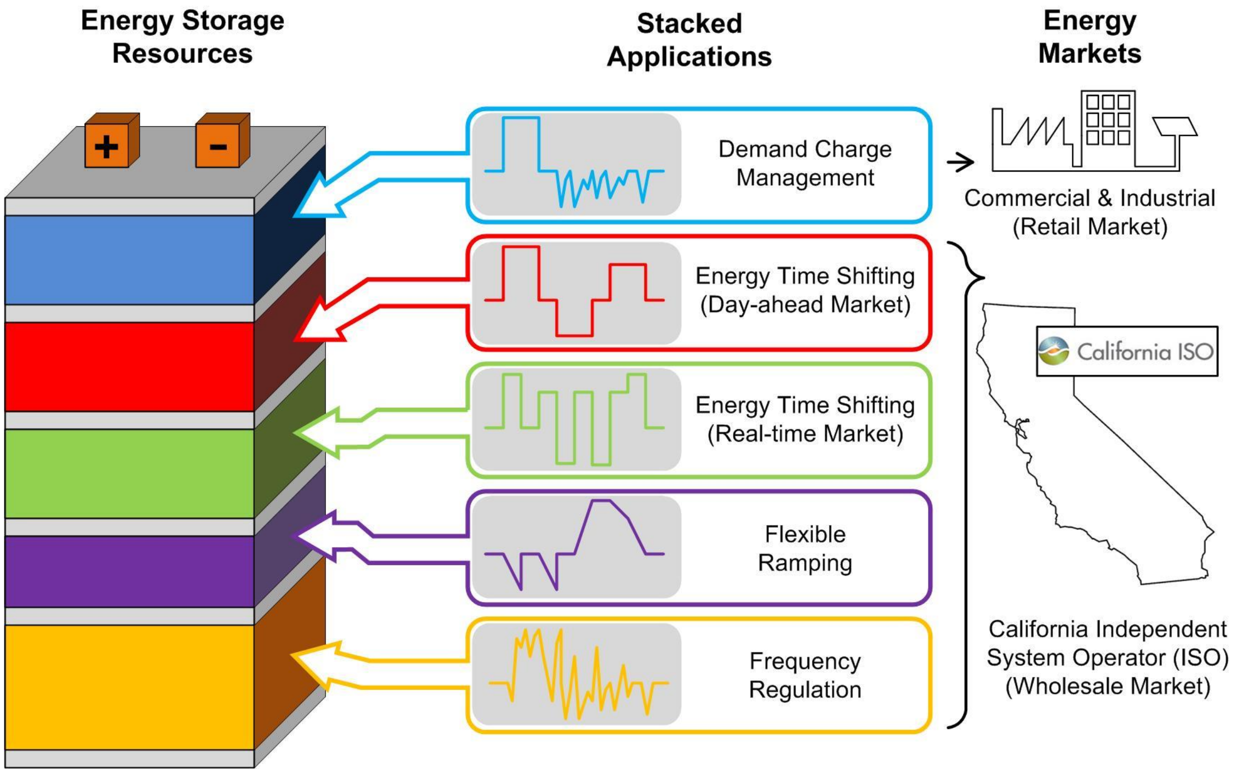
Stacked Application Duty Cycles



Motivation:

To provide economic valuation of energy storage benefits and testing protocols for performance of energy storage systems under conditions similar to how they would operate in the California markets

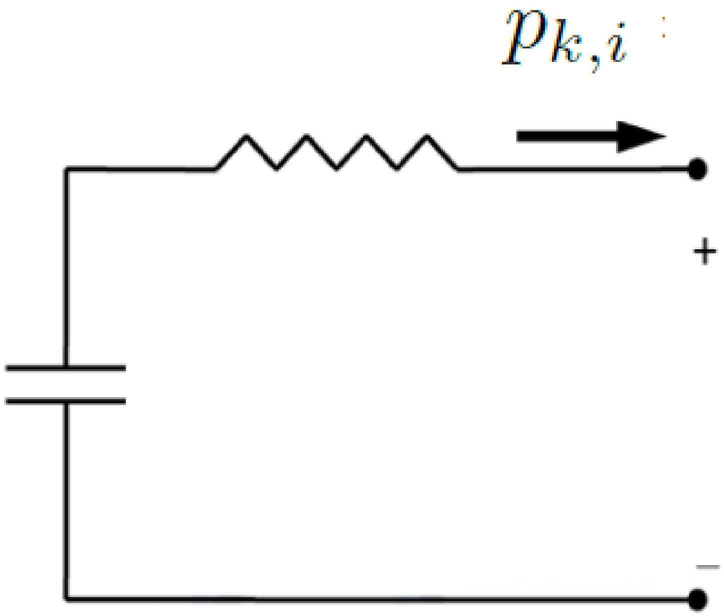
Stacked Application Duty Cycles



Economic Modeling and Valuation

of wholesale and retail energy market using data from utilities or independent system operators and forecasting for real world economic valuation. Developing stacked application duty cycles to investigate better energy storage value proposition.

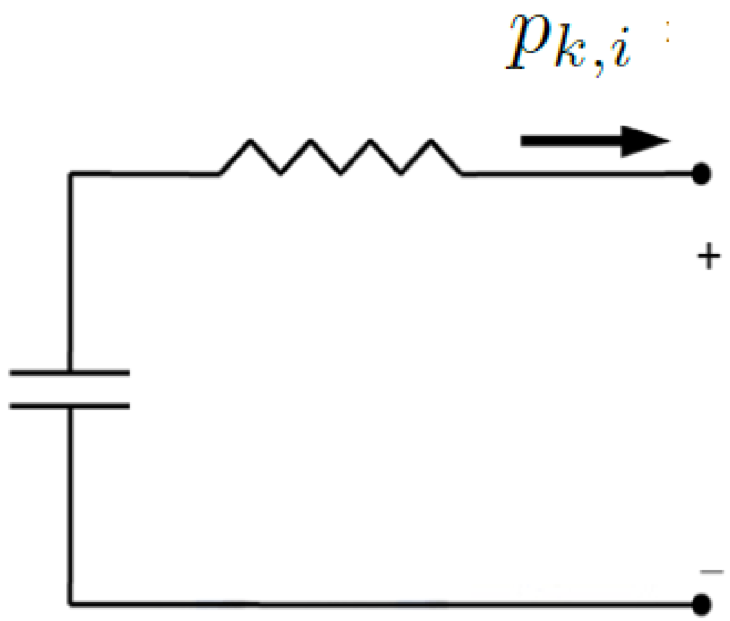
Stacked Application Duty Cycles



$$p_{k,i}$$

Stacked Application Duty Cycles

$$p_{k,i}$$



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1 Demand Charge Management

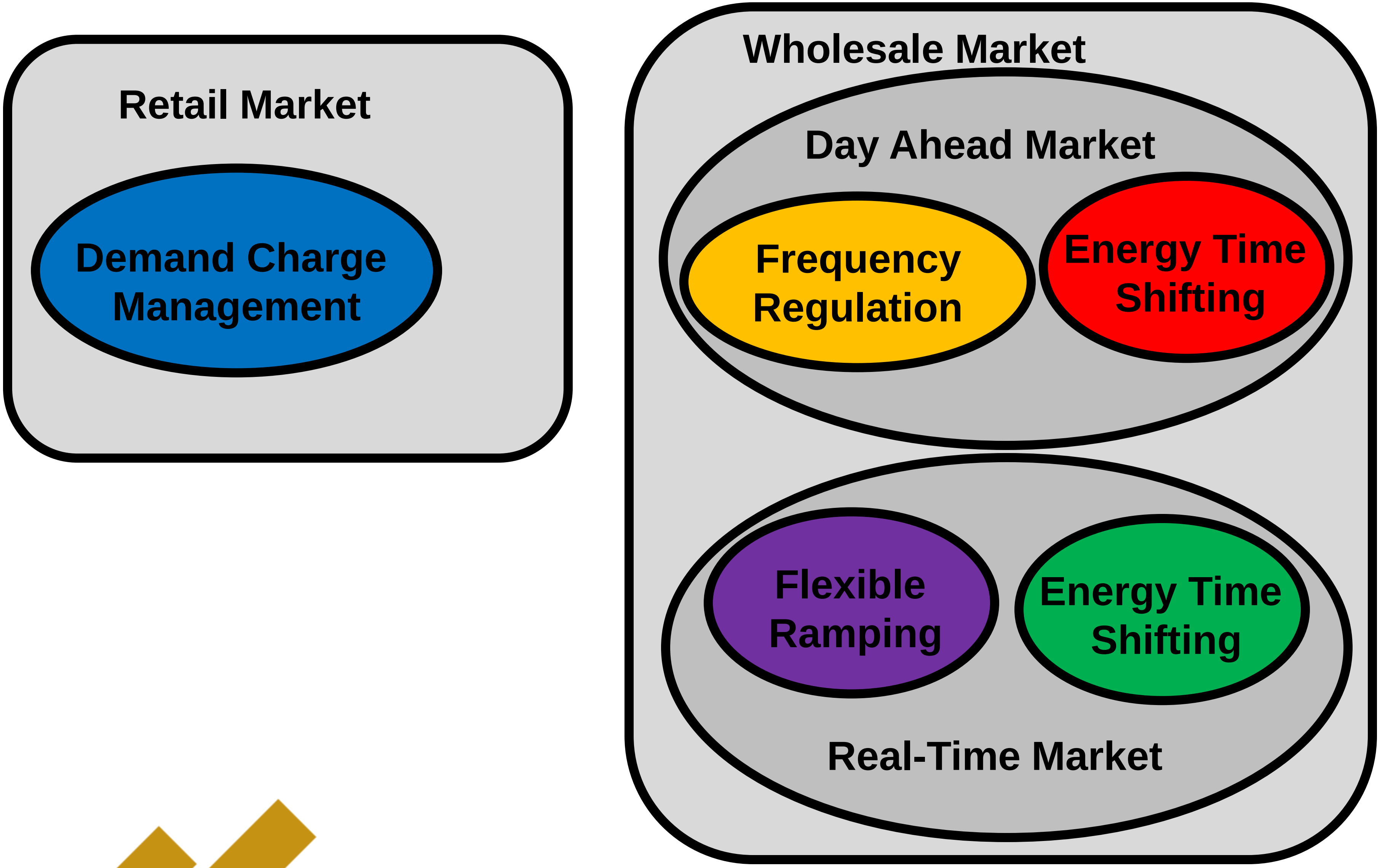
2 Day-Ahead Energy Time Shifting

3 Real-Time Energy Time Shifting

4 Flexible Ramping

5 Frequency Regulation

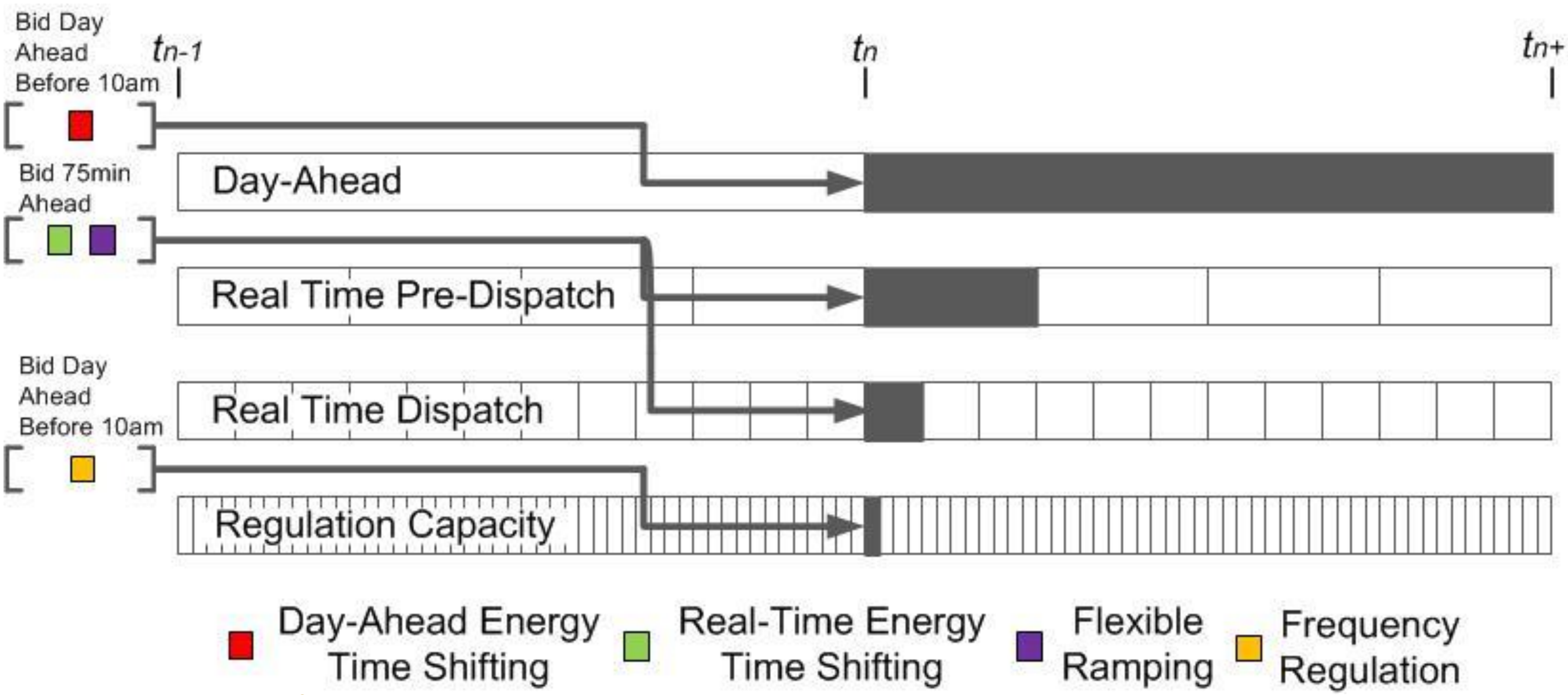
Stacked Application Duty Cycles



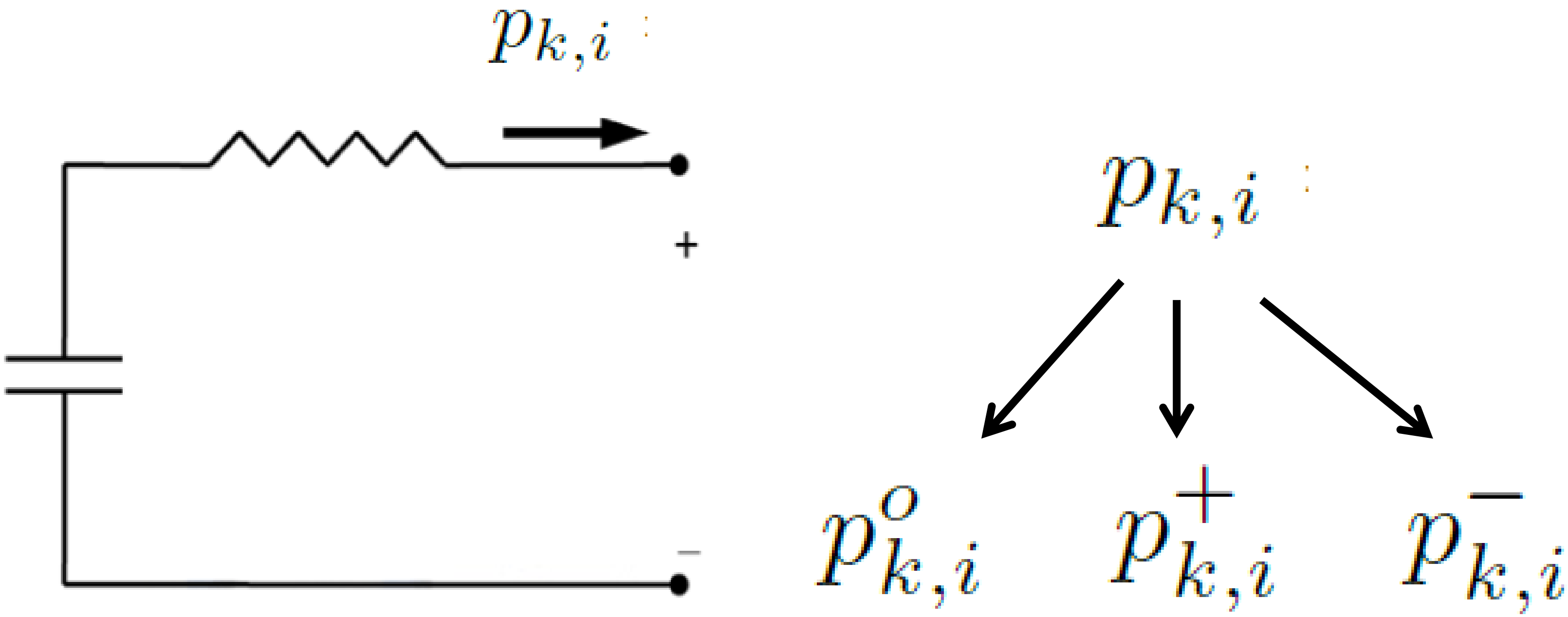
Stacked Application Duty Cycles

$$p_{k,i}$$

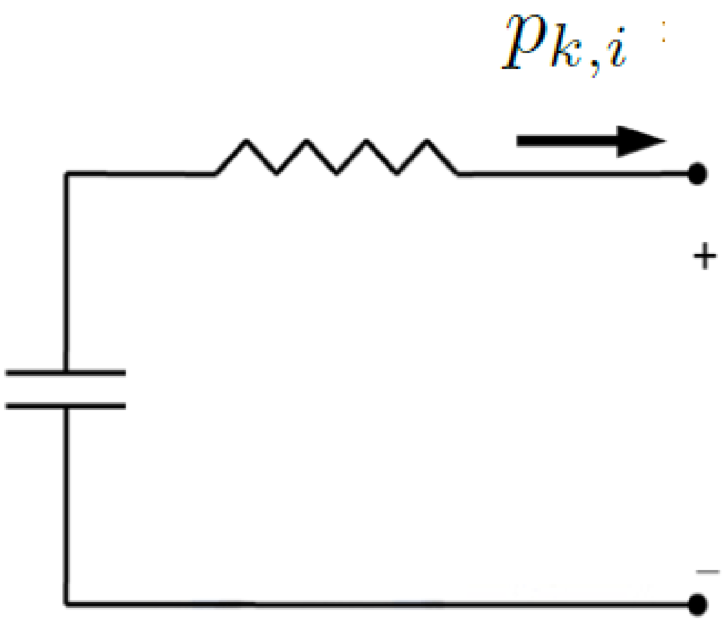
$$i = t1 \;\; t2 \;\; t3 \;\; \ldots\ldots \;\; tn$$



Stacked Application Duty Cycles



Stacked Application Duty Cycles



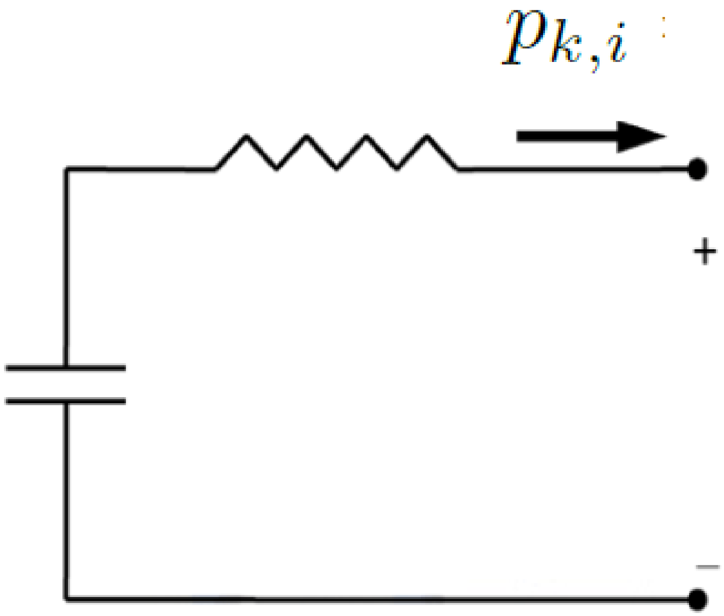
$$p_{k,i}$$

$$p^{o}_{k,i} \quad p^{+}_{k,i} \quad p^{-}_{k,i}$$

$$0 < p^{+}_{k,i} < W_k * \overline{p_k},$$

$$0 < p^{-}_{k,i} < (1 - W_k) * \underline{p_k},$$

Stacked Application Duty Cycles



$$p_{k,i}$$

$$p^{o}_{k,i} \qquad p^{+}_{k,i} \qquad p^{-}_{k,i}$$

$$p^{o}_{k,i} = p^{+}_{k,i} - p^{-}_{k,i},$$

Stacked Application Duty Cycles

Mix Integer Linear Programming

$$\begin{aligned} \underset{P,W}{\text{minimize}} \quad & J_{bat}(P,W) \\ \text{subject to} \quad & A(P,W) \leq B \\ & Aeq(P,W) = Beq \end{aligned}$$

Revenue Model

$$\begin{aligned} J_{bat}(P,W) = & \sum_{i=1}^{N} \sum_{k=1}^{K} J_{ene,k,i}(p_{k,i}, w_{k,i}) \\ & + \sum_{i=1}^{N} \sum_{k=1}^{K} J_{app,k,i}(p_{k,i}, w_{k,i}). \end{aligned}$$

Stacked Application Duty Cycles

Mix Integer Linear Programming

$$\begin{aligned} \underset{P,W}{\text{minimize}} \quad & J_{bat}(P,W) \\ \text{subject to} \quad & A(P,W) \leq B \\ & Aeq(P,W) = Beq \end{aligned}$$

Power Constraints

$$p_{k,i} = \{p^o_{k,i}, p^+_{k,i}, p^-_{k,i}\},$$

$$p^o_{k,i} = p^+_{k,i} - p^-_{k,i},$$

$$0 < p^+_{k,i} < W_k * \overline{p_k},$$

$$0 < p^-_{k,i} < (1 - W_k) * \underline{p_k},$$

Stacked Application Duty Cycles

Mix Integer Linear Programming

$$\begin{aligned} \underset{P,W}{\text{minimize}} \quad & J_{bat}(P,W) \\ \text{subject to} \quad & A(P,W) \le B \\ & Aeq(P,W) = Beq \end{aligned}$$

SoC Constraints

$$SoC_{bat,i} = SoC_0 + \sum_{i=1}^{n}\sum_{k=1}^{4}\left(\frac{\eta * p_{k,i}^{+} - p_{k,i}^{-}}{Q}\right)\Delta t + \frac{\eta * \frac{1}{\gamma_i^{+}} p_{5,i}^{+} - \frac{1}{\gamma_i^{-}} p_{5,i}^{-}}{Q}\Delta t,$$

$$\underline{SoC_{bat}} < SoC_{bat,i} < \overline{SoC_{bat}}.$$

Stacked Application Duty Cycles

Mix Integer Linear Programming

$$\begin{aligned} \underset{P,W}{\text{minimize}} \quad & J_{bat}(P,W) \\ \text{subject to} \quad & A(P,W) \leq B \\ & Aeq(P,W) = Beq \end{aligned}$$

Demand Charge Revenue

$$J_{1,ene} = \sum_{i=1}^{N} E_{tou}(p^o_{1,i} + L_i)\Delta t - \sum_{i=1}^{N} E_{tou}(Lr_i)\Delta t$$

$$J_{1,app} = E_{dc} max\{p^o_{1,i} + L_i - Lpk_i, 0\}, \; i = 1, 2, .., N$$

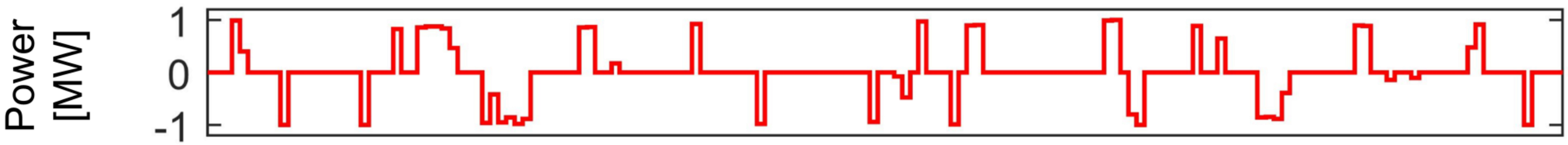
Stacked Application Duty Cycles

Mix Integer Linear Programming

$$\begin{aligned} \underset{P,W}{\text{minimize}} \quad & J_{bat}(P,W) \\ \text{subject to} \quad & A(P,W) \leq B \\ & Aeq(P,W) = Beq \end{aligned}$$

Energy Time Shifting

$$J_{2,ene} = \sum_{i=1}^{N} E_{da}(p_{2,i}^{o})\Delta t,$$



Stacked Application Duty Cycles

Mix Integer Linear Programming

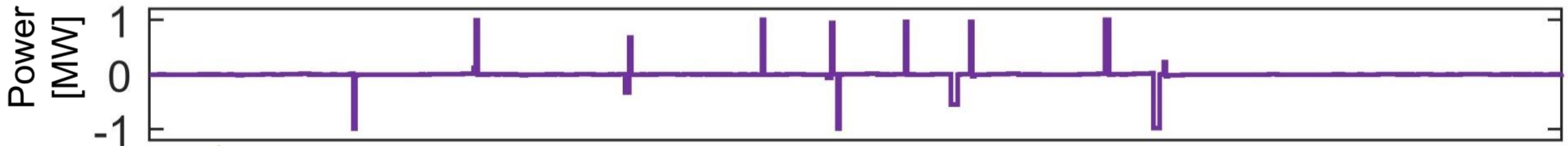
$$\begin{aligned} \underset{P,W}{\text{minimize}} \quad & J_{bat}(P,W) \\ \text{subject to} \quad & A(P,W) \leq B \\ & Aeq(P,W) = Beq \end{aligned}$$

Ramping Revenue

$$J_{4,app} = -\sum_{i=1}^{N} (E_{fr,down} \Delta p^{+}_{4,i} + E_{fr,up} \Delta p^{-}_{4,i}) \Delta t$$

$$\Delta p^{+}_{4,i} = max\{(p^{o}_{4,i}) - (p^{o}_{4,i-1}), 0\}$$

$$\Delta p^{-}_{4,i} = max\{-(p^{o}_{4,i}) + (p^{o}_{4,i-1}), 0\}$$



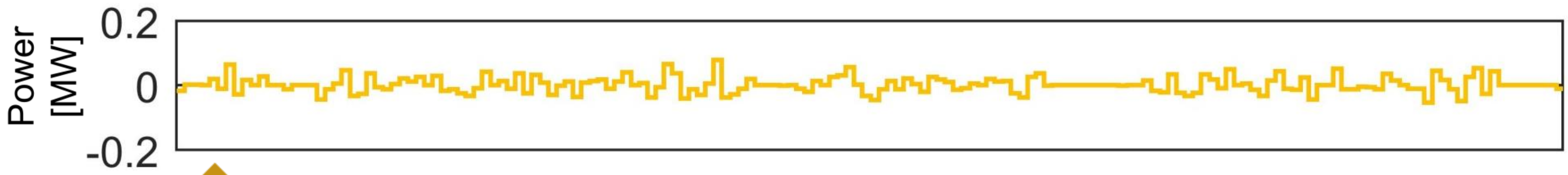
Stacked Application Duty Cycles

Mix Integer Linear Programming

$$\begin{aligned} \underset{P,W}{\text{minimize}} \quad & J_{bat}(P,W) \\ \text{subject to} \quad & A(P,W) \leq B \\ & Aeq(P,W) = Beq \end{aligned}$$

Regulation Revenue

$$J_{5,app} =$$
$$-(C_{FQ}^{+}\sum_{i=1}^{N}\frac{1}{\gamma_i^{+}}P_{5,i}^{+} + C_{FQ}^{-}\sum_{i=1}^{N}\frac{1}{\gamma_i^{-}}P_{5,i}^{-})\Delta t$$
$$-(E_{FQ}^{+}\sum_{i=1}^{N}M_i^{+}\frac{1}{\gamma_i^{+}}P_{5,i}^{+} + E_{FQ}^{-}\sum_{i=1}^{N}M_i^{-}\frac{1}{\gamma_i^{-}}P_{5,i}^{-})\Delta t,$$



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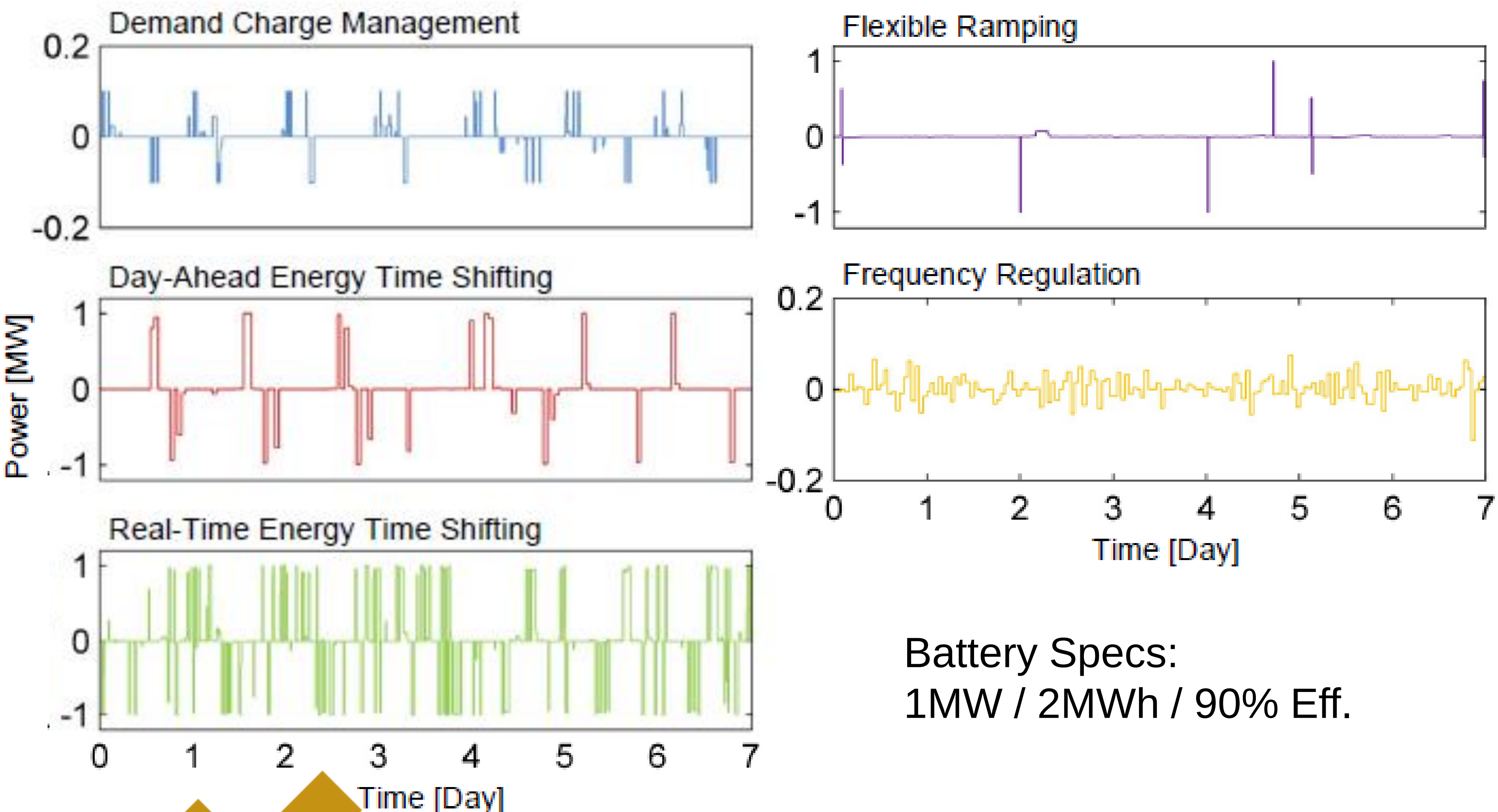
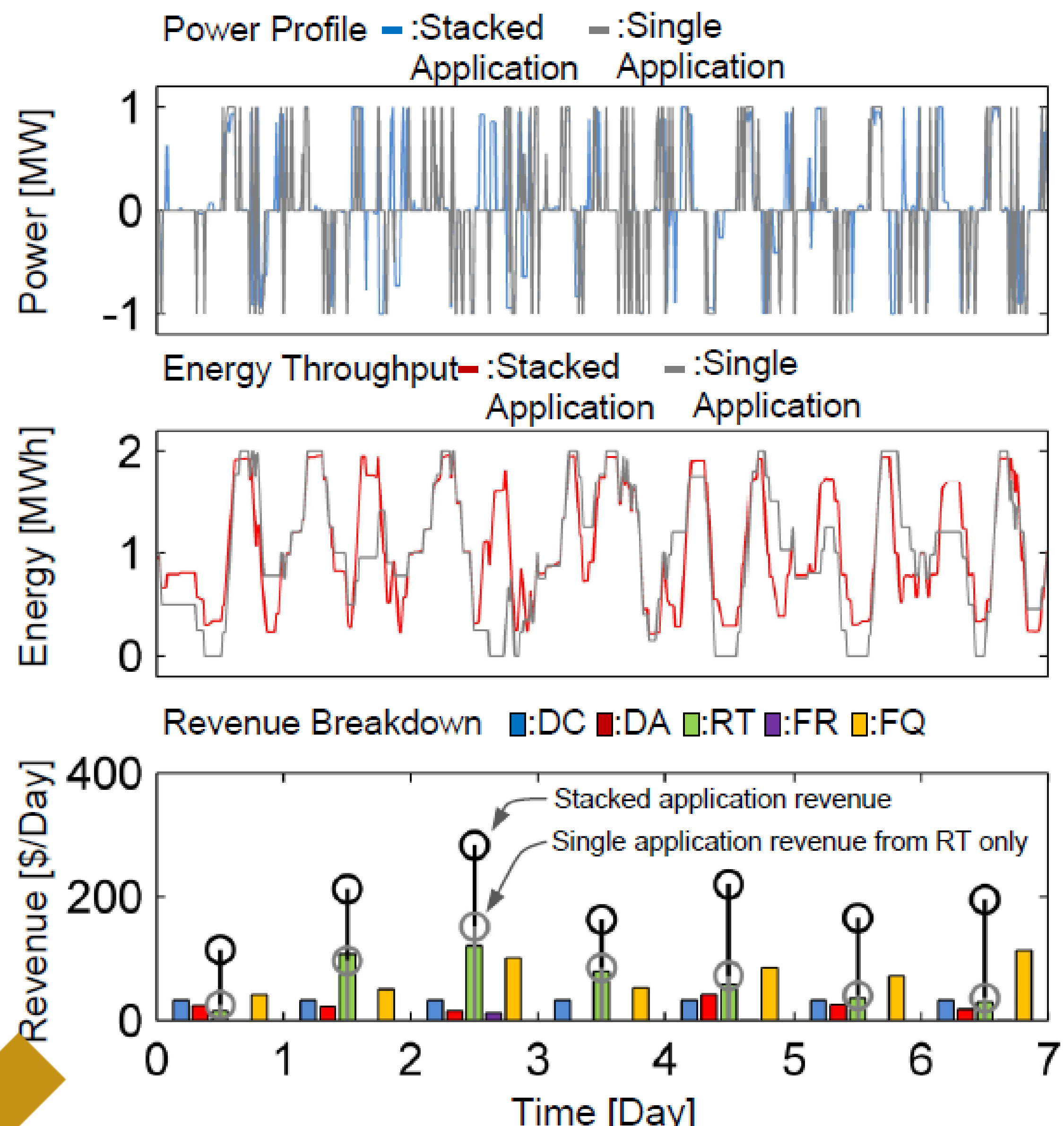
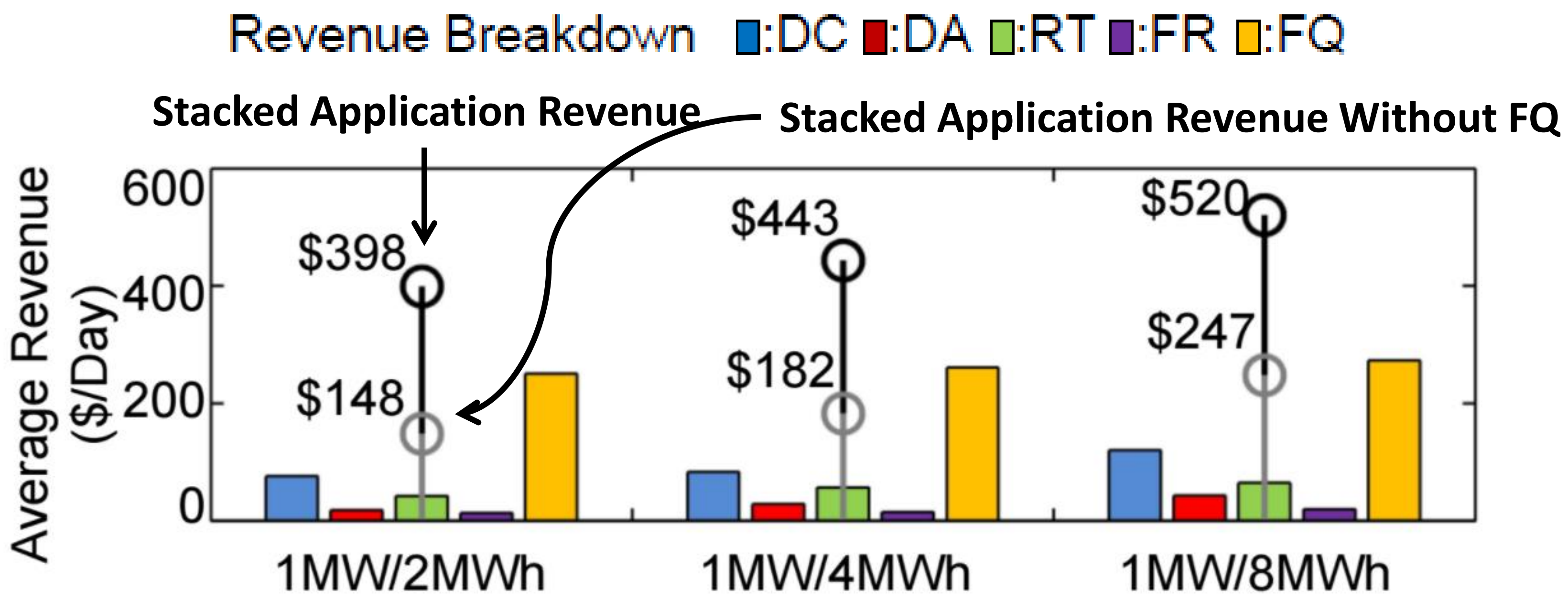


Battery Specs:
1MW / 2MWh / 90% Eff.

Stacked Application Duty Cycles



Stacked Application Duty Cycles



Grid integrated energy storage test pads

Battery Grid-Connected Testing

that leverages the highly diversified UCSD micro-grid and offers the unique capability to validate integrated energy storage solutions under a realistic setting

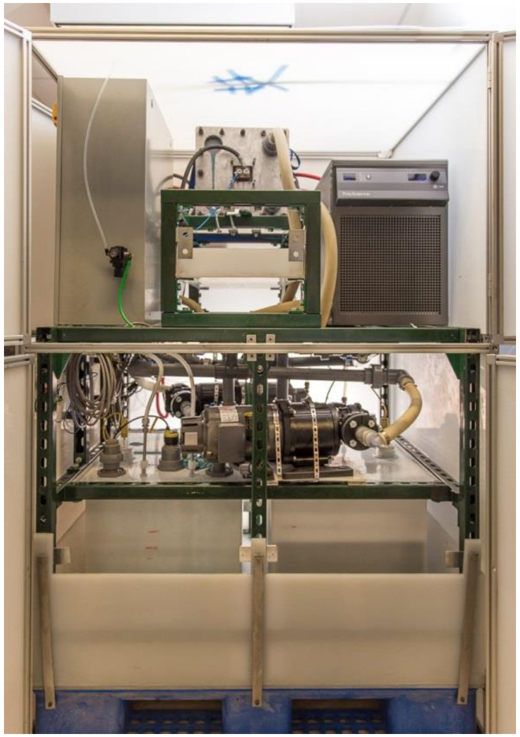
Grid integrated energy storage test pads

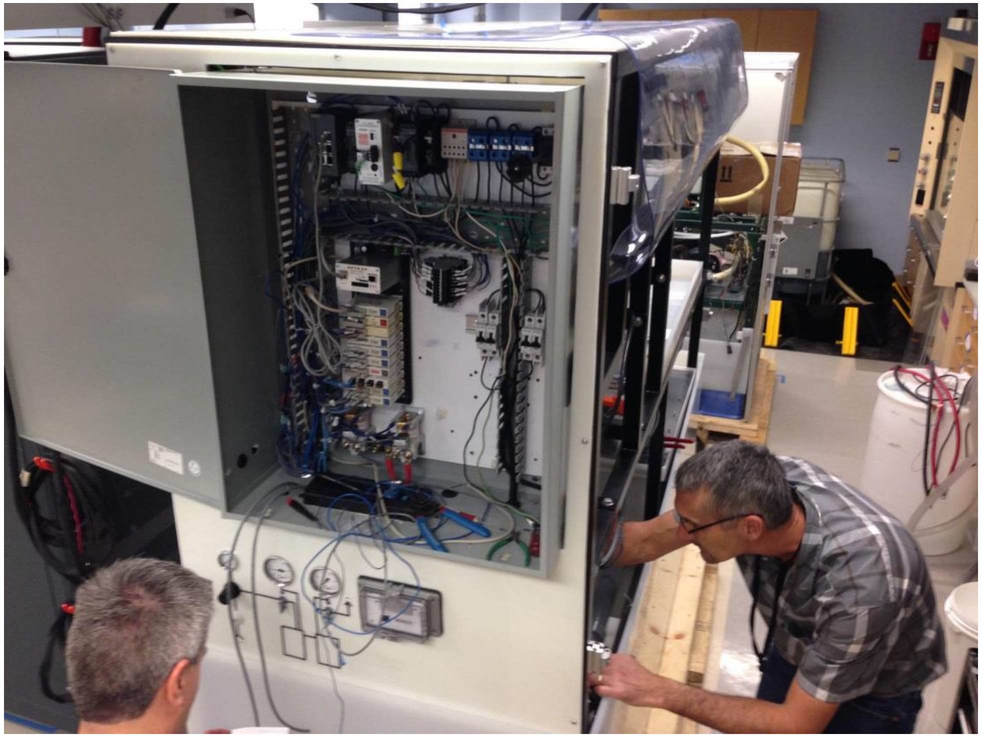
The deployed system and happy customers

Li-ion battery module testing

Battery Cell and Module Level Testing
which offers battery evaluation from electro-chemistry characteristics to energy market readiness.

Battery module testing





A flow battery system being tested in the module testing lab.

Thank You

Project link
https://cer.ucsd.edu/research/energy-storage/ARPA-E_CHARGES.html

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