Open Access Energy Storage

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Drivers for Energy Storage

Electric energy storage has the potential to significantly increase the social welfare of electric power systems through:

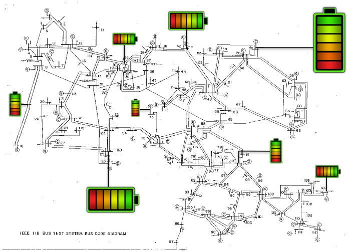
- load shifting, transmission decongestion, ancillary services

Increasing Gov't Mandates and Incentives

- FERC Orders 755, 792, 1000
- Storage 2013 Act (In Congress)
- AB 2514 (California's Energy Storage Statute)
  - storage procurement target of 1325 MW by 2020
  - requires each IOU to hold competitive RFOs that will culminate in bilateral, long-term contracts with energy storage providers.

How to Enable Efficient Expansion and Operation of Storage?

The social value of storage depends on its sizing, placement, and operation.



Basic Question: How to design markets that induce strategic expansion and operation of storage in a manner that is consistent with the maximization of social welfare over both the long and short run?

Who commands the storage?

This Talk

Outline:

1. Decentralized operating paradigm
2. Centralized operating paradigm
3. Financial storage rights (FSRs)
4. Potential applications

A Decentralized Operating Paradigm

Setting:

- Treat each storage unit as a generation asset
- Each storage owner-operator pursues it's individual (profit maximizing) interests in a T-period energy market.

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1. Operation: Each storage owner-operator (at a bus i) offers to produce/consumer a profile:

$$\mathbf{u}_i = (u_i(1), \ldots, u_i(T))$$

2. Payment: Each storage owner-operator receives a payment:

$$\text{payment} = \sum_{t=1}^{T} \lambda_i(t) u_i(t),$$

where sequence of LMPs at node i given by $\boldsymbol{\lambda}_i = (\lambda_i(1), \ldots, \lambda_i(T))$

Inefficiency of Decentralized Operation

Outcome Inefficiency: Using a stylized model, Sioshansi[1] shows that strategic interactions between storage owner-operators can result in market Nash equilibria with significant efficiency loss $> 90\%$

Explanation: Storage owner-operators will (at a Nash equilibrium) under-utilize their capacity relative to the socially optimal dispatch of storage

- Storage owners profit through price arbitrage (i.e. load shifting)
- Their load shifting, in turn, reduces the the peak/off-peak price differential;

Decentralized operation of storage assets by strategic owner-operators can result in its substantial underutilization from the network perspective.

[1] R. Sioshansi. "Welfare impacts of electricity storage and the implications of ownership structure." Energy Journal, 2010.

Broader Research Goals

Our approach: treat storage as a communal asset dispatched centrally by the ISO

Research aims to:

[1] Develop a general control theory and algorithms for

- optimal control of energy storage in networks (e.g. load shifting, regulation)
- optimal placement and sizing of storage

[2] Design tradable financial instruments that

- capture the system-value of storage
- enable market participants open access to energy storage
- reward (and correctly incentivize) storage capacity investments

[3] Analyze behavior of strategic storage expansion

A Centralized Operating Paradigm

Treat storage as a communal asset; accessible by all market participants[2]

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1. Operation: Storage is centrally dispatched by the (ISO) to maximize welfare[3]

2. Payment: (??)

Challenge: Design of (tradable) financial derivatives that

- Correctly monetize the system benefit of storage
- Incentivize (efficient) strategic expansion of storage
- Democratize access to storage

[2] X. He et al. "A novel business model for aggregating the values of electricity storage," Energy Policy, 2011.

[3] PJM, "Energy storage as a transmission asset," Technical Report, 2012.

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Stylized Multi-Period Economic Dispatch

The ISO's problem:

$$\text{minimize} \sum_{t=1}^{T} C_t(\mathbf{v}(t)) \quad \text{subject to} \quad \begin{cases} \text{[Transmission Constraints]} & \\ \mathbf{v}(t) + \mathbf{u}(t) \in \mathcal{P}, & t = 1, \ldots, T \\ \text{[Storage Constraints]} & \\ 0 \leq \; -\sum_{s=1}^{t} \mathbf{u}(s) \leq \mathbf{b}, & t = 1, \ldots, T \end{cases}$$

Let $\{\mathbf{u}^*(t), \mathbf{v}^*(t)\}$ be the optimal dispatch and $\{\boldsymbol{\lambda}^*(t)\}$ the LMPs

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Notation:

- $\mathbf{b} \in \mathbb{R}^n$, energy storage capacity profile
- $\mathbf{u}(t) \in \mathbb{R}^n$, storage generation profile at time t
- $\mathbf{v}(t) \in \mathbb{R}^n$, conventional generation profile at time t
- $\boldsymbol{\lambda}(t) \in \mathbb{R}^n$, vector of LMPs at time t

The Merchandising Surplus

The Merchandising Surplus (MS) collected by the ISO satisfies

$$MS = TCS + SCS,$$

Transmission Congestion Surplus $$TCS = \frac{1}{2}\sum_{t=1}^{T}\sum_{i,j=1}^{n}\left(\lambda_j^*(t) - \lambda_i^*(t)\right) p_{ij}^*(t),$$

Storage Congestion Surplus $$SCS = \sum_{t=1}^{T}\sum_{i=1}^{n}\lambda_i^*(t)u_i^*(t).$$

Fact

There does not exist a collection of simultaneously feasible[4] financial transmission rights (FTRs) whose rent exceeds the TCS.

[4] Wu, Felix, et al. "Folk theorems on transmission access: Proofs and counterexamples." Journal of Regulatory Economics, 1996.

Defining Financial Storage Rights (FSRs)

The previous fact motivates the definition of a new financial derivative

Definition (Financial Storage Right)

A financial storage right (FSR) is defined as any double $(i, \mathbf{s}_i)$ with $\mathbf{s}_i \in \mathbb{R}^T$ such that

$$\sum_{t=1}^{T} s_i(t) = 0.$$

A FSR $(i, \mathbf{s}_i)$ yields the holder a rent (or liability) of

$$\text{rent}(\mathbf{s}_i) = \sum_{t=1}^{T} \lambda_i^*(t) s_i(t).$$

Fact

There exists a collection of simultaneously feasible FTRs + FSRs whose rent fully recovers the merchandising surplus (MS).

The Role of Financial Storage Rights (FSRs)

Financial storage rights (FSRs) define a market framework that enables:

1. *(Operation).* Efficient centralized dispatch of storage
2. (Open Access) Open access to energy storage capacity
   - through redistribution of the storage congestion rent collected by ISO
3. (Expansion) A mechanism to remunerate investments in storage capacity

Applications:

- Perfect hedging of intertemporal (and spatial) price volatility
- intertemporal bilateral contracts
- building swing options[5] from FSRs
- enables long term investment in storage

[5] P. Jaillet et al., "Valuation of commodity-based swing options." Management science, 2004.

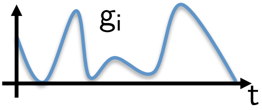
Example: Perfecting Hedging of Price Volatility

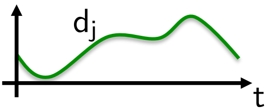
Setting

- $\mathbf{g}_i \in \mathbb{R}^T$, variable supply (e.g. wind) at bus i
- $\mathbf{d}_j \in \mathbb{R}^T$, variable demand at bus j

$$\sum_{t=1}^{T} g_i(t) = \sum_{t=1}^{T} d_j(t) = E$$

- $p_s \in \mathbb{R}_+$, contract strike price





Fact

There exists a combination of FSRs (i, s_i) and (j, s_j) that perfectly hedge the spatial and intertemporal congestion charges.

Namely, the supplier and demand can trade the quantity E at the strike price p_s.

Questions

[1] FSR auction design

- revenue adequacy
- allocation of auction revenue to reward capital investments in storage

[2] Accommodating inefficiencies in storage

- Injection-based vs. Constraint-based[6] definition of FSRs

[3] Generalize definition of FSRs to accommodate value streams derived from control at various time scales

- regulation
- ramping

[4] Role of FSRs in supporting renewable energy integration

[6] J.A. Taylor. "Financial rights and tracing for energy storage," IEEE PES General Meeting, 2014.

Related Work

1. X. He et al. A novel business model for aggregating the values of electricity storage. Energy Policy, 2011.
2. R. Sioshansi. Welfare impacts of electricity storage and the implications of ownership structure. Energy Journal, 2010.
3. J.A. Taylor. Financial rights and tracing for energy storage. IEEE PES General Meeting, 2014.

Our Work

1. D. Munoz-Alvarez, E. Bitar. Financial Storage Rights in Electric Power Networks. 2014 (Preprint).

2. D. Munoz-Alvarez, E. Bitar. Financial Storage Rights: Basic Definition and Properties. Proc. of the IEEE North American Power Symposium (NAPS). 2014.

3. E. Bitar, S. Bose. Zero crossings and the locational marginal value of storage. Proc. of the IEEE Conf. of Decision and Control (CDC). 2014.

4. E. Bitar, P. Khargonekar, K. Poolla. The marginal value of storage in forward markets with uncertain supply. 2014 (Preprint).