NREL
NATIONAL RENEWABLE ENERGY LABORATORY





Valuation of Utility-Scale Energy Storage in Production Cost Models

David Palchak

September 2017

Outline

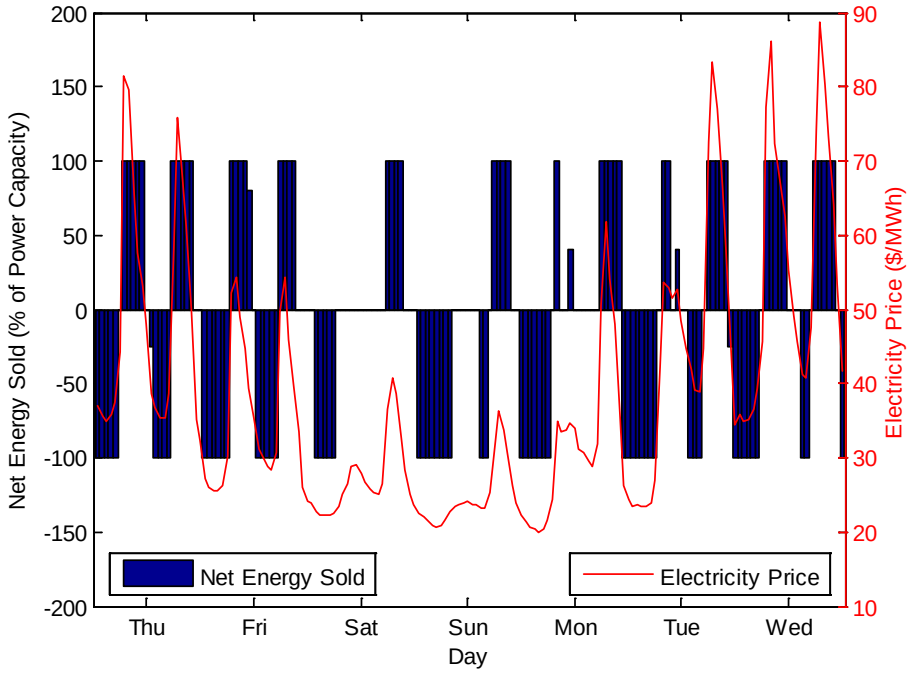
- Value of storage
  - Price-taker
  - Production cost models
- Energy Storage in India
- Markets for maximizing storage value

Valuation Approaches

- "Price Taker" approach — marginal value using historical market data
  - Approximates revenue to a merchant storage plant
  - Application to India may be different than market regions depending on off-taker (guaranteed fixed and variable costs versus market prices)
- Full system value using production cost models
  - Operational value to a utility or value to society, with some insight into market value

Price-Taker Value in Restructured Markets

- Use historical market data to estimate what a storage plant would have received if optimally dispatched (big caveat)
- Typically single unit optimal dispatch simulations
  - **Based on historical price and load patterns**
  - Use a mixed-integer linear program or other optimization technique



Price-Taker Approach

Advantages

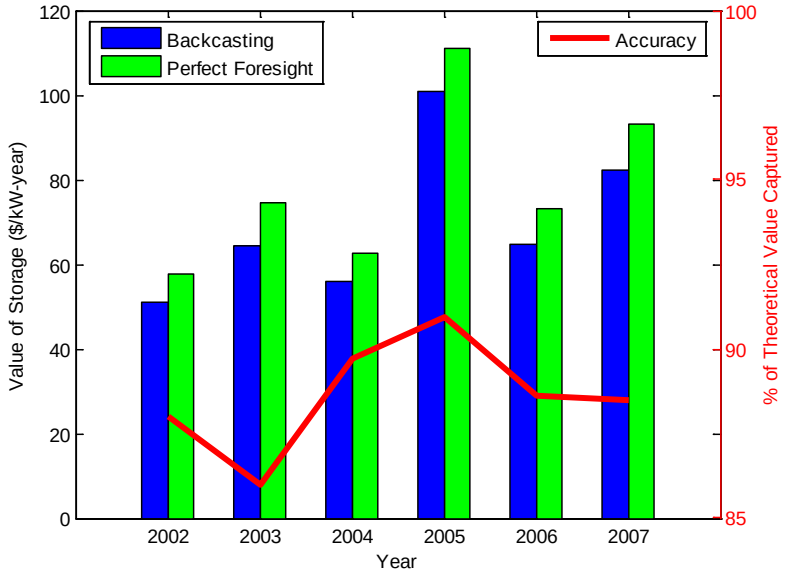
- Readily available data
- Fast and relatively easy to run simulations
- Generally accepted approach in the academic literature

Disadvantages

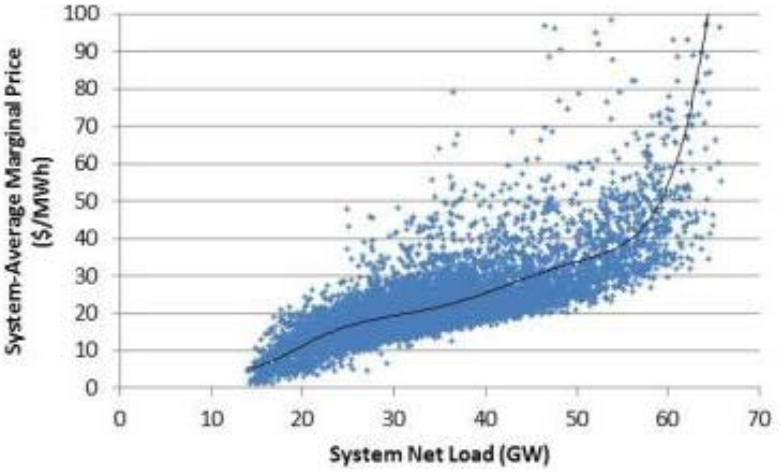
- Relies on externally generated prices and typically assumes perfect foresight of prices
- Examines a static historical system
- Examines only a marginal unit, ignores the rest of the generation stack
- Does not consider values not captured in today's markets
- Not applicable to least-cost planning studies
- Not *always* applicable to merit-order based dispatch

"Work-Arounds"

- Add Imperfect Foresight
  - Use historical dispatch to reflect uncertainty



- Add price impacts of different load shapes via price/load relationships



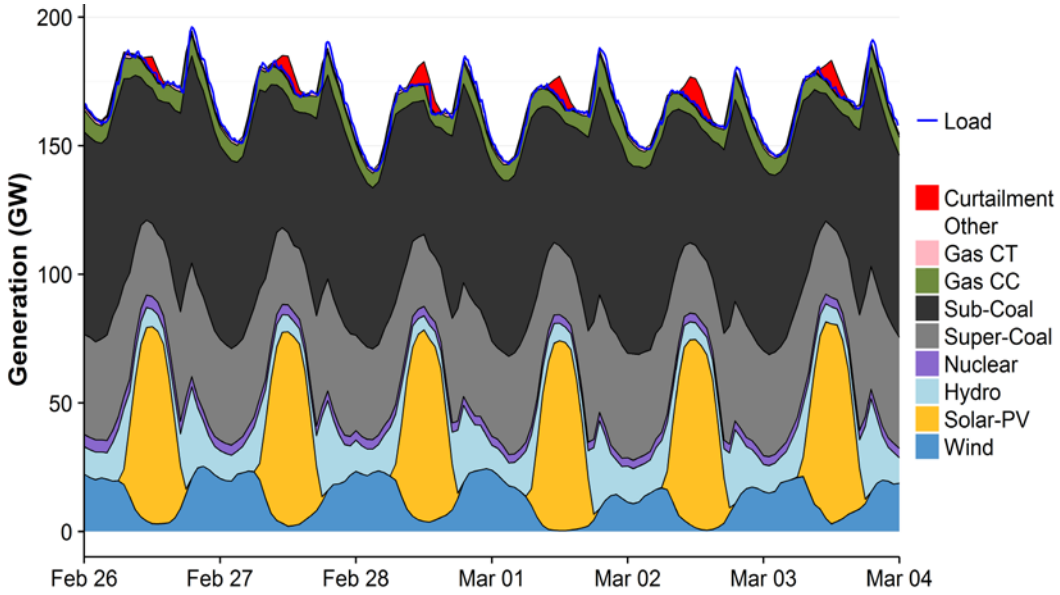
But price taker approaches are fundamentally limited in evaluating the future role and value of energy storage.

Production Cost Model Approach

- Production cost model (PCM) used to simulate the chronological, least-cost operation of the regional power grid (i.e. security constrained unit commitment and economic dispatch model)
- Model selects the least-cost mix of generators needed to meet annual hourly load while maintaining reliability requirements.

Outputs

- Total cost to meet load (fuel, VO&M, emissions, and start-ups)
- Locational price of generation
- Transmission usage/congestion



Modeling Storage in a PCM

1. Revenue
   - PCM Revenue: Run a PCM for a given scenario with storage and then calculate revenue based on marginal prices and storage dispatch
   - Price-taker (hybrid): Run a PCM for a given scenario and then run a price-taker model with PCM prices
2. "Difference-Based" Value
   - Run a PCM for a given scenario
   - Add storage to the scenario and re-run
   - Value of storage is difference between runs

Modeling Storage in a PCM

1. Revenue
   - PCM Revenue: Run a PCM for a given scenario with storage and then calculate revenue based on marginal prices and storage dispatch
   - Price-taker (hybrid): Run a PCM for a given scenario and then run a price-taker model with PCM prices
2. "Difference-Based" Value
   - Run a PCM for a given scenario
   - Add storage to the scenario and re-run
   - Value of storage is difference between runs

Case Study of Storage in India – 2022

Greening the Grid RE Integration Study

www.nrel.gov/india-grid-integration - Collaboration with Berkeley Lab and POSOCO

- Production cost model of India built for analyzing the impact of 100 GW solar, 60 GW wind

Sensitivity - value of storage:

1) Does storage help in mitigating challenges associated with RE integration?

2) Is storage is an effective alternative to coal capacity?

2022 Assumptions

- 100 GW solar, 60 GW wind target met
- Power system built based on CEA/CTU plans for load growth, generation, and transmission
- Dispatch modeled for each 15-minute period of the year

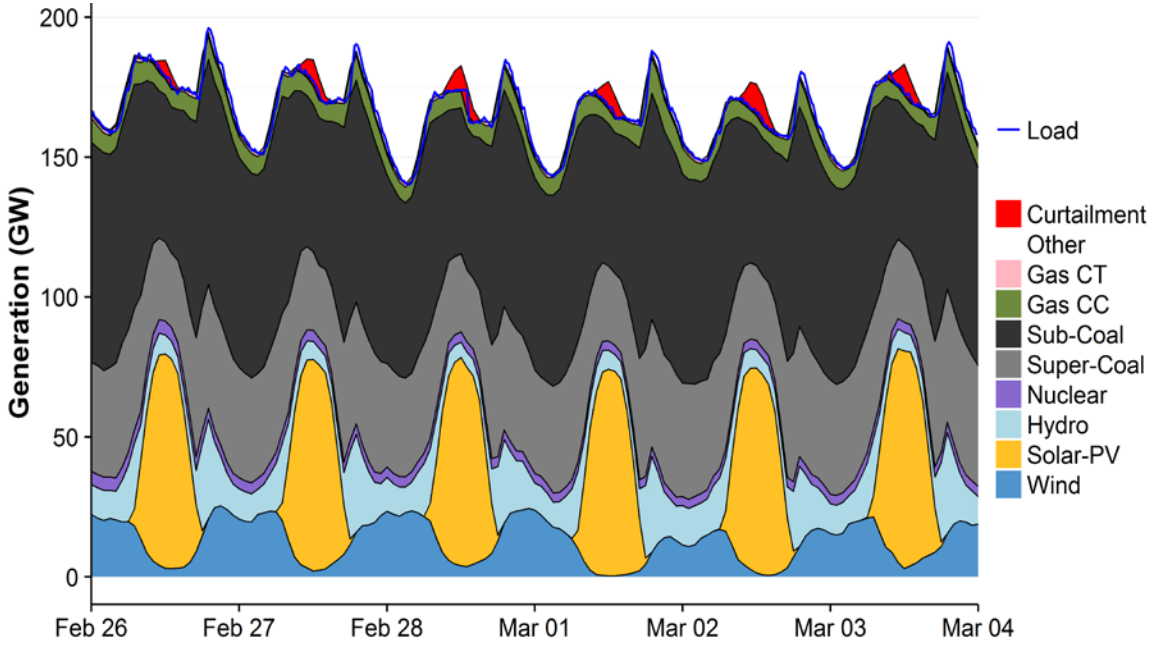
Storage sensitivity:

- **20 GWh of storage total added** in six states in India (Gujarat, Rajasthan, Maharashtra, Tamil Nadu, Karnataka, and Andhra Pradesh)
  - 2.5 GW at 8 hours at full discharge
  - 75% efficiency
  - Dispatch fixed from day-ahead schedule

Do batteries reduce operating costs?

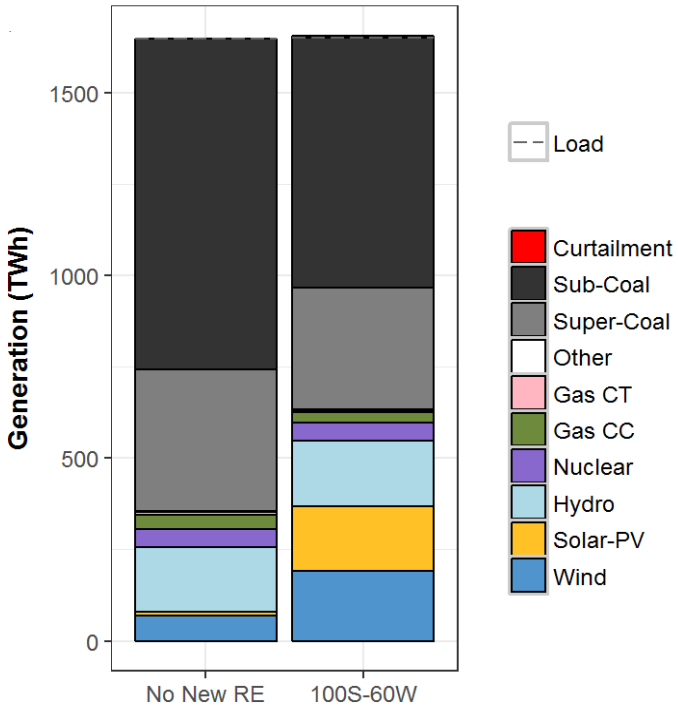
- **Hypothesis:** In systems with high levels of renewable energy, batteries can absorb RE energy when it isn't needed and discharge during peak demand.
  - Less wasting of RE results in less fuel usage and less variable cost

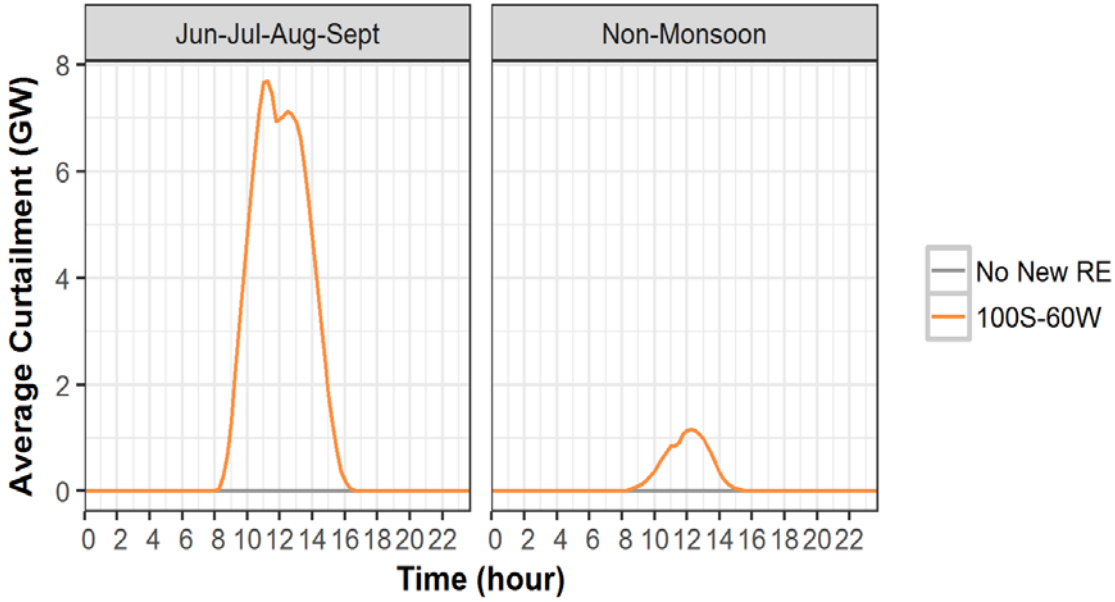
Western Region in 2022 scenario



Results of Base Scenario – No Storage

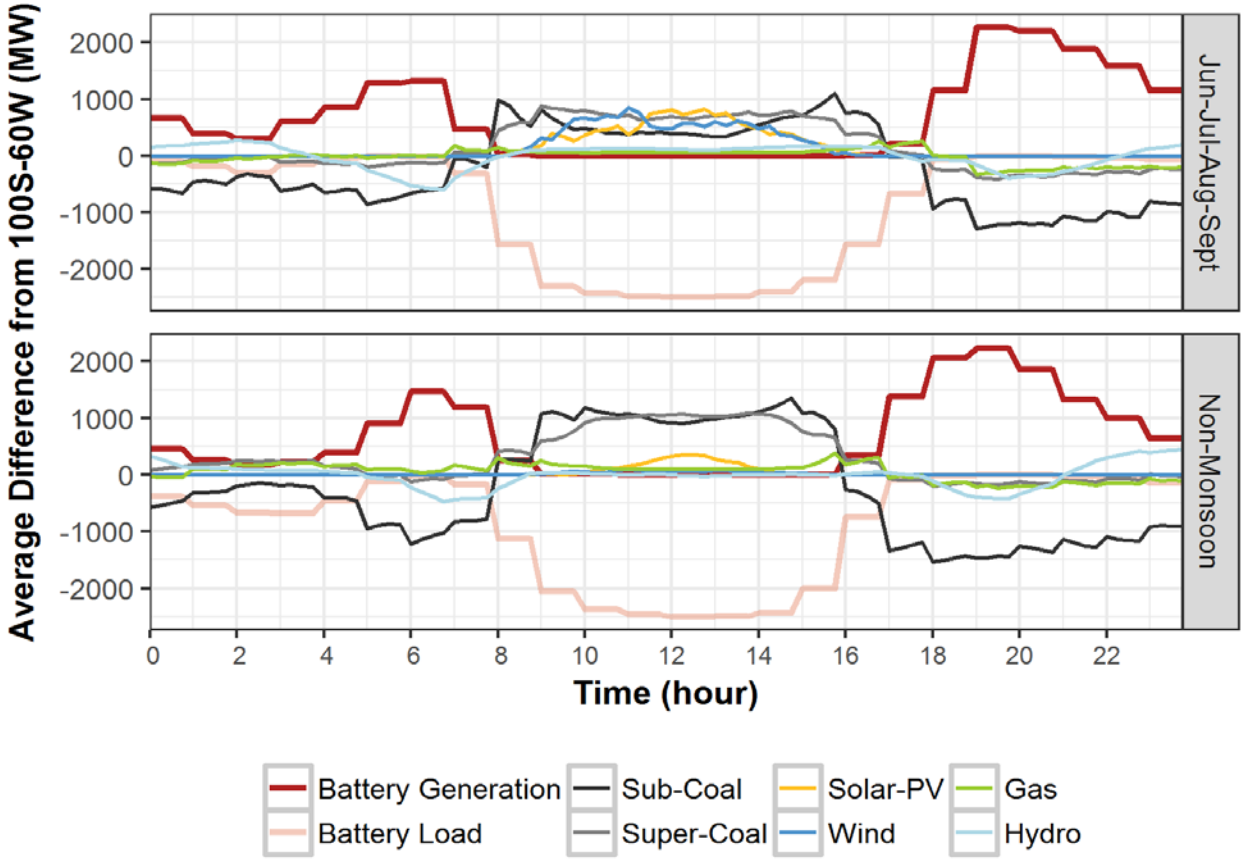
- Load and generation balanced for all periods year
- 1.6% RE curtailment
  - Majority in the Southern Region during monsoon season





Do batteries reduce operating costs?

- Batteries charge on solar during the day, but also on coal
- Relatively low curtailment coupled with minimal opportunities for arbitrage and battery losses lead to a **negligible savings** in the 15-minute dispatch timeframe



Does storage offset coal capacity if dispatched optimally?

	Peak Coal Generation (GW)	Difference with Batteries (GW)	Peak Gas Generation (GW)	Difference with Batteries (GW)
100S-60W	152.4		11.0	
100S-60W with batteries	151.4	-1.0 (0.66%)	10.5	-0.47 (4.5%)

- Displaces the need for some coal, although more expensive generation displaced first

Production Cost Model Approach

Advantages

- Can do most things

Disadvantages

- Very costly (even when free)
- Time consuming to learn
- Long solve times (hours to months)
- Data intensive
- Frequent and mysterious crashes
- In summary, running PCMs is often an incredibly expensive, frustrating, and confusing experience.

Storage Potential in India

- **Utility-scale**
  - **Energy –** Likely, but at what RE penetration does this add value to the system?
    - Challenge: can batteries get paid for the value they add (e.g., increasing energy ramping)?
  - **Ancillary services –** Likely, but how big is this market?
    - Proposed CERC regulation is less than 10 GW of spinning reserve, much of which can be covered by headroom already present from current dispatch.
  - **Firm capacity** – Unknown.
    - PLFs of coal plants suggest that there is adequate planning reserve margin.
- **Behind-the-meter** (Tesla powerwall, commercial, etc.)
  - **Replacing the need for captive power**
    - Will increased grid reliability displace the need for these?

Thank you!

Contact:
david.palchak@nrel.gov

www.nrel.gov/india-grid-integration

References:

Palchak, D., J. Cochran, R. Deshmukh, A. Ehlen, B. McBennett, Michael Milligan, Ilya Chernyakhovskiy, Nikit Abhyankar, S.K. Soonee, S. R. Narasimhan, M. Joshi, P. Sreedharan.. 2017. *Greening the Grid: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid, Vol. I -- National Study*. LBNL-2001012. http://www.nrel.gov/docs/fy17osti/68530.pdf.

Much of this was adopted from work by Paul Denholm:

Denholm, P. and R. Margolis (2016) Energy Storage Requirements for Achieving 50% Solar Photovoltaic Energy Penetration in California NREL/TP-6A20-66595

Eichman, J.; P. Denholm; J. Jorgenson; U. Helman (2015) Operational Benefits of Meeting California's Energy Storage Targets NREL/TP-5400-65061

Denholm, P., V. Diakov, R. Margolis (2015) The Relative Economic Merits of Storage and Combustion Turbines for Meeting Peak Capacity Requirements under Increased Penetration of Solar Photovoltaics. NREL/TP-6A20-64841

Sioshansi, R., S.H. Madaeni, and P. Denholm. (2014) "A Dynamic Programming Approach to Estimate the Capacity Value of Energy Storage" IEEE Transactions on Power Systems 29(1) 395-403.

Denholm, P., J. Jorgenson, M. Hummon, D. Palchak, B. Kirby, O. Ma, and M. O'Malley (2013) Impact of Wind and Solar on the Value of Energy Storage. NREL Report No. TP-6A20-60568.

Denholm, P., J. Jorgenson, M. Hummon, T. Jenkin, B. Kirby, O. Ma, M. O'Malley, and D. Palchak. (2013) Value of Energy Storage for Grid Applications. NREL Report No. TP-6A20-58465.

www.nrel.gov