Modeling of Battery Storage in Economic Studies

Planning Advisory Committee

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Today's Presentation

- In response to various questions asked about battery storage, the ISO has prepared this presentation to describe how batteries have been modeled in Economic Studies and why they were modeled this way.

- Battery Energy Storage Systems (BESS)
  - Relatively novel technology for the electric power networks
  - Can help facilitate the integration of zero-carbon renewable resources
  - Are flexible enough for a wide range of applications
  - Evolving costs and operating characteristics are a focus of research
  - Representing storage in a production cost model requires that most salient characteristics are reflected

Purpose of this Presentation

- This presentation will endeavor to:
  - Provide an overview of BESS in Economic Studies
  - Discuss several types of BESS deployments
    - Grid-scale market facing batteries
    - Co-located with Variable Energy Resources (VER)
    - Vehicle-to-Grid
    - Distribution system
    - Customer site
  - Introduce operational issues including battery degradation management
  - Discuss Variable O&M (VOM) costs
  - Present sensitivity cases showing the effect of VOM cost assumptions

BESS Modeling in Production Cost Simulations

- Energy storage has become a focus of Economic Studies
  - Pumped Storage
  - Grid-scale market facing batteries
  - Energy banking via Quebec in 2020 Economic Study
- GridView economic study production cost simulations
  - Investigate utilization of BESS under various cases and sensitivities
  - Capital cost and Fixed Operation and Maintenance (O&M) costs are not considered in ISO-NE Economic Studies

2,000 MW of Batteries Were Assumed in 2020 National Grid Economic Study Scenarios

<table>
<tr><th>Scenarios</th><th>Threshold Prices Used</th><th>Retirements</th><th>Must Run Units</th><th>Wind Additions (Nameplate)</th><th>Peak Demand from Heat Pumps</th><th>Peak Demand from Electric Vehicles</th><th>Nameplate Storage Additions</th><th>Bi-Directional External Tie(s)</th></tr>
<tr><td>Bi-Directional Reference (B)</td><td rowspan="4">REC-Inspired</td><td rowspan="4">FCA 14, Mystic 8&9, Millstone 2, NE Coal, + 75% of conventional NE oil including dual-fuel based on age</td><td rowspan="7">Nuclear, Municipal Solid Waste, Landfill Gas, Wood</td><td rowspan="7">1,330 MW Onshore
8,000 MW Offshore(2)</td><td rowspan="7">5,214 MW</td><td rowspan="7">1,817 MW (2.2 million vehicles)</td><td>2,000 MW Battery(2)</td><td>None</td></tr>
<tr><td>Bi-Directional Legacy (B_HQNB)</td><td rowspan="3">2,000 MW Battery(2) and Utilizing Hydro Quebec as Virtual Storage</td><td>HQ PHII and NB, NECEC</td></tr>
<tr><td>Bi-Directional New Transmission 1 (B_HQNB_1T)</td><td>HQ PHII, NB, NECEC One New 1,200 MW Tie(4)</td></tr>
<tr><td>Bi-Directional New Transmission 2(3) (B_HQNB_2T)</td><td>HQ PHII, NB, NECEC, Two New 1,200 MW Ties(4)</td></tr>
<tr><td>Incremental_8000 (I)</td><td rowspan="3">Positive Threshold Prices</td><td>FCA 14, Mystic 8&9, Millstone 2, NE Coal</td><td rowspan="3">2,000 MW Battery(2)</td><td rowspan="3">None</td></tr>
<tr><td>Incremental_8000 with Oil retirements (I_Oil)</td><td>Same as (I) plus the rest of the oil units</td></tr>
<tr><td>Incremental_8000 Oil and NG Retirements (I_Oil_NG)</td><td>Same as (I_Oil) plus 50% of the remaining NG units including dual-fuel units</td></tr>
</table>

(2) Other magnitudes of these resources may be considered as sensitivities

*(3) **May** be performed depending on utilization of the scenario where a single 1,200 MW transmission line is added*

(4) New ties added are from Hydro Québec to NEMA

BATTERY DEPLOYMENT

Deployment of BESS for Wide Range of Applications

- Grid interconnected FCM battery vs. non-network battery systems
  - ISO market-facing batteries
  - Co-located with wind or PV
  - Tesla power walls
  - Vehicle-to-Grid
  - Mobile batteries
  - Non-transmission alternatives
  - Distribution system management
- Technology being driven by successful experience with Li-ion
  - Other battery chemistries exist (Li-ion vs. flow batteries, etc.)
  - Flexible, expandable energy niches for ½, 1, 2, 4, 6 or 8 hours batteries
- Service duty: Arbitrage, regulation/reserves vs. customer-site applications

ISO Grid-Scale Market-Facing Batteries

- Market facing framework assumed in the 2019 and 2020 Economic Studies
  - Responds to Locational Market Prices (LMP)
  - Provides capacity for the Forward Capacity Market (FCM)
  - Provides ISO orchestrated regulation and reserves
- Dispatch is optimized by GridView in production cost simulations
  - Primarily energy arbitrage
  - BESS capacity can be allocated to spinning reserves instead of energy arbitrage
- EPECS
  - Will provide more granular time-step
  - Consider dispatch in different markets (day-ahead to real-time)

Co-located with Customer Load or Distribution System

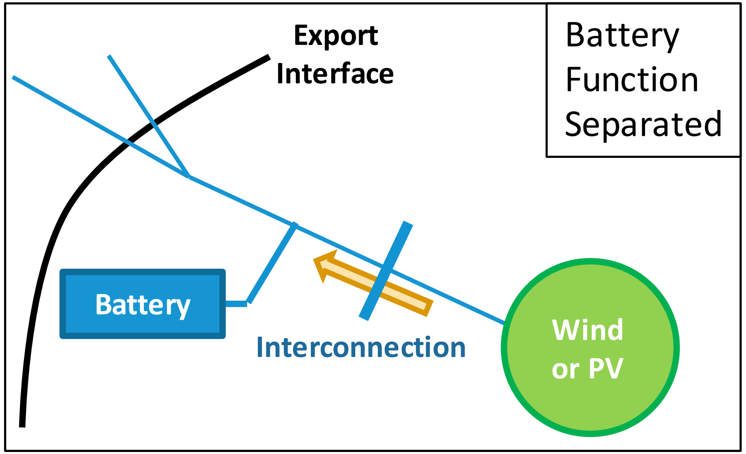
- Co-location of BESS
  - Primary function is to manage energy interaction with ISO Markets
  - Active participation in ISO markets is secondary to other considerations
- Co-located with distribution system or non-transmission alternative
  - Manage distribution system loading
  - Enhance local reliability
  - May respond to reserves
  - Profit motivation for participation in ISO markets is not clear
- Co-located with customer load
  - Manage customer's interaction with energy supplier
  - May respond to LMP if beneficial to customer
  - May decrease customer's retail demand charge
  - Providing regulation and reserves may be in conflict with customer's cost management objective

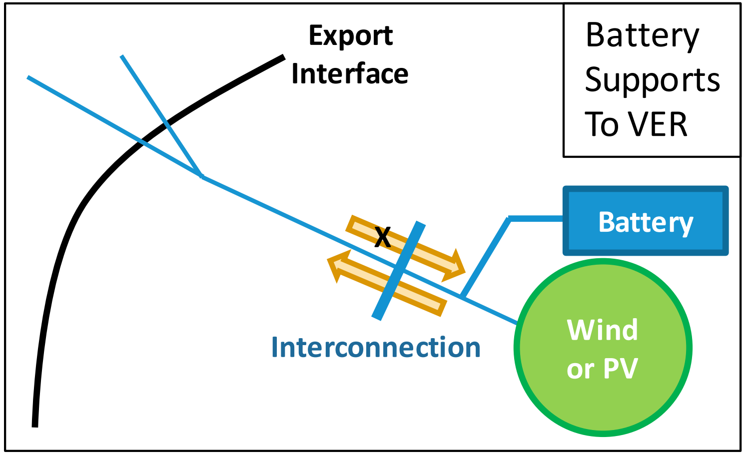
Co-located with Variable Energy Resources (VER)

- Co-located with variable energy resource behind an interconnection
  - May respond to LMP – subject to interconnection capability
  - Supports the FCM capacity attribute of the co-located VER
  - Enhances certainty of satisfying regulation, reserve and performance obligations of the co-located VER
- Interconnection to accommodate both VER and battery simultaneously
  - Increases size of interconnection
  - May exacerbate local weak-grid conditions
- Interconnection to accommodate only VER with battery as back-up
  - Does not increase the size of the interconnection
  - Prevents simultaneous operation of VER and battery

Co-located with Dedicated VER charging

- Battery co-located with VER may not be permitted to charge from grid
  - During periods of high VER output battery may be "full"
  - During slack periods, with low VER output
    - Battery may be prohibited from recharging using grid energy





Vehicle-to-Grid

- Large amounts of mobile batteries implied in the economic studies
  - 2020 study assumed 2.2 million electric vehicles
  - Equivalent to 180,000 MWh of vehicle battery storage
    - Based on Tesla Model 3 at 82 kWh
    - About 22 times the assumed market facing batteries
      - 8,000 MWh
      - Based on assumed 2,000 MW at 4 MWh/MW
  - Advocates claim batteries are not degraded by vehicle-to-grid operation
- Time-of-use incentives for charging / discharging
  - May be useful strategy with large penetration of diurnal PV
  - May not be optimal with large penetrations of non-diurnal OSW wind
- "Repurposing" degraded vehicle batteries can augment stationary batteries

OPERATING CHARACTERISTICS

Operating Characteristics

- Major BESS operating parameters
  - Round-trip efficiency of 86 percent modeled in the 2020 Economic Study
  - Battery degradation
    - Causes duration of MWh storage capability to fade both over time and due to use
    - Does not affect MW capability of the inverter based interface
  - Number of lifetime charge / discharge cycles
    - Not addressed in the literature as a quantified constraint
    - No specific number of charging/discharging cycles per period will be specified
    - Li-ion degradation affected by high and low states-of-charge, not only cycles

Simulating Aggregate Batteries in GridView

- Modeling of batteries in GridView are for relatively large aggregates
  - Aggregates of many battery facilities under many participants
  - Each facility may have multiple stacks that can be dispatched separately
  - Assumed that each operator will manage their BESS to minimize degradation
- Charging and discharging of individual batteries cannot be represented
- Dispatch of a fleet of batteries is likely to behave smoothly
  - Owners of specific battery stacks may elect to operate differently
  - Discharging for evening peak loads will be the dominate mode for large penetrations

Degradation / Variable O&M

- Approaches for BESS operator to compensate for expected degradation
  - Augment initial installation of storage MWh sufficiently to account for degradation at end of warranty period (e.g., part of "first cost")
  - Augment battery capability as degradation occurs (e.g., expects improved, lower cost battery modules in future)
- Literature supports various allocations of VOM to variable production
  - NREL uses zero for the VOM component
  - IEEE Access® paper on Li-ion battery sizing/degradation (October 14, 2020)
    - H. Shin and J. Hur, "Optimal Energy Storage Sizing With Battery Augmentation for Renewable-Plus-Storage Power Plants," in IEEE Access, vol. 8, pp. 187730-187743, 2020, doi: 10.1109/ACCESS.2020.3031197, https://ieeexplore.ieee.org/document/9223659
  - Effect of VOM costs assumption in GridView simulations will be investigated

From Paper by H. Shin and J. Hur

- SECTION I: Introduction

  "Several methods are available for BESS sizing. ***Oversizing is the conventional method to handle battery degradation*** *by installing higher battery capacity than the required one to deliver the intended amount of energy at the beginning of life. Another method is* ***battery augmentation, in which new batteries are added to the BESS over time****. Battery augmentation defers initial investments and can exploit future cost reductions in batteries."*

- SECTION III: Lithium-Ion Battery Degradation

  "Lithium-ion batteries are subject to capacity degradation as they are used ... The capacity degradation rate depends on many factors ... ***The stress factors determining the capacity retention are the levels of Depth of Discharge (DoD) and State of Charge (SoC), Charging-rate, cycle count, temperature, and total operation time."***

NREL Allocated Battery Replacement / Renewal / Cycling Expense as Fixed O&M

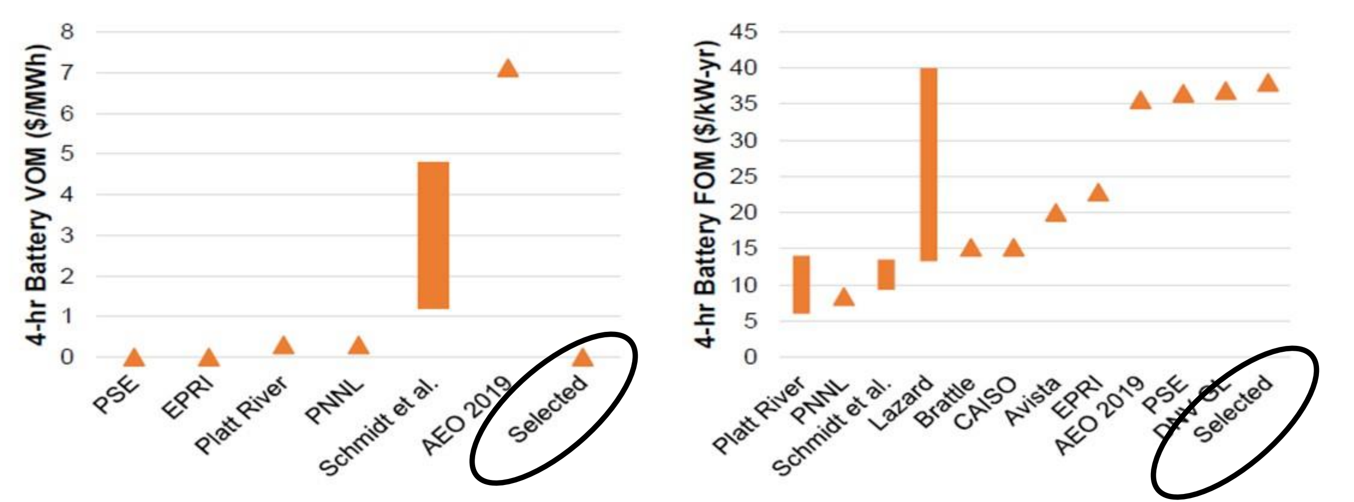


Figure 7. Variable O&M (top right) and fixed O&M (top left) from various published sources. The values selected for this study are the right-most values shown.

Source: *Cost Projections for Utility-Scale Battery Storage,* Wesley Cole and A. Will Frazier, June 2019, National Renewable Energy Laboratory, NREL/TP-6A20-73222, https://www.nrel.gov/docs/fy19osti/73222.pdf

EFFECT OF VARIABLE O&M

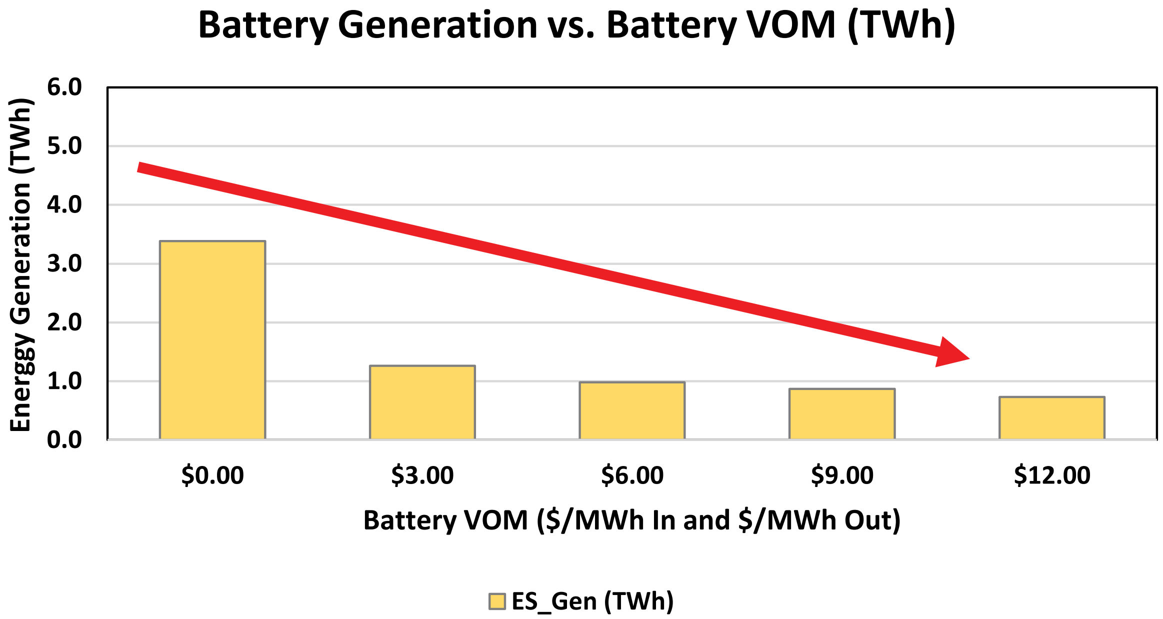
Effect of VOM for Batteries in GridView Simulations

- These simulations address questions of how sensitive GridView results are to VOM assumption

- GridView representation of BESS VOM
  - VOM applied for BOTH storing energy and discharging energy
  - Effective net VOM rate is slightly more that double (due to storage losses)

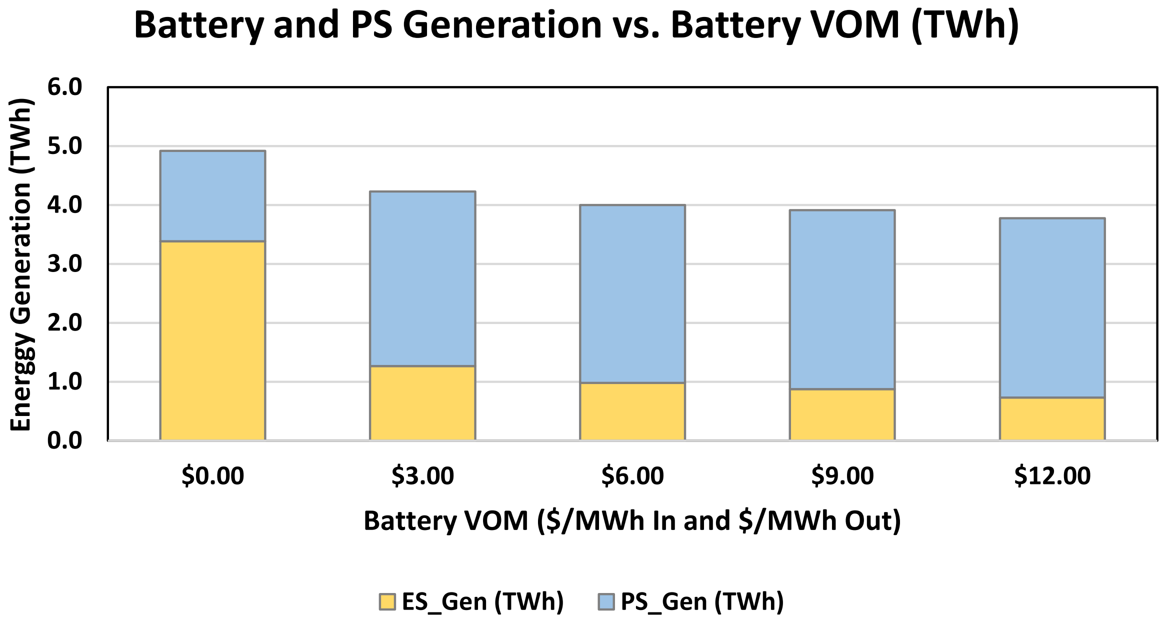
- VOM sensitivity cases
  - $ 0.00/MWh
  - $ 3.00/MWh
  - $ 6.00/MWh
  - $ 9.00/MWh
  - $12.00/MWh

Effect of VOM on Battery Generation (TWh)



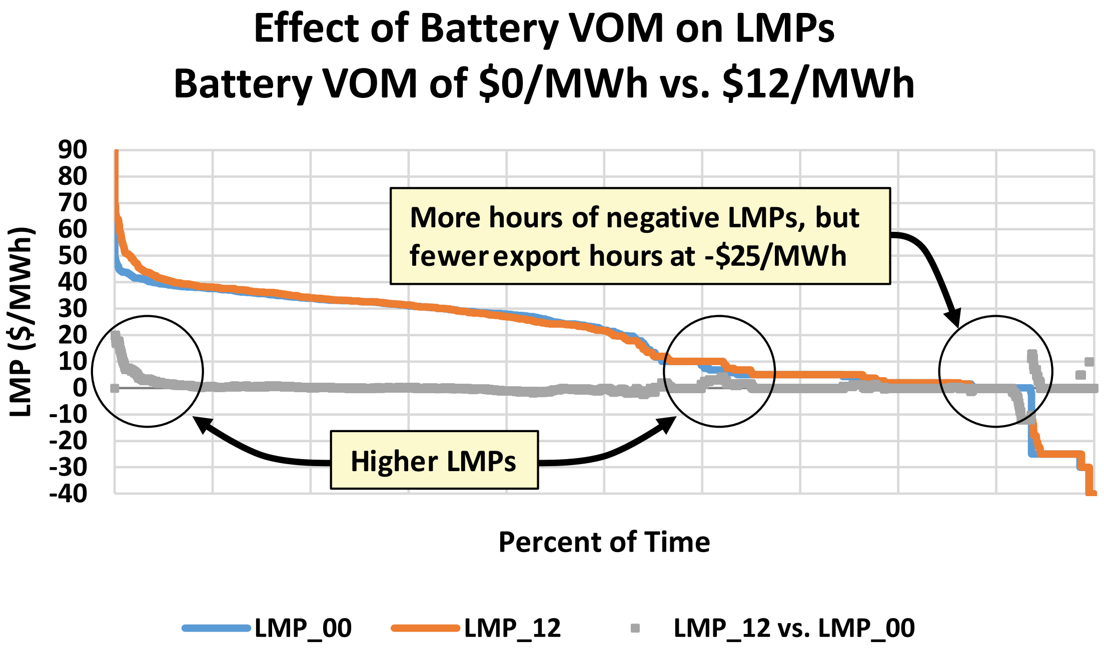
Battery generation TWh declines with the addition of VOM.

Effect of VOM on Battery and Pumped Storage (TWh)



Combined TWh generation of both battery and pumped storage is relatively stable as battery VOM increases.

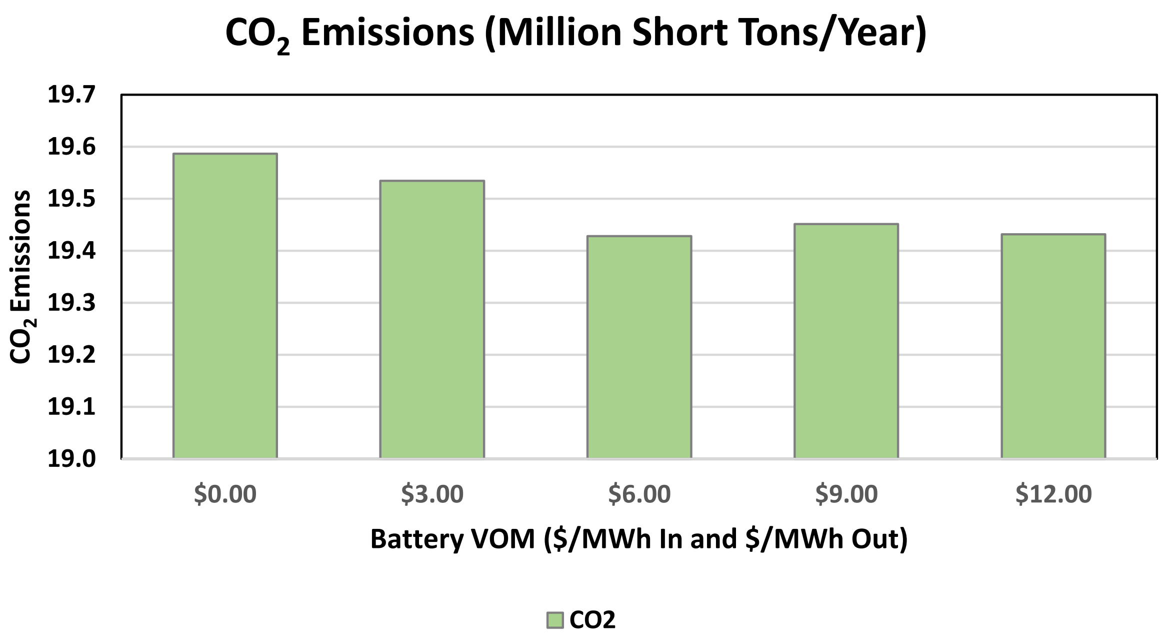
Effect of Battery VOM on LMPs ($0 vs. 12/MWh)



Addition of VOM on batteries increases positive LMPs and also increases the number of hours of negative LMPs.

Effect of VOM on New England CO_2 Emissions

Note: expanded scale



Effect of increasing VOM on CO_2 emissions is small.

The reduction in CO_2 appears to be related to reduced fossil generation needed because of lower total storage losses.

Change in unit commitment may also be a factor.

Summary

- For the key metrics used in the 2020 Economic Study, the effect of VOM to account for battery degradation and augmentation is relatively small
  - Primary effect of higher VOM for batteries
    - Shift energy storage opportunities to pumped storage
    - Raise LMPs in some hours because charge / discharge cannot be justified
  - Results in a small reduction in the number of export hours in bidirectional ties
- Developments in the evolution of batteries merit continued monitoring
  - Augmentation strategies and associated VOM to be reviewed prior to next economic studies
  - Assumed vehicle-to-grid batteries may be many times greater than assumed grid-facing batteries, but uncertainties exist if electric vehicle owners will be receptive to sharing batteries for power grid services

Questions

APPENDIX

Acronyms

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ACDR	Active Demand Capacity Resource
ACP	Alternative Compliance Payments
AGC	Automatic Generator Control
BESS	Battery Energy Storage Systems
BTM PV	Behind the Meter Photovoltaic
BOEM	Bureau of Ocean Energy Management
CCP	Capacity Commitment Period
CELT	Capacity, Energy, Load, and Transmission Report
CSO	Capacity Supply Obligation
Cstr.	Constrained
DR	Demand-Response
EE	Energy Efficiency

EFORd	Equivalent Forced Outage Rate demand
EIA	U.S. Energy Information Administration
EPECS	Electric Power Enterprise Control System
FCA	Forward Capacity Auction
FCM	Forward Capacity Market
FOM	Fixed Operation and Maintenance Costs
HDR	Hydro Daily, Run of River
HDP	Hydro Daily, Pondage
HQ	Hydro-Québec
HY	Hydro Weekly Cycle
LFR	Load Following Reserve
LMP	Locational Marginal Price

Acronyms, continued

LSE	Load-Serving Entity
MSW	Municipal Solid Waste
NECEC	New England Clean Energy Connect
NESCOE	New England States Committee on Electricity
NG	Natural Gas
NICR	Net Installed Capacity Requirement
NREL	National Renewable Energy Laboratory
OSW	Offshore Wind
O&M	Operation and Maintenance
PHII	Phase II line between Radisson and Sandy Pond
PV	Photovoltaic
RECs	Renewable Energy Credits

RFP	Request for Proposals
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewables Portfolio Standards
SCC	Seasonal Claimed Capability
Uncstr.	Unconstrained