ASSESSING THE ROLE OF ENERGY STORAGE AS A PEAKING CAPACITY RESOURCE IN THE UNITED STATES

Will Frazier* and Wesley Cole

*Corresponding author information:
Will Frazier
Energy Analyst
(303) 384-6488
Will.Frazier@nrel.gov
National Renewable Energy Laboratory
15013 Denver W Parkway
Golder, CO 80401
Abstract

There is growing interest in the ability of storage to play a role as a peaking capacity resource in the US power system. Last year, FERC order all ISOs/RTOs to modify their market structures so that storage could compete in all electricity markets. This included a duration requirement for storage to participate in capacity markets. These duration requirements could have an impact on the economic competitiveness of battery storage. We use the ReEDS (Regional Energy Deployment System) capacity expansion model to analyze battery deployment in the US electric power sector under various assumptions for storage duration requirements. We find that these requirements impact both long- and short-term deployment of battery storage, and have an impact on the reliability and operation of the grid as well as future energy and capacity markets.

Introduction

In their recently established order 841, FERC required all ISOs/RTOs to modify their market structures to allow storage resources to participate in all electricity markets within their respective jurisdictions (FERC, 2018). The order included a request for each ISO to establish a minimum duration requirement for storage generators to participate in capacity markets. A summary of the ISO responses is shown in Table 1. Storage resources with a duration less than the requirement are to be paid for the fraction of their capacity that they would be able to provide for the full required duration, also known as firm capacity. For example, if the required duration is 4 hours then a 100MW/200MWh battery would receive a capacity credit of 0.5 and would be paid for its firm capacity of 50MW, because that is the most power it would be able to provide for 4 continuous hours. This enables all storage resources to participate in all capacity markets while acknowledging the limitation of energy storage to provide peaking capacity.

<table>
<thead>
<tr>
<th>RTO/ISO</th>
<th>Duration requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO-NE</td>
<td>2 hours</td>
</tr>
<tr>
<td>CAISO</td>
<td>4 hours</td>
</tr>
<tr>
<td>NYISO</td>
<td>4 hours</td>
</tr>
<tr>
<td>SPP</td>
<td>4 hours</td>
</tr>
<tr>
<td>MISO</td>
<td>4 hours</td>
</tr>
<tr>
<td>PJM</td>
<td>10 hours</td>
</tr>
<tr>
<td>ERCOT</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 1: Responses from US ISOs to the duration requirement in FERC order 841.

These duration requirements are important for two reasons. First, they can serve either as a facilitator or as a barrier to battery storage deployment on the grid. Long duration requirements would restrict the potential revenue available to short duration storage resources. These conditions could artificially render short duration batteries uneconomical in peaking capacity markets where they would otherwise fill a valuable role. Batteries can provide other services such as operating reserves, curtailment recovery, and energy arbitrage, but studies have shown that providing peaking capacity offers a lot of potential for batteries (Denholm, Nunemaker, Gagnon, & Cole, 2019). If batteries cannot accrue enough value from those other services to recover their capital costs, then ISO duration requirements could have a significant impact on future battery deployment.
On the other hand, these requirements are necessary because too much short duration storage could be inefficient and unreliable. Batteries are limited by their energy capacity in serving a typical load peak. Short duration resources can serve a narrow tip of peak demand, but longer durations are required for continued battery penetration as a peaking resource. Continued deployment of short duration storage can result in system inefficiencies, as shown in Error! Reference source not found.. The figure depicts an example load profile peak being met with three 100MW/200MWh batteries, each shown in different colors. The first battery (dark blue) meets the peak load hour with 100MWh of energy left over that could be dispatched before or after. The second battery (sky blue) can work with the first to reduce the peak load another 100MW even though the width of the peak at that point is 3 hours. The third battery, however, is spread thin and can only further reduce the peak by 40MW. Without accounting for this issue, lots of short duration energy storage could affect the reliability of the grid.

Figure 1: An example system battery storage meeting peak demand.

Methods

We use the latest version of the Regional Energy Development System (ReEDS-2.0) capacity expansion model to analyze the effects of storage duration requirements on the deployment of battery storage in the United States electricity grid. ReEDS-2.0 is a sequential linear optimization model that determines capacity expansion in the US electricity sector from present day through 2050. The recent release of ReEDS-2.0 has many model improvements including a new module that handles the treatment of firm capacity of storage resources as well as required duration for storage investments. Briefly – referring back to Figure 1 – the method functions as follows: rather than treating each battery individually, the model would determine that 300MW of 2-hour storage could achieve a peak reduction of 240MW if it were to operate with an effective average duration of 2.5 hours (600MWh/240MW). These storage resources would each receive a peak reduction credit\(^1\) (PRC) of 0.8 (240MW/300MW) and would each be

\(^1\) Here we use the term peak reduction credit (PRC) because we are simply considering the physical ability of batteries to meet peak demand given a perfect load forecast. This is meant to distinguish it from capacity credit,
assigned a firm capacity of 80MW. The required duration for storage investments in this example would be 5 hours.²

ReEDS consists of 18 RTOs based on NERC “assessment areas”³. These are in turn comprised of 134 balancing areas (Figure 2) which gives ReEDS good spatial resolution relative to other nation-wide capacity expansion models. Storage assessments in ReEDS are calculated at the RTO level and use net-load profiles to capture the interactions between storage and variable renewable resources (VRRs)⁴. Load profiles are from 2012 and are scaled by the EIA load growth projections by census region. Net-load profiles are obtained endogenously using the model’s detailed VRR representation. We also include hourly production cost modelling results for the resulting 2050 system in each scenario to assess their performance and resource adequacy. These capabilities together make ReEDS-2.0 well-suited for studies involving non-trivial amounts of future battery storage.

Figure 2: Map of ReEDS balancing areas and RTOs.

There are five scenarios included in this work (Table 2): one with batteries excluded from the model and four with various duration requirements for storage. Three of these scenarios have a static storage duration requirement for all regions for the entirety of the model. The other uses the default which is traditionally calculated through a rigorous statistical analysis of a generator’s expected load-carrying capability (Garver, 1966) and used to determine firm capacity.

² The actual method in the model would look ahead for 1000MW (accounting for recharging limitations) and use that to determine the required duration for storage investments. More details on the method can be found in the ReEDS documentation.

³ PJM, MISO, and NWPP are further divided in ReEDS due to their large size.

⁴ It has been shown that VRR deployment can have significant impact on the ability of storage to meet peak demand (Denholm, Nunemaker, Gagnon, & Cole, 2019).
module in ReEDS-2.0 that determines the firm capacity and required duration of storage endogenously. The 2019 model version of ReEDS-2.0 includes only 4-hour batteries, so for this work we have added 2-, 6-, 8-, and 10- hour batteries as technology options. We extrapolated capital cost projections for these alternative durations from NREL’s 2019 Annual Technology Baseline (Figure 3).

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Duration Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic</td>
<td>determined dynamically by ReEDS</td>
</tr>
<tr>
<td>2-Hour</td>
<td>2 hours</td>
</tr>
<tr>
<td>4-Hour</td>
<td>4 hours</td>
</tr>
<tr>
<td>10-Hour</td>
<td>10 hours</td>
</tr>
<tr>
<td>No Batteries</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 2: List of sensitivity scenarios included in this study.

Figure 3: 2019 ATB cost projections for batteries of varying duration compared with natural gas combustion turbines.

Results:

Battery storage deployment varied considerably across the scenarios analyzed in this study. Figure 4 shows both the battery power capacity (top) and energy capacity (bottom) from 2025 to 2050 in each scenario. We see that the 2-hour scenario had the highest deployment of power capacity (253GW) because cheap 2-hour duration storage received full PRC for the entirety of the model. The 4-Hour scenario had the highest energy capacity deployment (737GWh) because even at 4 hours of duration batteries were cost competitive in the 2040s, although the amount of energy capacity is inefficient relative to the dynamic case. The dynamic case lies in between the 2- and 4-hour scenarios because the model chose to build mostly 2-hour batteries but also includes a smattering of 4-, 6-, 8-, and 10-hour batteries where 2-hour batteries were insufficient. This explains why it has nearly as much energy capacity as the 2-hour scenario despite having about 50GW less power capacity. The 10-hour case has a total of only
51 GW of battery storage deployed in 2050. This indicates that a long duration requirement can indeed stymie development that would otherwise be both economically andlogistically feasible.

Figure 4: Battery storage deployment (in GW and GWh) in each scenario that includes batteries.
We also see in Figure 4 that cumulative battery deployment in the 4-hour scenario is rapidly approaching that of the dynamic scenario toward the end of the model horizon. In the 4-hour scenario, battery capacity more than doubles from 80GW to 184GW between 2045 and 2050, while during this timeframe in the dynamic scenario there is a relatively modest capacity increase from 134GW to 193GW. The reason for this is that in the dynamic scenario the system is so saturated with 2-hour storage that the duration requirement for additional storage becomes relatively long. Figure 5 shows the duration requirements from the dynamic scenario for each of the 18 RTOs in ReEDS. We see that early on the duration requirement for most RTOs is 2-hours (the minimum allowed) with some outliers that have longer duration requirements as early as 2025. However, as short duration storage is deployed at scale the duration requirement grows until it falls mostly between 6 and 12 hours in 2050. Too much short-duration storage can saturate the peaking storage market and restrict the opportunity for more storage to come online in the future, eventually slowing down the overall deployment of energy storage.

Figure 5: Box and whisker plot of required durations for storage in each of the 18 RTOs.

While the trend of increasing storage duration requirement exists in all US regions, the actual behavior of the requirement over time is quite nuanced and varies widely between regions. It depends on a complex interaction of load profile shape, load growth, fleet retirements, VRR generation, planning reserve margin size, and prior storage deployment. Figure 6 provides a snapshot of this regional variation in the dynamic scenario in 2050. The points in the bottom right corner of the graph tend to represent either areas in the center of the country with very high wind penetrations or areas in the northeast with very wide load peaks. Alternatively, the points on the left of the graph represent regions with narrow load peaks and/or high PV penetrations such as CAISO and FRCC. Furthermore, we see that the effective duration of the existing storage fleet is much less than the duration requirement of incremental storage additions. Recall the toy example in Error! Reference source not found. where the fleet could operate at an average duration of 2.5 hours to achieve the maximum possible peak reduction, but the requirement for further storage to receive full PRC was 5 hours.
Figure 6: Battery penetration (firm capacity as percentage of peak load) and effective duration for each RTO in the dynamic scenario in 2050.

Production cost modelling results show that the scenarios also differ in their overall reliability. Error! Reference source not found. shows the amount of unserved load in 2050 in each of the scenarios when the ReEDS results were processed through the PLEXOS production cost model at hourly temporal resolution. Both the 2-hour and 4-hour scenarios rely too heavily upon short duration storage and do not have sufficient energy capacity to meet peak demand. Even though the 4-hour scenario has more total energy capacity and less power capacity than the dynamic scenario, the region-specific energy capacity limitations are not accounted for and as a result the system is unable to serve load in regions with wide demand peaks. The dynamic scenario was able to properly assess these regional limitations of energy storage. This capability allowed it to build a significant amount of battery storage capacity while also maintaining a reliable grid.
Figure 7: Unserved energy duration curve for each scenario analyzed in this study.

The method implemented for assessing storage duration assumes that the primary market for energy storage is in peaking capacity. The model, however, is free to build batteries of any duration if the value from providing other services exceeds the value it would get from firm capacity by building the optimal duration. Like any other generator, batteries are compensated for providing energy and ancillary services as well as capacity. Despite this, most of the battery deployment seems to be on the margins of capacity for serving peak demand and meeting the planning reserve margin. This is evident in the dynamic scenario as the model first builds 2-hour batteries and then moves on to longer durations as needed. Further evidence of the validity of this assumption exists in both the capacity and energy price results.

Figure 8 shows the evolution of capacity prices in ReEDS across all five scenarios. We see that through 2030 that capacity prices in each scenario are comparable, with the prices in the 2-hour and dynamic scenarios being slightly lower because cheap 2-hour battery storage is receiving full PRC at that point. Those scenarios diverge from the rest in the early 2030s, with the capacity price in the 2-hour scenario dropping through 2050 along with the capital costs shown in Figure 3. Around 2040 the capacity price in the dynamic scenario begins to increase, as the required duration for full PRC begins to lengthen significantly. Eventually the dynamic scenario capacity price rise above even the 4-hour scenario. In 2050 each scenario appears to have its respective capacity price set by whatever battery duration is required for PRC.
Figure 8: Average regional capacity prices in ReEDS weighted by regional capacity

Figure 9 shows price duration curves from the production cost modelling results for the dynamic, 10-hour, and no battery scenarios. We see that the high price hours in the dynamic scenario are significantly lower than the other two. This indicates that batteries are operating mostly during times of peak demand. This supports the claim that serving peak demand represents a large portion of the market potential for battery storage on the US electricity grid.

---

5 The 2-hour and 4-hour scenarios are omitted because the hours of unserved energy creating peak price spikes that make comparison not useful.
Figure 9: Price duration curves generated from hourly production cost modelling results from the dynamic, 10-hour, and no battery scenarios.

Conclusions

There is a large potential for energy storage to serve as peaking capacity in the United States. Recent capital cost projections for batteries indicate that batteries could be cost-competitive at scale on the US grid within the next 10 years and could fill a large role as a peaking capacity source in the coming decades. Storage duration requirements are needed to moderate this resource because of the constraints of energy storage systems.

The speed and extent of battery deployment depends on a variety of factors. This includes load growth and change, VRR penetration, capital costs, and policy requirements for battery storage duration. Duration requirements must be short enough to allow for batteries to compete economically. However, they must also be long enough and specific enough to be relevant for ensuring grid reliability in that region. Storage duration required to serve peak load increases as a function of battery penetration and depends on the load profile shape and VRR generation of a given region.

According to ReEDS model results, grid scale deployment of battery storage competes mostly on the margins of capacity with natural gas generators. More or less battery deployment is coincided with more or less natural gas deployment.

Works Cited

