Energy Storage as a Transmission Asset

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I. Introduction

Energy storage in the form of pumped hydro resources is a proven source of generation. Recently, advanced energy storage devices in the form of batteries have also begun participating in electricity markets. While energy storage is usually classified as a generation resource, the operational characteristics of advanced storage technologies and their use as transmission assets are worth exploring. As such, PJM and battery storage supplier/developer Xtreme Power collaborated to look further into the tools available to planning organizations to assess the use of storage as a transmission asset. There were four main objectives to this work:

- Identify transmission contingency definitions and cases where storage may be applied.
  - Use RTEP and/or off-cost generation reports to identify upgrades and/or contingencies that may be good candidates for modeling the storage asset’s performance.
- Gather operational history on events to determine the operational characteristics needed from storage.
- Determine whether PJM can model the storage asset in our Planning model.
- If results of #1-3 appear beneficial to the system, engage TOs for field demonstration project.

II. History

The use of storage as transmission has had its share of regulatory debate. In 2006, FERC denied a filing by Nevada Hydro to treat its pumped storage facility as a transmission asset (Docket No. EL06-278-000). However, the Federal Energy Regulatory Commission (FERC), in an order dated Jan. 21, 2010 (Docket No. EL10-19-000), regarding a filing by Western Grid Development, has decided to address the classification of energy storage devices on a case-by-case basis. In the same order, FERC ruled that given certain specific characteristics being met, storage devices could be treated as transmission facilities, and therefore be compensated in the
same way as other transmission facilities are compensated. These characteristics used to
distinguish storage as a transmission service in this particular case were:

- Western Grid will be responsible for all operating functions including communication
  system emergencies and including maintaining the state of charge of the device.
- The resource will be operated by CAISO just as they would operate other transmission
  assets like capacitors.
- Western Grid will not retain revenues outside of the transmission access charge (i.e. they
  will not have any other revenue stream).
- The resource will not participate in any wholesale electricity markets.

In addition to these rulings at FERC, utilities have installed energy storage assets at low voltage
transmission and distribution levels to achieve a variety of reliability objectives.

- Wisconsin Public Service – In July 2000, WPS and American Superconductor
  installed a Distributed-Superconducting Magnetic Energy Storage System (D-SMES)
  on the Rhinelander loop – a 115 kV, 200 mile loop in northern Wisconsin that is
  limited by stability issues. Alternative transmission upgrades were estimated to cost
  $35-46M, take 10 years to complete, and intrude on bald eagle habitat. The D-SMES
  solution provided the very short duration needed at roughly one tenth the cost and a
  faster, less intrusive installation.
- Presidio, Texas – 4 MW, 32 MWh Sodium-Sulfur (NaS) battery used to support
  power quality on a 100 km, radial 69 kV transmission line that feeds the border town
  of Presidio. The battery’s quick response time will address voltage fluctuations
  affecting power quality and the 8 hour duration can supply power during an outage
  and give grid operators enough time to import power from Mexico without power
  interruption. The battery system is part of a more complete $45M transmission
  upgrade to the region, approved by ERCOT and the Texas PUC. As such, the cost of
  the battery will be socialized across all rate payers in Texas.

These projects, and others at the distribution level not listed here, show precedence for the
successful use of storage as a transmission asset. This paper aims to better understand the use of
storage devices to solve NERC Reliability Standards at the transmission level and whether
evaluation and utilization by planning organizations like PJM is possible with the tools available
today.

III. Planning Department Results

In order to investigate the use of a battery energy storage device as a transmission upgrade
solution, the PJM Planning Department was engaged to reflect on the range of storage properties
that might address transmission criteria violations and/or upgrades. In response, the Planning
Department took a more practical and direct approach, and tried to identify applications relevant
to PJM’s Regional Transmission Expansion Plan (RTEP). Initially, there was thought that
certain Transmission Owners in PJM may be willing to look deeper into a real project
demonstration given the upgrades to their system identified in the RTEP; however, upon interest
gathering, no commitments were reached. This corroborated the need for an initial desktop
investigation into some of the particulars of implementing such a project.

The PJM Planning Department was asked to provide input on 1) how or if a battery facility could
be modeled using PSSE techniques, and 2) what selection criteria are currently used to identify
upgrade solutions for different types of NERC Reliability Standards violations (i.e. thermal,
voltage, contingency analysis) and whether or not these selection criteria could be applied to a
battery storage device. The reasoning behind this was that if there existed a set of performance
specifications to solve a particular type of NERC criteria violation, a battery could be compared
more easily with other potential solutions. An example of a simplistic way to characterize
criteria violations in a way that allows them to be evaluated for storage solutions is shown in
Table 1.

Table 1. Transmission needs and performance specifications matrix

<table>
<thead>
<tr>
<th>Transmission Needs and Types of Contingency</th>
<th>Response Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria Violation</td>
<td>Response Speed</td>
</tr>
<tr>
<td>Contingency A</td>
<td>A</td>
</tr>
<tr>
<td>Contingency B</td>
<td>Response Speed B</td>
</tr>
<tr>
<td></td>
<td>Response Duration A</td>
</tr>
<tr>
<td></td>
<td>Response Duration B</td>
</tr>
</tbody>
</table>
Where:

1. **Criteria Violation**: The threshold condition(s) on transmission component that trigger need for upgrade or congestion, (e.g. under voltage).
2. **Type of Contingency**: Event categories that trigger the problem or criteria violation. Examples: line trip, stuck breaker, generator outage.
3. **Response speed**: The minimum time in which the solution device needs to react by providing power, VARS, etc.
4. **Response duration**: The minimum and/or maximum time for which the solution device needs to stay activated to alleviate reliability violations.

In response to (1) above, the Planning Department determined that PSSE modeling of a battery storage device was possible, but would only be useful for very short-term stability analysis and would not cover longer term duration violations. The analogy used to describe a longer term event was a 4 hour thermal violation and it was offered that four hour duration would be a typical time frame that Planning would use to study a solution to a thermal violation. In order to study a longer term duration event, it was thought that market modeling simulation could be a tool used to analyze a storage resources response to potential thermal overloads caused by transmission congestion.

In response to (2) above, PJM did not attempt to create a complete list of types of contingencies and response specifications. Rather than PJM creating a master list of performance specifications and criteria violations, PJM is ready to consider proposals for specific applications to solve specific criteria needs from asset owners or developers.

**IV. Market Modeling Simulation**

Following the dialogue with the Planning Department, the pilot was brought to PJM staff with market modeling capabilities. The objective of this shift was to identify the potential tools available to PJM for evaluation of energy storage facilities’ ability to function as a congestion management tool. Unlike typical energy storage devices such as pump storage whose dispatch is optimized based on the spread of On and Off Peak Prices, modeling the device as a transmission
asset necessitated making it less sensitive to changes in energy prices. Instead the device would need to charge and discharge at a sufficient rate to respond to reliability events, namely opportunities to mitigate congestion. To be treated on par with other reliability devices such as capacitors or SVC devices, it was also necessary to model the device so it remains revenue neutral while still providing system benefits that can be measured economically. The primary modeling tool for evaluating the device was Ventyx Promod IV (PROMOD), a software model that performs a Security Constrained Economic Dispatch and can be used to identify the impacts to congestion and market prices of changes in generation behavior as well as of perturbations to the transmission system. The nodal simulation is based on a DC linearized powerflow and consequently only monitors the thermal capability of the transmission system. Because transmission elements are static in PROMOD, either in service or out, and do not respond to operational signals, it was necessary to model the device with features of both an energy storage device and as a Transmission asset.

In keeping with the pilot’s objectives of illustrating storage as Transmission asset, the device was modeled using a combination of PROMOD’s energy storage module, as well as with nomograms. Nomograms are essentially a set of weighted elements whose function is to impose a flow limit on the sum of its members. To not perturb the economic unit commitment and dispatch, the energy storage device was modeled at a fraction of its actual capability. Doing so ensures that PROMOD would not allow the device to cause a displacement of economic generation. While the device is not modeled to be load serving, the nomogram would magnify the impact of the device to simulate the actual loading of the transmission system as a result of its operation. The analysis implemented a hypothetical storage facility with a 100 MW injection/withdrawal at a location characterized by significant historical congestion but also where transmission line voltages are lower, and a relatively small injection could achieve the greatest impact. Table 2 below shows one of the locations selected to test the device impacts.
Table 2: List of locations chosen for congestion study

<table>
<thead>
<tr>
<th>Facility</th>
<th>Contingency</th>
<th>Congestion in 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brues to West Bellaire (AEP 138 KV Transmission Line)</td>
<td>Loss of Kammer 500/138 KV XFMR 1B</td>
<td>$10.7 M</td>
</tr>
</tbody>
</table>

The modeling assumed the asset would not be bid into the energy market and thus would not be dispatched based on its economics, but rather the unit would be controlled so as to allow improvement of energy flows that would lower congestion. Because the device is modeled at a fraction of its total output, prior to running the PROMOD simulation, the MW impact on the transmission system as a function of the device output must first be measured. Once the set of distribution factors were determined an equivalent set of nomogram equations were developed to assess the net system benefits of the storage device. Nomograms enabled us to measure the simultaneous impact of the device on all significant constraints. The transmission security analysis monitors the flows on the nomogram just as it does for other constraints throughout the full PROMOD simulation.

Using Nomograms to represent the device impact was a somewhat novel approach as Nomograms increase the complexity of the linear program and we were uncertain as to whether PROMOD would maintain the Nomogram during periods where the transmission system model was under a significant amount of stress, namely for contingency evaluation. Preliminary analysis showed that the modeling approach accurately reflected the presence of the storage unit for 96% of its charge/discharge cycles. The error in PROMOD’s handling the nomogram may result in the device benefits being understated or overstated within a given simulation. However, for the purpose of economic modeling, this level of accuracy provides adequate confidence for further use of PROMOD in evaluating system-wide economic impacts of using storage to relieve congestion. The results of the preliminary analysis for one of the locations identified in Table 2 are shown in the figures below. The charts show the congestion impacts observed over one year as well as the shorter term impacts of charge/discharge cycles observed within an operating day. The effectiveness of the device in responding to congestion as measured in the PROMOD simulation will vary by season and location. Over the course of a longer period of time however,
the results show that the storage device can lower congestion costs. Below are some of the initial simulation results from the modeling:

Figure 1: Storage Impacts Observed on West Bellaire to Brues Transmission Line on Jun-01, 2012 Simulation Day

![Graph showing storage impacts on June 1, 2012](image1.png)

Figure 2: Storage Impacts Observed on West Bellaire to Brues Transmission Line on Sep-01, 2012 Simulation Day

![Graph showing storage impacts on September 1, 2012](image2.png)
This set of demonstration runs with PROMOD also allowed a discussion of potential limitations of the tool for various purposes. Some of the challenges and limitations for the use of PROMOD are typical for production cost modeling generally:

1. Model depends on setting up the base case conditions and assumptions of the power system for the year to be modeled
2. Hourly analysis is less granular than actual 5-minute economic dispatch of generation; DC power flow model does not include stability and voltage limits, and only represents the thermal benefits of the device.

Beyond these, specific limits that affect the analysis of storage systems include at least two concerns that merit discussion. The battery device is capable of more charge and discharge cycles than what was represented in the initial PROMOD simulation. Representing the device’s ability to quickly charge and discharge will enable a more optimal response to system conditions.
In practice, if the objective is to minimize congestion, then the storage unit operation should optimize the charging cycle to best take advantage of transmission line flow and congestion spreads. Typically Energy Storage Devices are scheduled to charge during off-peak hours where prices are low and discharge during peak hours resulting in generally a single daily cycle. While Promod is capable of scheduling the device to minimize total system production cost, forcing it to charge or discharge when uneconomic is a more difficult task. Moreover, increasing the number of cycles may significantly increase the program’s run-time and result in a decline in the nomogram’s accuracy. Second, PROMOD is limited in its ability to directly model energy storage as part of a post-contingency plan, such as simulating the device within a Special Protection Scheme or Remedial Action Plan triggered by a line outage. Amongst the questions that PROMOD cannot address is the interaction between a charge/discharge schedule and an objective of maintaining device availability to respond to reliability actions that may not be economic. None of these limitations interfere with the validity of this pilot effort to establish the capability of PJM tools. Instead, these point to the opportunities for further development by market participants and system owners to find the highest value applications for storage.

V. Conclusions

The nature of a pilot at PJM is to establish a basic, preliminary understanding for a new technology to be used in the power system in a proposed manner that is not well defined by PJM practices, manuals or rules. This pilot was intended to clarify parameters to allow a future proposal to be evaluated as smoothly as possible.

This pilot establishes for PJM a needed foundation in three areas. These are (1) modeling tools; (2) performance specs, and (3) responsibility for ownership and operation. Taken together, these points allow PJM to understand, review, and depending on the merits, accept the proposition of Storage as a Transmission asset.

- PSSE modeling of energy storage assets can be used to assess their viability as a resource to address short-term stability violations.
• PROMOD can be used as a tool to model the use of storage for alleviating congestion. The challenges and limitations with PROMOD mean that initial screening may understate benefits and generally needs to be supplemented by additional studies.

• Performance specifications may vary depending on the criteria violation to be addressed. Further, the intended application, either economic upgrade or reliability upgrade, may require different performance capabilities and operational practices. The specific opportunities for a match between needs and capabilities can be discovered and proposed by project requirements.

• Any discussion of storage as a transmission asset inevitably leads to good questions about who operates the asset and how the injection of real power and energy into the system are handled in the energy market, and whether that activity qualifies the asset as a generator. Given the FERC order issued to Western Grid, discussed above, some of these questions have been answered.

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