UTILITY-SCALE ENERGY STORAGE TO SUPPORT HIGHER PENETRATION OF VARIABLE RENEWABLE ENERGY

Impact of Energy Storage on the Grid: Overview and Integration Studies

Astana, November 2019
Agenda

• The future of the grid role of energy storage
• Impact of Renewables on the Grid and Role of Storage
• System Impact Studies in Grids with ES
Future Grid and Role of Energy Storage (ES)
There is a massive transformation coming because of falling prices of dispatchable VRE

### Wind Energy Auctions (USc/kWh)
- Mexico, 2017, 1.773
- India, 2017, 4.0
- Brazil, 2015, 4.8
- South Africa, 2015, 5
- Egypt, 2015, 4.7

### Solar Energy Auctions (USc/kWh)
- Saudi Arabia, 2017, 1.79
- Mexico, 2017, 1.97
- Uzbekistan, 2019, 2.679
- India, 2018, < 4
- Cambodia, 2019, 3.877

#### Dispatchable Solar Plant - PV+Storage
- Kauai @13.9c/kWh (2017)
  - PV = 17 MW, Storage = 13 MW x 4 hours
- Kauai @11c/kWh (late 2018)
  - PV = 28 MW, Storage = 20 MW x 5 hours
- Tucson @4.5c/kWh (2019)
  - PV = 100 MW, Storage = 30 MW x 4 hours
- Nevada, 3.5 c/kWh
  - PV=300 MW, Storage=135 MW x 4 hrs
- LA County @3.3 c/kWh (2023)
  - PV=400 MW, Storage=100 MW x 4 hrs?
  - @4 c/kWh for Storage=150 MW x 4 hrs?
The LA County Large Solar + Battery Project

Roles:

• “**shock absorber** of sorts for the solar farm, keeping each phase's output to the transmission system as close to a steady 200 megawatts as needed.”

• “**absorb excess solar** generated during the day, and **discharge** it through the late afternoon and evening to bolster the dropoff in solar generation, combined with the steep rise in customer demand for electricity as people come home from work”

• 1,660 megawatts of future gas generation capacity, will be **replaced** with clean-energy alternatives

• Replace peaker capacity with energy storage

• California: 100% Clean Energy (SB 100, De Leon) Bill sets a 60% RPS requirement by December 31, 2030 and requires **100% of retail sales of electricity to come from zero-carbon resources by December 31, 2045**

Scenario description, 5 years in the future:

- LCOE of rooftop solar PV + Storage is below retail rate
- LCOE of utility scale wind and solar PV with storage is close to wholesale rate
- Customers are shaping the market/load
  - Objective: Reduce waste and reduce cost
  - How: EV Charging, Solar PV+Storage, IoT
- Self consumption by the most profitable customers and grid defection

What happens when: Residential, commercial and industrial customers are able to perform all 5 functions
Old versus New Paradigm in the Grid

- Centralized system, one-directional flow
- Decentralized, distributed, bi-directional flow

Expect massive transformation of the grid
Current Grid: Impact of Renewables on Grid and Role of Storage
Potential Impacts of VRE on the Grid, on Geographical and Time Continuum

- Power Quality
- Secondary Frequency Response
- Load Following Reserve
- Ramping Reserve
- Contingency Reserve
- Voltage Management
- Grid Stability
- Congestion Management
- Thermal Generation Efficiency
- Generation Adequacy
- Grid Cost
- Generation Cost
- Ramping Reserve
- Congestion Management
- Grid Stability
- Voltage Management

System-wide
Regional
Local
ms - sec  sec - min  min - hr  hr - days  years
## Potential Impacts of VRE in ms to secs

<table>
<thead>
<tr>
<th>Impact</th>
<th>Description of Impact</th>
<th>Beneficial Role of Energy Storage</th>
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<tbody>
<tr>
<td><strong>Power quality</strong></td>
<td>Injection of harmonics and voltage flickers are the primary power quality issues. The impact is local and in the millisecond timeframe.</td>
<td>ES (example Supercapacitors) can reduce harmonics and voltage flicker through active filter</td>
</tr>
<tr>
<td><strong>Voltage management</strong></td>
<td>VRE can cause voltage at buses to be outside the range allowed by grid code. The impact is local and, in the millisecond-to-second timeframe.</td>
<td>ES with inverters can provide reactive power to support voltage management</td>
</tr>
<tr>
<td><strong>Grid stability</strong></td>
<td>VRE can cause the grid inertia to be reduced causing transient instability. The impact is regional and in the millisecond to second timeframe.</td>
<td>ES controllers provide synthetic inertia. Unlike synchronized systems, this relies of rate of change of frequency signal to inject power. This is provided in ms for seconds</td>
</tr>
<tr>
<td><strong>Primary frequency response</strong></td>
<td>VRE can cause a sluggish primary frequency response because of reduced governor response. The impact is system-wide and millisecond-to-second timeframe.</td>
<td>ES controllers provide governor response. Dead band, droop and others are defined. Typically provided in secs for &lt;15 mins.</td>
</tr>
<tr>
<td><strong>Secondary frequency response</strong></td>
<td>VRE can result in higher uncertainty and variability in power supply leading to a requirement for higher secondary frequency response with AGC.</td>
<td>ES controllers provide AGC response to restore frequency. Typically provided in seconds for about 15 mins</td>
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Properties of Energy Storage Systems (ESS) for milliseconds to seconds response

- Frequency response is generally the most expensive ancillary service
- VRE penetration can negatively impact frequency response
- ESS can provide exceptionally fast acting characteristics to support frequency response
- ESS can combine support for synthetic inertia, primary frequency and secondary frequency responses
- This can be the most lucrative market for ESS, regardless of openness of the ancillary services market

## Potential Impacts of VRE in Minutes to Hours

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<td>Congestion management</td>
<td>VRE can result in congestion on transmission lines or overloading of transformers and other equipment. The impact is system-wide and in the minute-to-hour timeframe.</td>
<td>ES, placed at strategic locations can reduce congestion. It can defer or eliminate need for expensive upgrades to transmission network. This is provided through bulk energy storage.</td>
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<tr>
<td>Additional Reserves</td>
<td>VRE can result in higher load following, ramping and contingency reserves because of uncertainty and variability of power supply. The impact is system-wide and in the minute-to-day timeframe.</td>
<td>ES can provide the necessary reserves. This was described in previous slides.</td>
</tr>
<tr>
<td>Thermal generation</td>
<td>VRE can result in lower capacity factor or cycling of thermal generation during the low load periods. The impact is system-wide and in the minute-to-day timeframe.</td>
<td>ES can either remove thermal generation or if required allow it to operate more efficiently. This is provided through bulk energy storage.</td>
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### Potential Impacts of VRE in Days to Years

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<td><strong>Generation adequacy</strong></td>
<td>VRE can result in requirement for additional flexible capacity due to increased ramping, variability and forecast error of VRE generation. The impact is system-wide and in the year timeframe.</td>
<td>ES can reduce the ramping need on thermal generation through peak shaving. It can manage the duck curve effect. This is provided through bulk energy storage.</td>
</tr>
<tr>
<td><strong>Grid adequacy</strong></td>
<td>VRE can result in requirement for additional transmission capacity due to geographic location of VRE plants. The impact is system-wide and in the year timeframe.</td>
<td>ES can assist in limited manner</td>
</tr>
<tr>
<td><strong>Generation cost</strong></td>
<td>VRE can result in requirement for larger amount of reserves, which can increase the overall cost of generation. The impact is system-wide and in the year timeframe.</td>
<td>VRE coupled with storage is dispatchable, hence requirement for reserves are reduced significantly. This is provided through both fast response and bulk energy storage.</td>
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Duck Curve and Other Peak Shaving

Role of ESS:
- Minimize curtailment of VRE
- Peak shaving
- Reduce ramping needs
- Curves like this at congested node can assess storage requirement for congestion management
Quotes

• “The greatest strength of energy storage is flexibility — both its fast response and its ability to charge and discharge based on grid needs” Colin Cushnie, Southern California Edison

• "Not only does energy storage allow us to integrate more renewable energy, it helps to stabilize the grid and increase reliability, especially as renewable energy drops off in the later afternoon and energy demand throughout the state is rising,” Wes Jones, San Diego Gas & Electric
System Impact Studies in Grids with ES
Types of ES Deployments

Utility-scale dispatchable VRE plant
- ES is part of the solar PV or wind power plant
- Often ES is on the DC bus
- Supervisory controller decides
  - When & how much to store
  - When & how much to discharge
- Controller makes decisions based on inputs from:
  - Solar PV generation
  - Grid frequency, voltage
  - SOC, temperature
  - Future demand for energy
  - Objective: single- or multi-purpose

Standalone utility-scale ES
- ES is a load at times
- ES is a generator at times
- Controller makes decisions based on inputs from:
  - Control signals from dispatcher—AGC, load following, dispatch
  - Grid frequency—Inertial, primary frequency response
  - POI Voltage—Reactive power
  - SOC, temperature
  - Future demands
  - Objective: single- or multi-purpose
Four Types of System Impact Studies

• Study 1: Unit commitment and Economic Dispatch (UCED) simulation, which includes hour-by-hour production cost simulation. It is used to study the impact of VRE + ES on system operations.

• Study 2: Steady-state analysis of the power network, which includes load flow, short-circuit and power quality studies. It is used to study the impact of VRE + ES on static properties of the grid.

• Study 3: Dynamic stability analysis of the power grid, which includes transient stability studies. It is used to study the impact of VRE + ES on dynamic properties of the grid.

• Study 4: Estimate flexible capacity for dispatching and operating reserves requirements in the presence of VRE + ES
# Four Types of System Impact Studies

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| **Study 1: Unit commitment and Economic Dispatch (UCED) simulation**  
{Tools: Plexos, DlgsILENT}                  | Full year simulation of Unit Commitment and Economic Dispatch           |
|                                              | • Check if any technical or contractual constraints are violated        |
|                                              | • Resource adequacy                                                     |
|                                              | • Grid adequacy                                                         |
| **Study 2: Steady-state analysis of the power network**  
{Tools: DlgsILENT, PSS/E, ETAP}              | Power systems analysis for extreme scenarios                            |
|                                              | • Check if voltage or line loading limits are within range              |
|                                              | • Short-circuit power and protection system                              |
|                                              | • Power quality                                                         |
| **Study 3: Dynamic stability analysis**  
{Tools: DlgsILENT, PSS/E, ETAP}              | Power systems simulation for extreme scenarios with disturbances        |
|                                              | • Check if system is stable after disturbance                           |
|                                              | • Check frequency, voltage or line loading limits are within range      |
Four Types of System Impact Studies

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| Study 4: Estimate requirements for flexible capacity for dispatching and operating reserves {Tools: Statistics, Excel} | Monthly analysis of flexible capacity and reserves requirement based on uncertainty and variability of CE generation:  
  • Statistical analysis of VRE generation  
  • Forecasting error analysis  
  • 3-hour ramp requirement  
  • Computation of flexible capacity need and how much can be provided by ES. Pricing can be based on day-ahead and real time energy market  
  • Regulation Reserve up and down requirement based on uncertainty and variability of VRE+ES plants, and Standalone ES plants |
Study 1: UCED Simulation for valuation of storage

• Revenue of storage:
  – Run PCM model with storage dispatch and marginal prices

• Value of storage:
  – Run PCM with out and with storage. Difference yields value of storage

• Other value streams: Store curtailed VRE
Applications of the Four Studies

1. Application 1: Interconnection Impact Study for specific VRE+ES or Standalone ES projects
   • This impact study is conducted project-by-project as they seek interconnection agreement or for cluster of projects seeking interconnection
   • Scenarios of interest for this study are 1 to 5 years in the future
   • Studies 2 and 3 are primarily used to study the impact on Reliability and Stability from specific proposed projects

2. Application 2: System-wide Impact Study for various scenarios of Clean Energy (CE) Penetration with VRE+ES or Standalone ES
   • This impact study is conducted for various clean energy target penetrations like 20% target by 2025, and 30% by 2030
   • Scenarios of interest for this study are 5 to 10 years in the future
   • All four studies are used to study impact on System Operations, and Reliability and Stability of the grid
Two Applications of the Four System Impact Studies for VRE+ES or Standalone ES

Application 1: Project Interconnection Impact Study

- Impact of specific proposed VRE+ES or Standalone ES projects on Reliability and Stability, and System Operations of the grid
- Scenarios of interest for this study are 1 to 5 years in the future
- Study is done project-by-project or for cluster of proposed projects

Application 2: System-wide Clean Energy Penetration Impact Study

- System-wide impact of different penetration levels of Clean Energy on System Operations (SO), and Reliability and Stability (RS) of the grid
- Study scenarios of 20% CE by 2025, and 30% by 2030

Darker shading indicates higher importance of study
Application 1: Baseline Model Input and assumptions
Which VRE projects should be part of the Baseline model?

- Baseline Model of Grid shall contain the following projects:
  - Already commissioned VRE plants
  - Percentage (e.g. 75%) of all VRE projects with PPA/Interconnection Agreement. Percentage should be decided.
  - Percentage (e.g. 30%) of all VRE projects with MOU or undergoing interconnection study.
  - Note: It is important develop a master list of VRE projects and to categorize projects by status. This would allow percentages to be assigned and baseline model to accurately reflect all VRE projects that are already under consideration
  - Already commissioned ES projects
Application 1: Initial Setup of Model

What are the primary issues with baseline models during initial setup?

- From past experiences in interconnection studies, the following issues were found in the several baseline models
  - The baseline scenarios pertaining to No Wind, No Solar (no VRE) do not converge or do not satisfy all the constraints.
    - Example 1: New coal plant has been commissioned. In wet season, off-peak load and no VRE scenario, energy balance cannot be attained because there is excess generation despite all generators are operating at minimum capacity factors.
    - Example 2: In dry season, peak load and no VRE scenario, energy balance cannot be attained because there is insufficient generation despite all generators operating at maximum capacity factors.
    - Example 3: With existing VRE generation, there are scenarios in which energy balance cannot be attained
  - These are issues beyond validation of the baseline model. This points to deficiencies in the grid that must be documented and fixed before impact of VRE can be assessed.

- From past experience, when the grid deficiencies (with out VRE) are fixed, addition of VRE to the grid poses no adverse impact.
Application 2: System-wide Clean Energy Penetration Impact Study

• Purposes are to
  – Identify potential adverse impacts of 20% CE penetration in 2025, and 30% RE in 2030 on System Operations, and Reliability and Stability of the grid
  – Develop measures to mitigate the identified adverse impacts so the grid can accommodate the targeted CE penetrations. The measures may include grid upgrades, new transmission and/or distribution lines, grid operational system upgrades, or changes in Grid Code
Application 2: Baseline Model Input and assumptions

• A CE potential assessment needs to be performed to estimate the CE potential by technology and location for various CE penetration scenarios

• CE penetration scenarios should include all the existing and planned CE projects
Application 2: Timeline

• Application 2, when done for the first time can take an year or more
  – CE potential assessment, data collection and building the baseline model will take the longest, 6 to 9 months
  – Running the models for different scenarios and developing solutions for the grid can take 3 months
  – Estimation of the cost for upgrades and cost of integration can take 1 month
  – Documentation of the results and preparing a final report can take 1 month
• Subsequent updates to Application 2 can be shorter—2 to 3 months
Four Studies for Assessing Impact of CE on the Grid

Study 1: UCED study
- Hour-by-hour simulation with one year of data to assess type and amount of flexible generation requirement

Study 2: Steady state analysis of network
- Load flow, short-circuit and power quality studies to assess bus voltages, line congestion and power quality

Study 3: Dynamic stability analysis of network
- Transient stability studies to assess frequency response during contingency

Study 4: Reserves requirement estimation
- Statistical analysis of ramping, variability, uncertainty
Key to Grid Impact Studies of VRE+ES or Standalone ES

• Modeling of the objective in the controller logic
  – Controller interacts with the grid parameters and makes decisions

• Single purpose:
  a) Net-load ramping due to solar profile
  b) Peak shaving
  c) AGC
  d) Primary frequency
  e) Inertial
  f) Reactive power

• Multi-purpose: What is the relative importance of each of the objectives?
Summary

• System impact studies is an emerging area
• It stands on the shoulder of VRE System Impact Studies
• Results of VRE impact studies may require addition of ES
• The above would trigger an extension of the impact study to include ES
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