Commissioning Overview
A Safety Focus
Daniel Borneo
Construction Project Implementation Process

1. PROJECT DEVELOPMENT
2. DESIGN
3. PROCUREMENT/CONSTRUCTION/STARTUP-TESTING
4. OPERATION/CLOSEOUT

Commissioning
Summary - What is needed?

• **Obvious**
  • Safer, higher energy density batteries
  • Codes and standards
    • Need to be clear and implementable

• **Not so Obvious**
  • Load Profile and testing procedures
  • Fire suppression means are confusing
  • BMS controls need to have fail safe mechanisms to
    • Control max charge SOC
    • Discharge point
    • Temperature feedback and control charge/discharge rates based upon temperature
    • Energy isolation means
  • Need to have testing methodology that is consistent and easy to follow
  • Predictive maintenance tools
    • Can we predict cycle life?
Start with the End in Mind

• R&D considerations for an installation of a safe reliable system
  • Commissioning can support and verify these efforts
• Operational Vs. Safety Issues
COMMISSIONING
Safety and Reliability Focus

GOAL: To Ensure a **Safe and Reliable** System is:
- Installed as designed
- Operates, and
- Performs the services intended.

**Commissioning / Testing Process details**

1. **Commissioning Program initiation**
   - Team and program development.
   - R&R

2. **Factory Witness Test (FWT)**
   - Test system performance
   - Individual components

3. **Operational Acceptance Test (OAT)**
   - System as a whole including all controls

4. **Start-up**
   - Sequence of operation/Applicati
cn testing. Base line info
   - Apply BLUE tag

5. **Site Acceptance Test (SAT)**
   - Anomaly/Safety performance

6. **Shakedown**
   - Owner operates and Controls
## Elements of Battery Energy Storage System (ESS)

<table>
<thead>
<tr>
<th>Storage and BMS</th>
<th>Power Control System (PCS)</th>
<th>Energy management System (EMS)</th>
<th>Site Management System (SMS)</th>
<th>Balance of Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Storage device</td>
<td>• Bi-directional Inverter</td>
<td>• Charge / Discharge</td>
<td>• Distributed Energy Resources (DER) control</td>
<td>• Housing</td>
</tr>
<tr>
<td>• Battery Management &amp; Protection (BMS)</td>
<td>• Interconnection / Switchgear</td>
<td>• Load Management</td>
<td>• Synchronization</td>
<td>• Wiring</td>
</tr>
<tr>
<td>• Racking</td>
<td>• Transformer</td>
<td>• Ramp rate control</td>
<td>• Islanding and Microgrid control</td>
<td>• Climate control</td>
</tr>
<tr>
<td>• $/KWh</td>
<td>• $/KW</td>
<td>• Grid Stability</td>
<td>• $ / ESS</td>
<td>• Fire protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Monitoring</td>
<td></td>
<td>• Construction and Permitting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Grid Stability</td>
<td></td>
<td>• $ / project</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Monitoring</td>
<td></td>
<td>(function of scale)</td>
</tr>
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</table>
Battery technologies and their energy densities

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRFB</td>
<td>Vanadium Redox Battery</td>
</tr>
<tr>
<td>Lead Acid</td>
<td>Lead Acid</td>
</tr>
<tr>
<td>NiCd</td>
<td>Nickel Cadmium</td>
</tr>
<tr>
<td>NiMH</td>
<td>Nickel Metal Hydride</td>
</tr>
<tr>
<td>LTO</td>
<td>Lithium Titanate</td>
</tr>
<tr>
<td>LFP</td>
<td>Lithium Iron Phosphate</td>
</tr>
<tr>
<td>LMO</td>
<td>Lithium Ion Manganese Oxide</td>
</tr>
<tr>
<td>NMC</td>
<td>Lithium Nickel Manganese Cobalt Oxide</td>
</tr>
<tr>
<td>LCO</td>
<td>Lithium Cobalt Oxide</td>
</tr>
<tr>
<td>NCA</td>
<td>Lithium Nickel Cobalt Aluminum Oxide</td>
</tr>
<tr>
<td>Zn-MgO2</td>
<td>Zinc Manganese Oxide</td>
</tr>
<tr>
<td>NaNiCl2</td>
<td>Sodium Nickel Chloride (Zebra)</td>
</tr>
</tbody>
</table>

**Energy Density**

<table>
<thead>
<tr>
<th>Wh/kg</th>
<th>VRFB</th>
<th>Lead Acid</th>
<th>NiCd</th>
<th>NiMH</th>
<th>LTO</th>
<th>NaNiCl2</th>
<th>Zn-MnO2 (future)</th>
<th>LFP</th>
<th>LMO</th>
<th>NMC</th>
<th>LCO</th>
<th>NCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>300</td>
<td>350</td>
<td>400</td>
<td>450</td>
<td>500</td>
</tr>
</tbody>
</table>

Curtesy of: Battery University
Battery technologies and their cycle life (at 80% DOD)

• Battery lifetime depends on 4 main factors - %State-of-Charge (SOC), %Depth-of-Discharge (DOD), temperature, rate of re-charge.

• When cycling once per day or more, the lifetime depends mainly on %DOD and re-charge rate.
Batteries What to do know and watch out for

• Much energy in small area
  • Isolation means
    • Reduce the available fault current in system
      • Circuit interrupters
    • Packaging needs to help eliminate cascading
  • No leakers
• The BMS controls (in conjunction with the energy management system) the charge and discharge of the battery
  • BMS adjusts charge voltage –
    • Charging to a lower Voltage limit allows extended operation at partial SOC
  • The BMS monitors cell health and detects and annunciates cell and module failures.
    • The BMS measures cell voltages and temperatures, and balances cells.

• The BMS is part of the overall safety system.
  • Battery safety is DEPENDENT on Controls
    • Can we get fail safe system?
    • How do we limit the available fault energy?
      • High Energy...High Safety
Power Electronics

• Converts DC to AC and Vice Versa

PCS components:
• AC/DC circuit breakers
• AC/DC contractors
• Inverter modules. **Switching Diodes**
  • More and more in a smaller package
• Master and Local Controller
• Battery Management System (BMS) interface
• System monitoring
• Cooling System

• Controls and provides applications:
  • Controls real (P) and reactive (Q) power
  • Ability to look like generator to grid
    • Operate in anti-islanding or Island mode
    • Grid stabilization (synthetic inertia, and active damping)
  • Black start (REQUIRES AUX Power)
  • Needs to Switch between Current source ands Voltage Source. SEEMLESSLY
Energy Management System

- Monitors grid voltage
- Manages energy flow to/from grid
- Controls current or voltage source mode of operation of inverter
- Controls ESS
  - Communicates with inverter
  - Communicates with BMS
  - Communicates with customer interface
  - **Controls balance of plant – HVAC, emergency stop, fire protection**
- **Insures inverters operate batteries within the battery parameters.**
  - **PREDICTIVE MAINTENACE TOOL**
The SMS interfaces with the ES energy management system, distributed energy resources and the grid and acts as the Master Controller

- Monitors Grid
  - Measure grid electrical conditions – voltage, current, frequency, Power
  - Event logging
  - Data Management
    - Historical records
  - **Sensors, Breakers, re-closers, Power Measurement Unit (PMU)**
    - **Needs to coordinate both ways**
      - **HOW do you effectively test in the field**
  - Distributed energy resources (DER)
  - State of Charge of ES
  - Determines Role of ES
    - Enable stability control
    - Demand reduction
    - Regulation/power quality
Site Management System (SMS) - 2

- Real time operational decision making
  - Financial
    - Electric rates
    - Fuel tariffs
    - Time of day rates
    - Demand Charge reduction
    - Emission vs. energy cost optimization
- Safety
  - What should we look for, how and why
- Forecast
  - loads – electrical, thermal
  - Weather
- Optimize unit scheduling
- Cyber Security
  - How do we test this
- Creates and controls microgrid
  - Controls isolation breakers
  - Manages loads and load shedding
  - Enable Island mode
  - Synchronization and integration of various DER- renewable and traditional
Balance of Plant

• Balance of plant
  • **HVAC**: battery temperature operations (10-40°C)
  • **Fire protection**: water sprinklers; oxygen-depleting chemicals; smoke alarms; fail-safe shut-down controls; emergency off
  • **Electrical distribution**: Over-current protection, i.e., coordinated breakers / fused disconnects
• Communications
• Site work: pad, fencing, conduit / wiring **AND GROUNDING**
  • What are the grounding requirements

On board cooling system for EPC 125kW bi-directional inverter.
Communications / Control have become an essential piece of the Energy Storage System

- Several approaches to communications are currently popular: Modbus and DNP3
- Remote monitoring mandatory for utility interface
- Data storage useful for understanding performance and analyzing economic impact
- Data should be stored both onsite and at remote location.
  - Need to pick data points. We have lists of data to be collected and sampling rates.
Commissioning Activities during Construction

• Factory Acceptance Tests
  • Vendor conducts factory Acceptance testing using SOO
    • Do we know what tests to run and what the results should be?
      • What is it we are looking for

• Develop start-up procedures
  • Based on equipment list, system manuals, SOO and operating specifications
    • Operating Specifications – Parameters that the system should operate within.

• Develop testing procedures
  • Based on SOO and applications
  • PNNL/Sandia Testing Protocol
    • We need to revise this document to include more applications

• Develop installation review checklists and perform inspections
  • Design Verification – Installed as designed & specified; labeling and signage in place, clearances,
  • Code adherence
  • Punchlist items noted

• Develop Training and emergency response procedures
  • MSDS

• Implement Lock-out/Tag-out process
Commissioning Process - Operational Acceptance Testing (OAT)

Do the Individual components of the system operate?

• Verify and test that the individual electrical, mechanical components of the system are ready for start-up.
  • Meggering, torqueing, rotation/phasing, covers and barriers

• Verify that the controls are in place and test operation
  • Point to point check

• Verify electrical protection and relays are coordinated and are operational

• Verify and test that all safety systems are installed and operating.
  • Temperature, leak, security, fire alarm, flow, pressure

• Verify and test that all communication systems are operating

• Emergency procedures are in place and Lock/out tag out process implemented

• **Tag and sign off – System is ready to operate**

*Note: Is 3rd party testing required?*
Commissioning Process—Start-up

Do the components operate as a system?

- Using start-up procedures, operate all components as a system
  - Record base-line data
    - Voltage, currents,
    - temperatures, flows, pressures
    - ES Capacity
    - Charge time
    - Discharge time
    - IR scan connections and batteries

- Record and repair punch list items

✓ Does Automatic and remote control operate as required
✓ Are Safeties functioning and annunciation and control working
✓ Is Data Acquisition system operating, recording data and transmitting/Saving as required
Commissioning Process - Functional Acceptance Test (FAT)

- Using PROTOCOLs, Testing plans and procedures test to insure systems performs the functions/applications for which it was designed.
  - Are all components and sub-systems operating in unison
  - Do controls operate as intended
  - Is communication system sending and receiving data as intended- type and frequency. Are anomalies being annunciated
  - Is data collected adequate to determine system performance
  - Record and repair punchlist items
  - Is training complete for operators, maintenance and first responders
  - Is operation and maintenance plan in place
  - Is warranty in place
  - Is emergency response procedures in place- 1-800 number in the event of an emergency
  - Log additional baseline data

✓ Tag and sign off that system is now owned and operated by customer/owner
Commissioning Process - Shakedown

When any site utility is interrupted, and then restored (e.g., electricity, gas, water, data, communication, etc.), does the system operate in such a manner as to protect the people, the environment, the equipment, and the facilities?

- **Turn off major utilities serving project.**
  - Determine if safety systems work as designed or needed.
  - Evaluate if systems fail in a safe mode.
  - Assess if back-up systems operate as needed.
  - Do alarms serve the purpose
- **Turn on major utilities**
  Determine if the systems come up in a safe manner.
  Assess if backup systems turn off in a safe/ready mode.

**Hard to do on a working GRID**

❖ **How do we Insure the fail safe mechanisms work**
System Operation

• Monitor capacity fade
• Predictive maintenance adventure
• Warranty
• Data Collection, Monitoring
  • Remote Access
  • On-board Storage
• We don’t know what we don’t know
  • What’s going on inside the battery
Companies looking for an accurate method to gauge how well large batteries and other grid-scale energy storage systems work use these evaluation guidelines, called the Energy Storage Performance Protocol.

The guidelines currently evaluate three energy storage performance uses:
- Peak Shaving
- Frequency Regulation
- Islanded Microgrids

Additional Lab Protocols:
- Duty Cycle for ESS Firming
- Duty Cycle for PV Smoothing
Thank You

Daniel Borneo drborne@sandia.gov

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