1. Battery Energy Storage System (BESS) - The Equipment
2. Applications of Energy Storage
3. Solar + Storage
4. Commercial and Industrial Storage (C&I)
5. Augmentations
AGENDA

1. Battery Energy Storage System (BESS) - The Equipment
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BESS – The Equipment – Battery (Li-ion)
BESS – The Equipment – Battery (Li-ion)

**Advantages**
- High energy density - potential for yet higher capacities.
- Relatively low self-discharge - self-discharge is less than half that of nickel-based batteries.
- Low Maintenance - no periodic discharge is needed; there is no memory.

**Limitations**
- Requires protection circuit to maintain voltage and current within safe limits. (BMS or Battery Management System)
- Subject to aging, even if not in use – Storage Degradation
- Transportation restrictions - shipment of larger quantities may be subject to regulatory control. Special UN38.3 Certification is required to meet transportation regulations.
- Sensitivity to high temperature - Lithium-ion battery is susceptible to heat caused by overheating of the device or overcharging. Heat causes the cells of the battery to degrade faster than they normally would. Over-heating or internal short circuit can also ignite the electrolyte and cause fire.
BESS – The Equipment – Battery (Li-ion) – Common Terms

DoD - A battery's depth of discharge (DoD) indicates the percentage of the battery that has been discharged relative to the overall capacity of the battery. Depth of Discharge is defined as the capacity that is discharged from a fully charged battery, divided by battery nominal capacity.

SOC - State of charge (SoC) is the level of charge of relative to its capacity. The units of SoC are a percentage (0% = empty; 100% = full). SoC is normally used when discussing the current state of a battery in use, while DoD is most often seen when discussing the lifetime of the battery after repeated use.
BESS – The Equipment – Heat Mitigation and Temp Control
BESS – Battery Degradation

What is a Cycle? 100% SOC to 0% SOC
**BESS – The Equipment – Inverter**

- **DC/AC Inverter** => Transforms DC (Direct Current) to AC (Alternating Current)
- **AC/DC Rectifier** => Transforms AC to DC
- **DC/DC Converter** => Transforms DC to DC

Taken one form of power source (DC/AC) and transform to another form (DC/AC)
Provides system protection
What is in the Inverter?

- **DC termination + Fusing**: (For cable protection)
- **Fusing**: (For cable protection)
- **DC disconnect**: (breaker, contactor, or NLB disconnect Switch)
- **PCBs**: Control cards, mother PCBs etc.
- **LCL Filter**: (Inductor "Inverter" + Capacitor + Inductor "Grid")
- **AC Breaker**
- **AC Fuse**
- **Conversion Stack**: (typ. DC Capacitor + IGBT)
- **Cooling System**
Put it all together - BESS

- HVAC
- Container
- System Controls
- Battery Racks
- DC/AC Inverter or DC/DC Converter
- MV Transformer (for DC/AC Systems)

Example Container Plan View
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Solar + Energy Storage Convergence

Solar + Storage PPA
Added Value & Incentives with Solar + Storage

PV System Design with Storage
Simple Load Shifting

Charging the Battery from Solar vs Charging from the Grid

Energy Arbitrage
- Charge when Pricing is Low
- Discharge when Pricing is High
Solar + Storage Value with DC Coupling

- Combination of clipped energy harvest & charge from solar
- Decreased solar generation peaks
- Decreased load peaks

- System Load
- Solar Generation
- Solar + Storage

Typical Day
Let’s make the duck healthy...

Solar Generation Diet
DC Coupled System Differences in Architecture

<table>
<thead>
<tr>
<th></th>
<th>Design 1</th>
<th>Design 2</th>
<th>Design 3</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Typical Design</td>
<td>DC Constant Voltage Architecture</td>
<td>DC Variable Voltage Architecture</td>
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<tr>
<td>DC/DC Converter</td>
<td>High Cost</td>
<td>Medium Cost</td>
<td>No Cost</td>
</tr>
<tr>
<td>DC Optimizer</td>
<td>No Cost</td>
<td>Medium Cost (Simpler charger)</td>
<td>High Cost</td>
</tr>
<tr>
<td>DC Voltage Control</td>
<td>Centralized MPP Control</td>
<td>Distributed MPP / Constant Voltage</td>
<td>Distributed MPP / Variable Voltage</td>
</tr>
<tr>
<td>PV Inverter</td>
<td>Standard PV inverter cost</td>
<td>20-30% inverter cost reduction</td>
<td>Standard “ESS Inverter“ Cost</td>
</tr>
<tr>
<td>PV Inverter Power-flow</td>
<td>Single direction (to grid)</td>
<td>Bidirectional</td>
<td>Bidirectional</td>
</tr>
<tr>
<td>System Controls</td>
<td>DC/DC &amp; DC/AC Inverter Control</td>
<td>DC/DC &amp; DC/AC Inverter Control</td>
<td>DC/AC Inverter Control</td>
</tr>
<tr>
<td>ESS Availability</td>
<td>Medium</td>
<td>Medium-Low</td>
<td>High</td>
</tr>
</tbody>
</table>
DC Coupled Solar + Storage Value: RTE & Cost

Additional Transformer Cost $ 

<table>
<thead>
<tr>
<th></th>
<th>DC Coupled</th>
<th>AC Coupled</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC/DC CHG</td>
<td>99%</td>
<td>N/A</td>
</tr>
<tr>
<td>DC/DC DCHG</td>
<td>99%</td>
<td>N/A</td>
</tr>
<tr>
<td>PV INV DCHG</td>
<td>98%</td>
<td>98%</td>
</tr>
<tr>
<td>ESS INV CHG</td>
<td>N/A</td>
<td>98%</td>
</tr>
<tr>
<td>ESS INV DCHG</td>
<td>N/A</td>
<td>98%</td>
</tr>
<tr>
<td>XFMR CHG</td>
<td>N/A</td>
<td>99%</td>
</tr>
<tr>
<td>XFMR DCHG</td>
<td>99%</td>
<td>99%</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>95.1%</strong></td>
<td><strong>92.2%</strong></td>
</tr>
</tbody>
</table>

Additional reclosure / GSU Transformer cost $ 

$95.1%$ versus $92.2%$
DC Coupled System Design – Hardware Overview
DC Coupled System Design - Controls Architecture Overview

Cloud based Optimization
- Forecast based schedule & arbitrage

PV System
- Combiner
- Reconnector
- PV PCS
- ISU Xfmr

Next Block

Battery
- BMS management
- SOH management
- Rack level protection
- System balancing

PV Inverter
- +/- P & +/- Q commands
- MPP coordination
- Clipped mode coordination
- Power limit control
- Start-up / shut-down
- Frequency Control
- Slew/Ramp-Rate Control

DC/DC Converter
- +/- P commands
- MPP coordination
- Clipped mode control

Site Controller
- Site Scheduler
- Solar Power Plant Controller
- Mode Control

Battery & Solar Plant Control
- ES/Pilot

Plant Metering
- Plant output monitoring

Meter
- GSU Xfmr
System Design - Optimal ESS Power & Energy

**ESS Power & Energy Sizing**
- System modeling directly linking kW/kWh sizing to revenue is important.

**Project & Design Specific Modeling is KEY**

**Conditions:**
- Solar Irradiance
- DC/AC Ratio
- Market Price
- ESS Price

**Solar Irradiance**
- Geographical location
- YOY solar variance

**DC:AC Ratio**
- Module pricing
- PV System design / LCOE modeling

**Market Price / Structure**
- Whole sale market
- PPA / Flexible PPA
- Application

**ESS Price**
- Converter Price ($/kW)
- Battery Price ($/kWh)
- Enclosure Price ($/kW)
- Degradation Modeling
Controls - Clipped Energy Harvest & Time Shift

Available Inverter Capacity

<table>
<thead>
<tr>
<th>Time of the day</th>
<th>Discharge</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning Peak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-peak hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evening Peak</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Modes of Operation

<table>
<thead>
<tr>
<th>Solar Charge During Clipping</th>
<th>Controller</th>
<th>DC/DC Converter</th>
<th>DC/AC Inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Charge During MPPT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Discharge During MPPT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forced ESS charge during the time when the plant is not clipped. Discharge during On-peak time.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. **Controller** dynamically charges the ESS when DC/AC inverter is in MPP state.
   - Rule based optimal discharge during on-peak hours.

2. **Controller** dynamically charges DC/DC converter while monitoring DC/AC inverter status during power limit.
   - DC/DC converter follows voltage dictated by DC/AC inverter.
   - Dynamically control current and charge based on commands.

3. **Controller** charges DC/DC converter while monitoring DC/AC inverter status during power limit.
   - DC/DC converter follows voltage dictated by DC/AC inverter.
   - Dynamically control current and charge based on commands.

### Solar Charge During Clipping
- Charge ESS when DC energy is clipped due to maximum power capacity of the PV inverter.

### Solar Charge During MPPT
- Controller dynamically charges the ESS when DC/AC inverter is in MPP state.
- Rule based optimal discharge during on-peak hours.

### Solar Discharge During MPPT
- Controller dynamically charges the ESS when DC/AC inverter is in MPP state.
- Rule based optimal discharge during on-peak hours.

### Solar Discharge During Night
- Optimal discharge during evening peak hours (Scheduled dispatch).
- Break open for PV during night or use RBD.
- Switch to IV-Mode.

### DC/DC Converter
- Operate at power limit.
- Operate at nominal MPP during night discharge.

### DC/AC Inverter
- Operate at nominal MPP during charge.
- Operate at nominal MPP during night discharge.
Controls – Full Sun

Days with full sun having ample amount of charging opportunity = “Scheduled Dispatch”

- Fully charge clipped energy and hold at top of the charge until discharge opportunity
- Discharge at high evening peak discharge opportunity
Controls – Partial Sun (Charging using forecast)

Days with partial sun having partial clipped charging opportunity = “Dynamic Optimization” based on Solar Forecast

By utilizing solar forecast, charging optimization can be achieved to preemptively charge non-clipped energy to fully charge battery capacity. Discharge at high evening peak discharge opportunity.

Solar Forecast

Optimized charging

Clipped Region

SOC 100%

Morning Peak

Off-peak hours

Evening Peak

Time of the day
DC-Coupled System - Overview

Battery System Scalable & Configurable for 2-4+ HR System.

DC/DC Converter suitable for 1500PV System

PCS DC connection flexible to allow variety of DC/DC converter sizing with augmentation readiness
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Commercial & Industrial Systems - Ontario Market Background

The Global Adjustment (GA) charge is a line-item charge for customers in Ontario IESO territory which supports the sustained deployment of energy in Ontario, even during unexpected peak events.

Any customer participating in the ICI (Industrial Conservation Initiative) is charged a GA fee proportional to their energy usage during the five highest system peaks of the year.

- Save CAD400K – CAD430K/MW/yr by reducing your energy usage during these peak hours.
Commercial & Industrial Systems - 5 System Coincident Peak Patterns

Number of 5 coincident peaks (past 5, 10 years)

% of 5 coincident peaks (past 5, 10 years)
Other Participation Strategies

- Global adjustment reduction (~80%)
  - Past 5 years
  - Past 10 years

- Demand response (~15%)

- Energy arbitrage (~5%)

Figure 1: Customer Net Load
Honolulu, Hawaii, December 16, 2015
- Net Load
- Load
- Energy saved from storage transfers

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Commercial & Industrial Systems - Reducing your GA with Energy Storage

- Reduce your electricity usage without disrupting operations
- Maintain energy usage reduction with technology that can be used up to 10+ years
- Participate demand response programs without operational disruptions for generating revenue
- Reduce your electricity bill by energy arbitrage
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Battery Augmentation

- Cell: 111Ah
- Ambient Temperature: 23°C±5
- Pattern: 7Days' Profile
- Rest: SOC60%
Battery Augmentation

New & Old Batteries Mix

<table>
<thead>
<tr>
<th>Voltage</th>
<th>SOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% Degradation</td>
<td>100%</td>
</tr>
<tr>
<td>80% (80Ah)</td>
<td>100% (100Ah)</td>
</tr>
</tbody>
</table>

- With higher internal resistance on the old racks, the current will flow more to the newer racks potentially causing over current issues.
- Old and new racks will charge/discharge unevenly and rack to rack balancing will be disturbed.

Solution

- **Distribution Augmentation**
  Design increased footprint with empty space at Yr0. Empty one of the PCS blocks and distribute to older PCS blocks. Replace the emptied block with new battery racks.

- **DC/DC Converter Augmentation**
  Fully maximize initial design with fully populated battery container at Yr0. Utilize DC/DC converter during augmentation to control DC Bus voltage.
A subsidiary of IHI Corporation

Jeff Zwijack
IHI Terrasun Solutions, Inc.
https://www.ihiterrasun.com/
AGENDA

Bonus Slides
Video - Adjust your volume as necessary