DC POWER DISTRIBUTION ARCHITECTURE
Most Building Devices Already Use DC

**Local Sources**
- Solar photovoltaic
- Modern generators
  - Gensets
  - CHP
  - Wind
- Fuel cells

**Energy Storage**
- Battery
- Ultra capacitor
- Flywheel
- EV

**Electrical Loads**
- Efficient lighting
  - LED
  - Fluorescent
  - Induction
- Motors (VFDs)
  - Industrial fans
  - HVAC
  - Refrigeration
  - Automation
- EV chargers
- IT equipment

...but must utilize power conversion equipment to operate on the existing AC grid
Benefits of DC Microgrids:
- Lower energy losses
- 7-10% avg. improvement in utilization of on-site generation
- Higher reliability
- Resiliency during grid outages
- Emergency lighting support
- Reduced interconnection costs
- Lower investment
- Controls without additional infrastructure
- Minimizes emissions
Bosch DC Microgrid

Overview

- Integration of distributed generation and energy efficient building loads on a 380V Direct Current (DC) network
  - On-site generation: solar PV and energy storage
  - Building loads: LED fixtures, industrial fans, fork lift chargers, etc.
- For behind the meter commercial buildings
  - Converts major building loads to DC during EE upgrades, while more specialized loads remain AC (i.e. plug loads)
  - Grid connected and capable of islanding during a grid outage
  - Added cost savings through increased efficiency
- Lower total cost of ownership (TCO) compared to conventional systems
  - >30% improvement in TCO
Ideal First Bosch DC Microgrid Applications

- Best economics with 7-day operation and on-site solar

- Initial target: Always-on DC ceiling loads
  - LED lighting
  - Large industrial ceiling fans

- Attractive for “big box” buildings (i.e. warehouse, maintenance facility, manufacturing plant, fitness center, parking structure, retail store, etc.)
  - Hundreds of lights with expensive O&M
  - Roof space available for solar PV array
  - Other major DC loads: Fork-lift chargers, EV chargers
DC Microgrid DOD Demonstration Project: Fort Bragg

- Small, but representative
- Daytime operation all week
- Newer roof good for solar
- Two high-bay areas
  - Basketball court
  - Weight room
- Used as emergency shelter
- In need of upgrades
  - Inefficient metal halide lights
  - Weight room ventilation
- Could re-use existing AC wiring infrastructure
DC Loads Operating at 380 VDC on Existing AC wiring

45 KW Roof-top Solar PV Array

Completed basketball court with 24 DC high-bay lights and 2 DC ceiling fans
DC Controls and Monitoring

DC panel contains instrumentation for control and monitoring

Simple touch screen user interface for facility managers

Performance monitoring

<table>
<thead>
<tr>
<th>Grid Power</th>
<th>Solar Power</th>
<th>DC Loads</th>
<th>Reference Array Inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.09 kW</td>
<td>10.19 kW</td>
<td>13.28 kW</td>
<td>6.55 kW</td>
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</tbody>
</table>

Solar Power Contribution to DC Loads: PV 76.74%
Long-term Performance Data

DC Load Power Sources

- **GRID**: 44%
- **PV**: 56%

Real-Time AC Losses
- Inverter: 4.3%
- Real-Time AC Losses: 7.0%

Long Term AC Losses
- Total: 12.5%
- Lights: 7.0%
- Inverter: 4.3%

Long Term DC Losses
- Total: 3.0%
- Lights: 3.0%
- Inverter: 5.5%

Long Term AC vs DC
- Total: 9.5%
Example NREL modeling output: Performance comparison map of building energy intensity across US – DC-Microgrid compared to conventional AC baseline

Bosch DC Microgrid saves energy in all climate zones; greatest energy impact* in heavily air-conditioned regions (heat generation eliminated through omission of AC-DC conversions)
### Other Demonstration Projects

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Location</th>
<th>Year</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>1) <strong>Lab Scale Demo</strong></td>
<td>Plymouth, MI</td>
<td>2013</td>
<td>FINISHED</td>
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<td>DC Load Size: 3.3 kW</td>
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<td>2) <strong>Building Scale Demo</strong></td>
<td>Charlotte, NC</td>
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<td>DC Load Size: 15 kW</td>
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<td>3) <strong>DOD Awarded Demo</strong></td>
<td>Ft.Bragg, NC</td>
<td>2015</td>
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<td>DC Load Size: 15 kW</td>
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<tr>
<td>4) <strong>Bosch Building Installation</strong></td>
<td>Plymouth, MI</td>
<td>2016</td>
<td>UNDERWAY</td>
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<td>DC Load Size: 30 kW</td>
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<td>5) <strong>Bosch Dev Lab 2.0</strong></td>
<td>Mooresville, NC</td>
<td>2016</td>
<td>UNDERWAY</td>
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<td>DC Load Size: 30 kW</td>
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<td>6) <strong>CEC Awarded Demo (Honda)</strong></td>
<td>California</td>
<td>2016</td>
<td>IN DESIGN</td>
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<td>DC Load Size: 175 kW</td>
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CEC Awarded DC Microgrid Project

Project Details:
- Host site: 350,000 sq. ft. distribution center
Preliminary Cost-Benefit Analysis

- Example Case-Study: DC Microgrid vs. Conventional AC system
  - California warehouse with approximately 100 lights
  - 48 kW metal halide lighting replaced with 20 kW LED lighting
  - 52 kW solar PV system provides 89% of the energy for lighting (net export enabled)

25 Year Lifetime Discounted Savings

Base case: AC Metal Halide  
Case 2: AC PV + LED, Customer owned PV  
Case 3: DC PV + LED, Customer owned PV

AC  
DC  
~30%
Conclusions and Next Steps

- Benefits of the Bosch DC Microgrid are proven
  - Inherent resiliency provides energy security
  - 7-10% better utilization of local energy sources
  - Higher reliability through reduced electronics
  - ~30% lower lifetime costs
  - No major barriers in implementing DC power distribution under current NEC code

- Ready for first commercial applications
  - LED lighting is first available DC load
  - Suitable for retrofit or new construction
  - Ideal for large “big-box” type buildings
  - Economics best with (daytime) 7-day operation

- Bosch seeking projects for 2017 installations
Thank you!

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