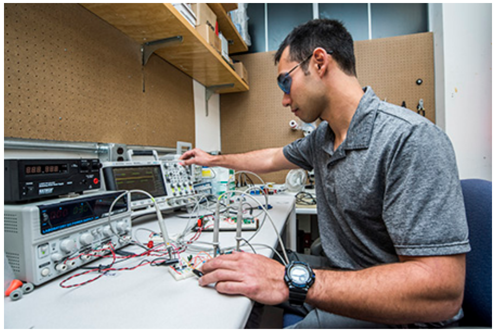
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

U.S.-China Clean Energy Research Center Buildings Energy Efficiency (CERC-BEE)

Direct Current (DC) Buildings & Smart Grid



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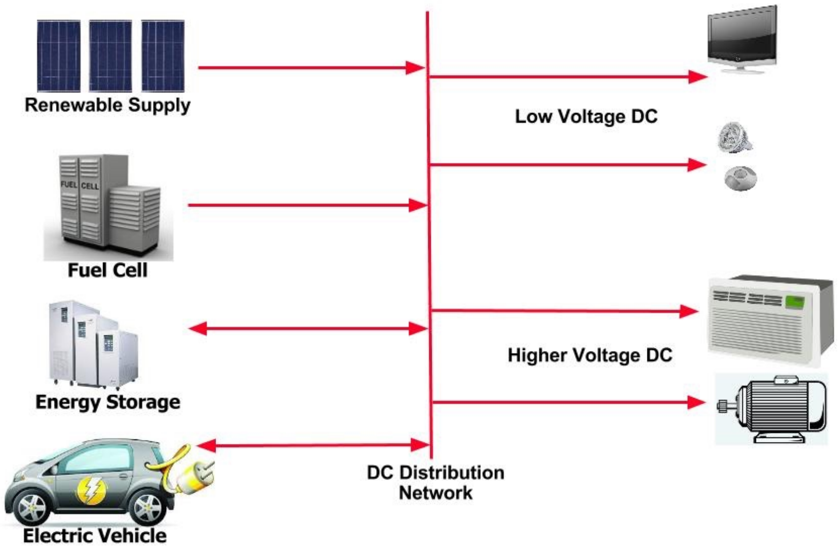
Tsinghua University

Beijing University of Civil Engineering and Architecture

Xiamen University

iBR 深圳市建筑科学研究院 Shenzhen Institute Of Building Research



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Project Summary

Timeline:

Start date: April 1, 2016

Planned end date: March 31, 2021

Key Milestones

1. Simulated savings estimate for large office; 2017 Q3
2. Apply power simulation model to CERC demo building; 2018 Q4
3. Controls simulation model applied to 10 buildings; 2020 Q4

Budget:

Total Project $ to Date:

- DOE: $500,000
- Cost Share: $1,325,000

Total Project $:

- DOE: $1,350,000 (funded annually)
- Cost Share: $3,525,000

Key Partners:

U.S.	China
Nextek Power Systems	Tsinghua University
Saint-Gobain	BUCEA University
Johnson Controls	Shenzhen IBR
Lumencache	Xiamen University
Legrand/Wattstopper	Singyes Solar
NextEnergy	
ForestCity	
CA CEC EPIC program	

Project Outcome:

- Validated models of energy savings for DC power distribution in buildings
- Technologies for digitally managing power distribution using network principles
- Contribute to BTO MYPP goals: Efficiency, Resilience, Grid interaction

Team

BERKELEY LAB

LBNL Staff:

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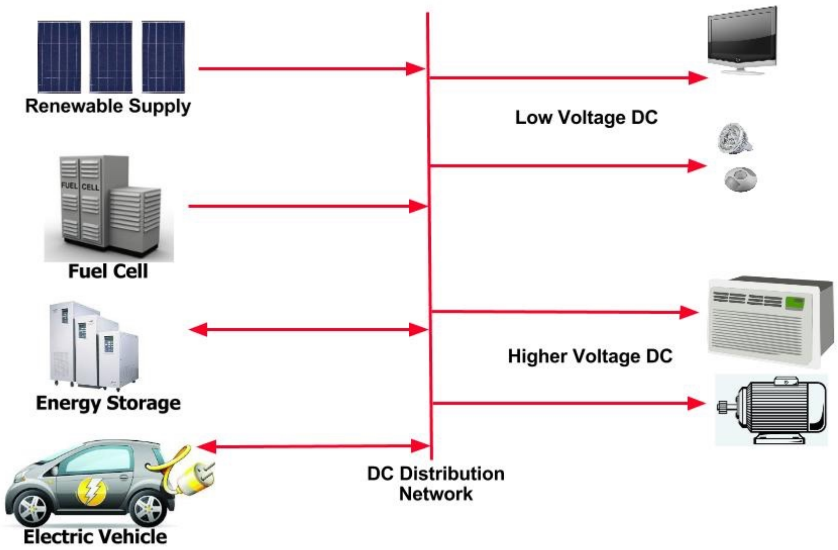
Challenge

- We increasingly live in a DC world (generation, storage, end use)
  - Very low (zero-net) energy buildings becoming common and encouraged by policies
  - Distributed Energy Resources (DER) becoming common in many states
- Integrating native-DC DERs into legacy AC system requires AC-DC conversions
  - Adds capital cost and wastes energy
- AC has other limitations
  - Power quality, grid reliability, safety, lacks integrated power control capability
- Direct DC distribution can solve these problems, but need to:
  - Identify right applications for DC in buildings
  - Quantify benefits (efficiency and other)
  - Develop "smart" technologies to manage DC distribution using modern communication and control

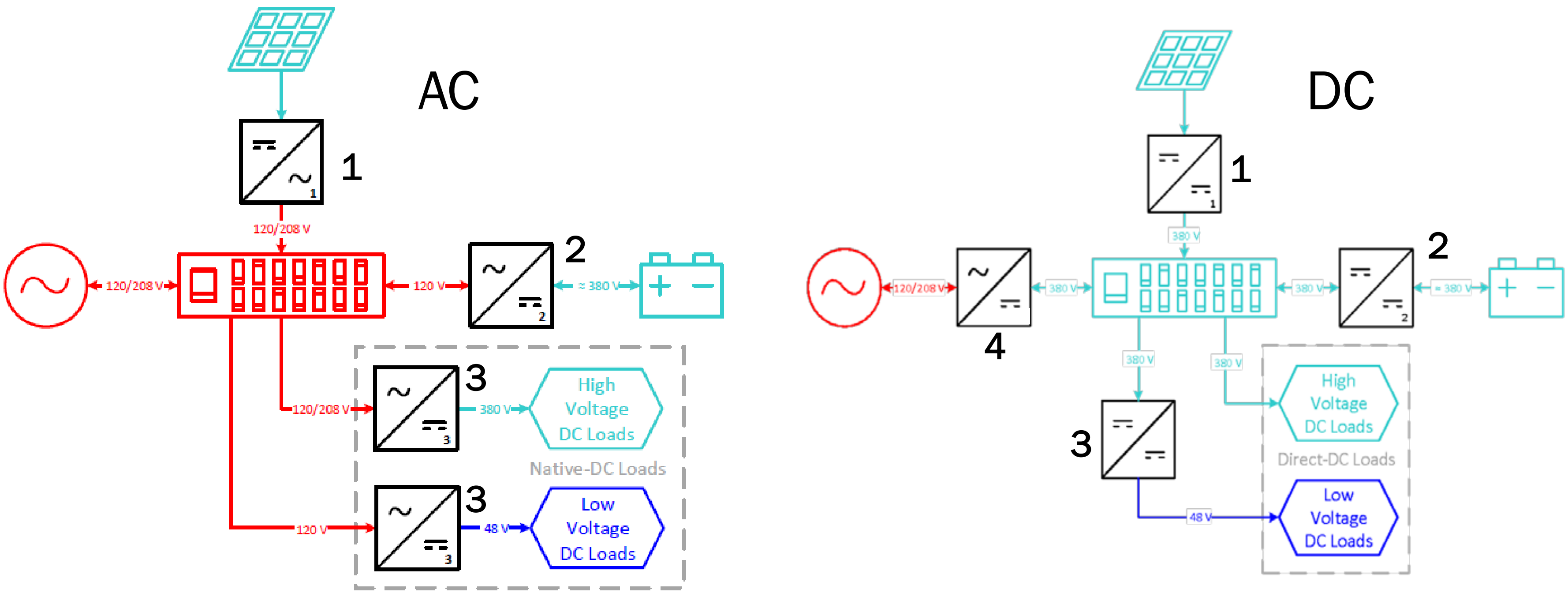


Approach

	Task 1 - Quantify DC Savings	Task 2 – Communication & Control
How project will solve these problems	• Produce **empirical data** and models to increase confidence of manufacturers, designers, engineers, and building owners about appropriately deploying DC distribution – Model savings, tech-econ analysis, data compilation and direct measurements	• Create **new technology for control** and introduce it into market via technology standards – Develop technology to digitally manage DC in networks; introduce into tech. standards
Key barriers and challenges	• Validating savings with accurate models and lab/field measurements	• Proving that technical approach for communication/control has value in theory and works in practice
Comparison to others' efforts	• No one else doing comprehensive efficiency analysis	• Other control approaches are generally analog and limited to traditional methods – we leverage IT technology and architectures

Approach: Task 1 - Energy Savings Modeling

- Review and analyze previous results from the literature
- Model and measure energy savings from DC, to compare to AC baseline, for efficient buildings with direct DC distribution, on-site solar and storage,
- Conduct techno-economic analysis of AC & DC system life-cycle performance

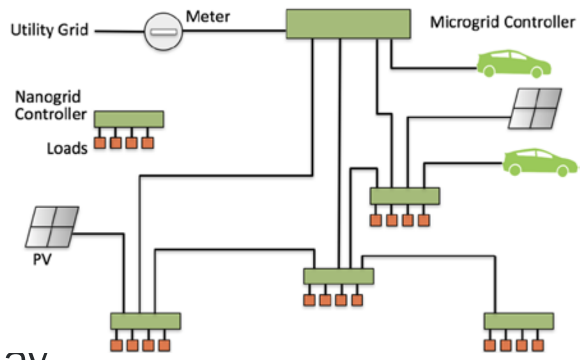


1: Solar Converter
2: Battery Converter
3: Load Converter
4: Grid-tie Inverter

AC
DC

For modeling purposes, we assumed all-DC buildings, but expect all buildings to be hybrid AC/DC for near- to mid-term

Approach: Task 2 - Local Power Distribution

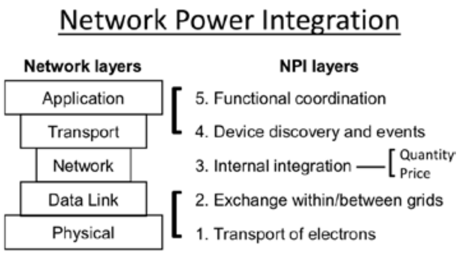


What

- "Network model of power" - requires DC power
- Organized bottom-up, into "nanogrids", w/local price
- All power exchange peer-to-peer, digitally managed

Why

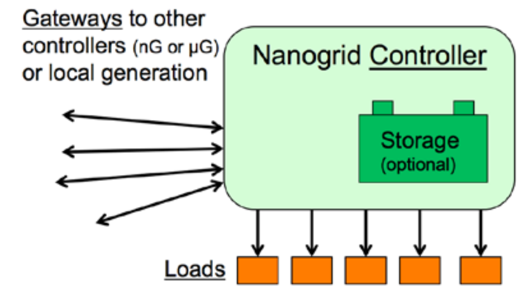
- Enable local storage and generation to be truly plug-and-play
- Inherently safe; simple, flexible; inter-building power links
- Create better value proposition for Direct DC – efficiency gains
- Enable inexpensive microgrids - inexpensive local reliability



Overall Plan

- System architecture → Communication model
- Simulation model → Quantitative benefits
- Hardware → It really works

- Communication model → Technology standards



Market Impact:

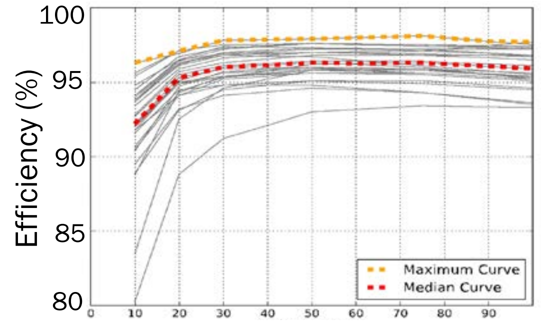
- Technology standards → **Products**
- Simulation code → **Sample algorithms for industry**

Progress: Task 1 - Energy Savings Modeling

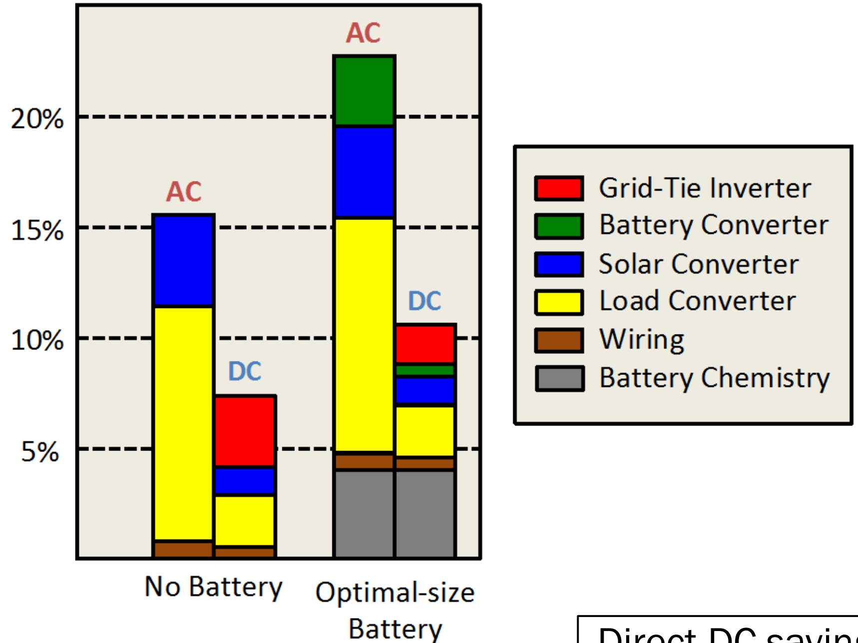
Model Inputs:

- Converters largest contributor to power loss
- Simulation model uses efficiency curves to account for larger losses at low load levels
- Also account for wiring losses

Sample Efficiency Curve – Solar Inverter



Energy Loss for Medium-Size Commercial ZNE Building



Results*: Major sources of loss –

- AC: **load converters**, **solar inverter**, **battery converter**
- DC: **grid-tie inverter**
- **Battery chemical loss**

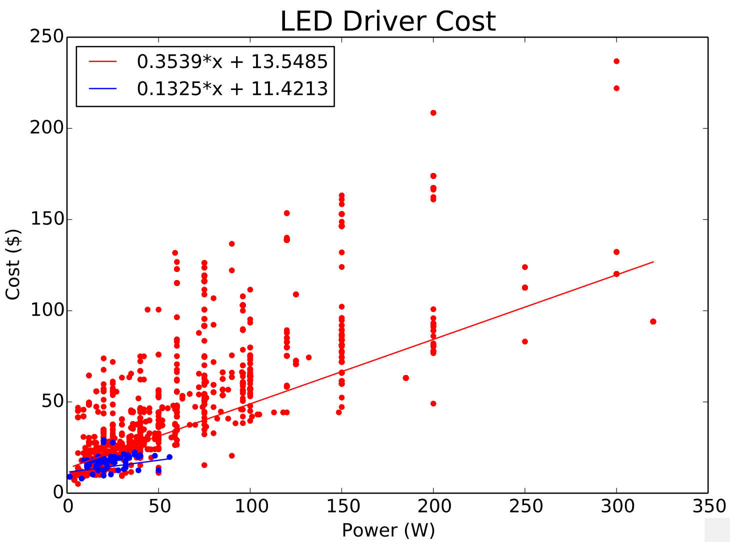
- Savings from DC: 5% – 15%

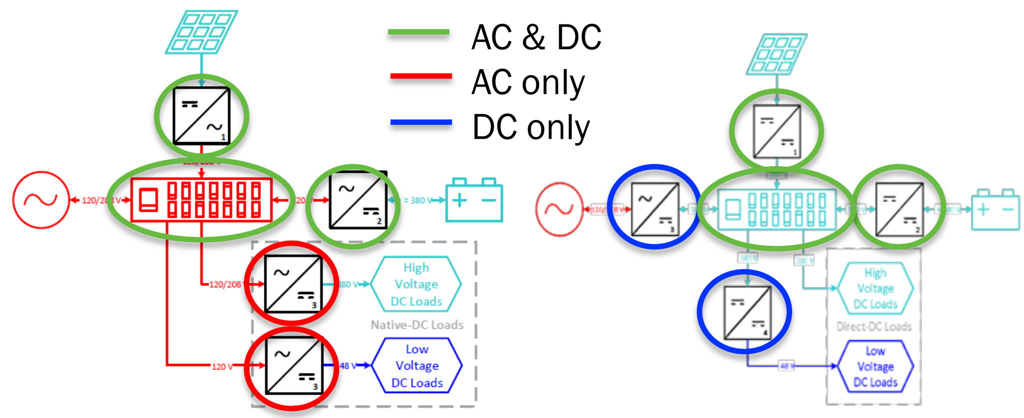
*Gerber et al. 2018. "A simulation-based efficiency comparison of AC and DC power distribution networks in commercial buildings." *Applied Energy*. January.

Direct DC savings large enough to merit pursuing
Need better input data and validation using lab/field measurements

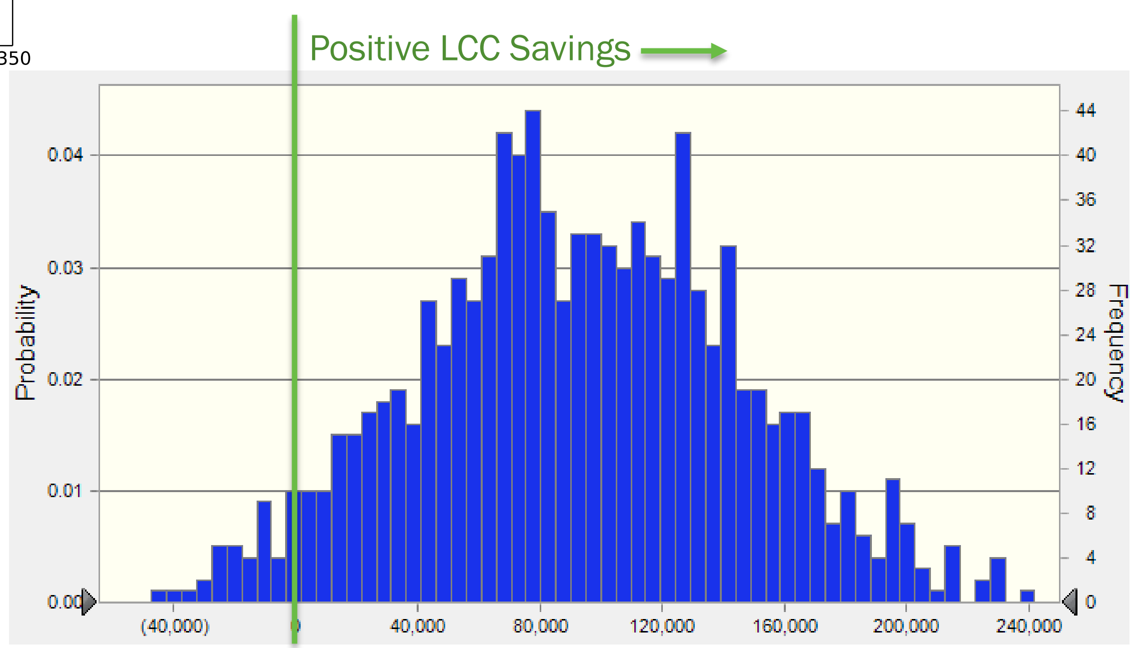
Progress: Task 1 - Techno-Economic Analysis

Compile key AC & DC component cost data, analyze mature market life-cycle cost



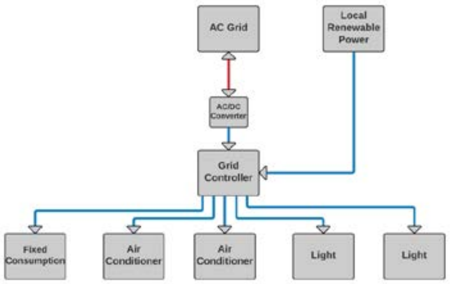


Monte Carlo Analysis:
96% of cases have positive life-cycle cost (LCC) savings for medium office building with PV and battery; small savings in scenarios without battery



Progress: Task 2 - Local Power Distribution

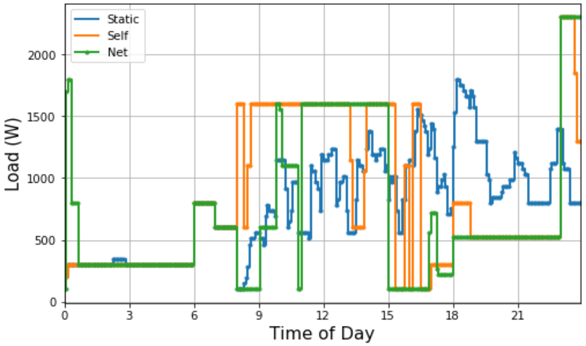
Established basic principles of networked power
Published findings in two conference papers



- Created simulation model of devices & power infrastructure
  - Defined architecture /mechanisms for networked power
  - Connections to utility grids, local renewables
  - **Price-responsive end-use devices**
  - User interfaces/tools for easy exploration of results

- Initial results
  - Modeled single, simple nanogrid with 3 tariffs
  - Cost and energy significantly different from base case operation
  - Tariffs drive local price, causing different:
    - Use of battery
    - End–use device operation
  - Large shift of load among price periods
  - Dynamic **local prices** reduce total energy cost

Sample load shapes by scenario



Results include energy and cost at meter

	Static	Self Supply	Net Metering
Energy (kWh)			
Low - $0.05/kWh	-2.35	0.16	1.16
Medium - $0.10/kWh	4.23	7.35	3.89
High - $0.15/kWh	6.7	2.23	2.03
Total	**8.58**	**9.74**	**7.09**
Cost ($)			
Low - $0.05/kWh	-0.12	0.01	0.06
Medium - $0.10/kWh	0.42	0.73	0.39
High - $0.15/kWh	1.01	0.33	0.31
Total	**1.31**	**1.08**	**0.75**
Total – Export $0.00	**1.56**	**1.11**	**0.98**

Impact

DC distribution has unique comparative advantages & value proposition

- DC can save energy and reduce costs for integrating local generation and storage
- DC powering provides non-energy benefits like power quality, safety, and resiliency

Project Impact

- Efficiency analysis provides better information about DC system benefits to:
  - Document the **5-15% whole-building efficiency gains** from Direct DC
    - Max 2025 savings: 0.7 Quads U.S., 1.5 Q China – Substantial contribution to BTO's goal
  - Encourage manufacturers to introduce new, high-efficiency **direct-DC products**
  - Help building owners and designers find the **best applications of DC** in projects
- Networked DC enables new capabilities that consumers value and improve grid-responsiveness of buildings
- Collaboration between U.S. and China to drive common solutions

How will impact be realized

- Design Tools: Apply models to DC Design Tool (joint project with NREL)
- Technology Standards: Incorporate project approach for communications, e.g. Ethernet (done), USB, new higher-capacity power links (e.g. 380V)
- Market Trends: Increasing interest in coupling storage to PV with Direct DC
  - Next logical step is coupling end uses to the same DC network

Stakeholder Engagement

Core U.S. work

- CERC Industrial Advisory Board – several members interested in DC power
- Efficiency analysis: work with various companies to establish reliable efficiency data for power distribution devices
- Starting to test products and components from partner companies
- Have been collaborating with Ethernet Alliance and several member companies on our addition to the Ethernet Standard

ethernet alliance

WattStopper

NEXTEK Power Systems

LUMENCACHE

NEXTENERGY

FORESTCITY

Engagement with China partners and companies

- Hosting visiting researchers from Chinese research partners
- Work with Chinese partners to leverage vibrant construction market for field demonstrations:
  - Singyes Solar DC power demonstration in their HQ building
  - Shenzhen Institute of Building Research DC microgrid in Shenzhen "Low Carbon City"
  - Gree HVAC product demonstrations

GREE

Tsinghua University

Beijing University of Civil Engineering and Architecture

Xiamen University

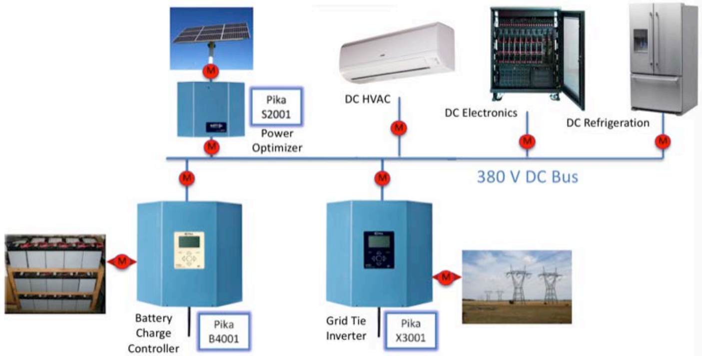
興業太陽能 SINGYES SOLAR

IBR 深圳市建筑科学研究院

Shenzhen Institute of Building Research

Remaining Project Work: Task 1

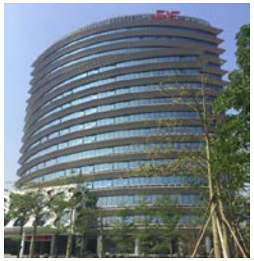
Validate model through lab measurements of components, devices, and systems

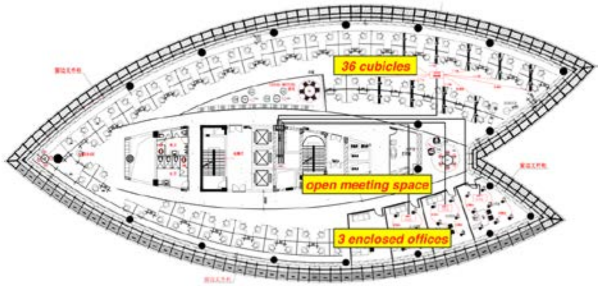


FlexGrid

Advise and assist with field demonstrations in China

Singyes Solar HQ building



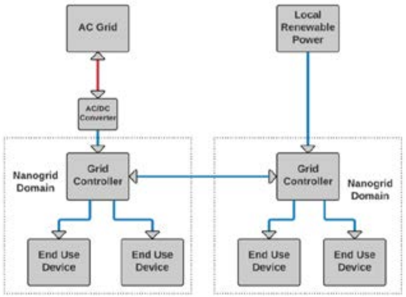


Seek field test opportunities in U.S.

IIT Chicago AC/DC Microgrid

Gree PhoenixMart DC air conditioning

Remaining Project Work: Task 2



Use simulation model

- Test / **improve algorithms**
  - Grid controllers and end-use devices (& add more)
- Create example scenarios that demonstrate new functionality
  - Ordinary operation plus utility grid outages
  - Multiple link technologies (e.g. Ethernet, USB, 380V)
  - Scale to complex networks
- Quantify energy and other **benefits**
- Begin building **hardware** to demonstrate concept working in practice
  - First, "device simulators" to model any end-use device in electrical consumption
  - Year 4, nanogrid controller with internal battery
- Work with IEEE and Ethernet Alliance to create awareness of local pricing feature of new Ethernet standard and contribute to development of new Ethernet technologies with buildings and efficiency as primary
  - New "Single-pair Ethernet" will be more optimized for power delivery

Thank You

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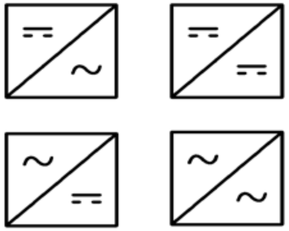

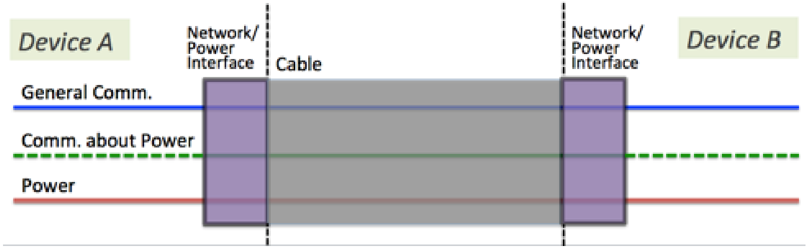

REFERENCE SLIDES

Project Budget

Variances: No variances from original planned budget
Cost to Date: 40% of DOE-funded costs have been expended to date
Additional Funding: No other funding for LBNL, but substantial cost share

Budget History					
April 1, 2016– FY 2017 (past)		FY 2018 (current)		FY 2019 – March 31,2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$500,000	$1,325,000	$250,000	$825,000	$500,000	$1,450,000

Project Plan and Schedule

- Duration: April 1, 2016 – March 31, 2021
- Schedule and Milestones on schedule below
- Project is on schedule and on budget

BTO Year	16		2017				2018				2019				2020				21	
CERC Year	1				2				3				4				5			
Task Activity	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Task 1. Energy Savings																				
Data Compilation			D		D															
Power Simulation Model Development					G		D													
Tech-Economic Analysis					D/G															
Power Simulation Model Application								D	G					D						
Hardware Deployment Testing																				D
Savings Commercialization																				D
Task 2. Communications and Control																				
Controls Simulation Model Development				D				G				D								
Controls Simulation Model Application														G						D
Controls Commercialization											D									D