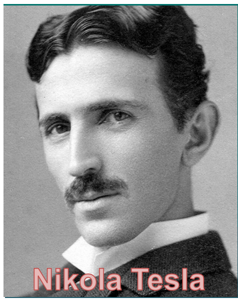
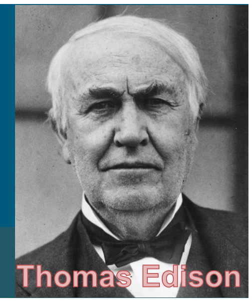


Comparison of AC versus DC Distribution in Commercial Building Nanogrids

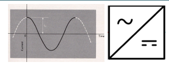


AC & DC Power Background

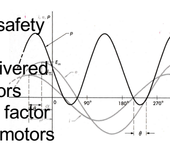
Research Objective

- ▹ research & demonstrate technical viability of DC building distribution
- ▹ focus on low (< 600) voltage DC in commercial buildings
- ▹ direct integration of renewable sources and batteries
- ▹ simulate and measure potential energy efficiency & economic benefits
- ▹ evaluate communication opportunities

Alternating Current



- ▹ the *building* power we're all accustomed to
- ▹ has huge advantage of easy voltage changes
- ▹ enables long distance transmission with local safety
- ▹ voltage and current cycles at fixed frequency
- ▹ when working well, energy is always being delivered
- ▹ approach is closely related to rotating generators
- ▹ has many *power quality* problems, e.g., power factor
- ▹ has few advantages at end-use, but induction motors
- ▹ end-use rectification to DC common and increasingly efficient



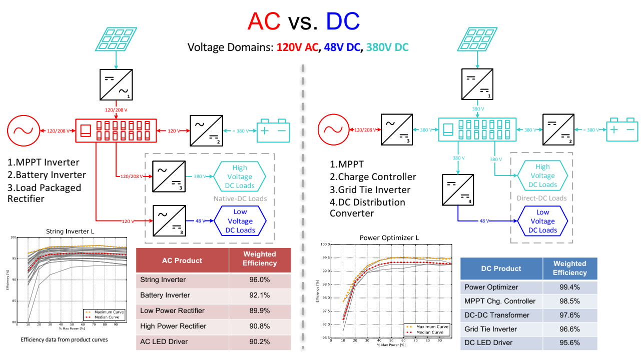
Direct Current

- ▹ the *vehicle* power we're all accustomed to
- ▹ many efficient DC loads (LEDs, variable speed motors, etc.)
- ▹ many power sources (PV, batteries) also DC
- ▹ less losses and power quality issues with all DC distribution
- ▹ simpler systems should be cheaper, more reliable & resilient
- ▹ creates a favorable environment for PV integration & EVs
- ▹ EVs and heat pump heating/cooling are significant DC loads
- ▹ safety and other standards needed and a formidable barrier
- ▹ easy connection to electronics permits smart distribution

Analysis Approach

AC vs. DC

Voltage Domains: 120V AC, 48V DC, 380V DC

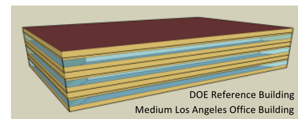


AC Product	Weighted Efficiency
String Inverter	96.0%
Battery Inverter	92.1%
Low Power Rectifier	89.9%
High Power Rectifier	90.8%
AC LED Driver	90.2%

DC Product	Weighted Efficiency
Power Optimizer	99.4%
MPPT Chg. Controller	98.5%
DC-DC Transformer	97.6%
Grid Tie Inverter	96.6%
DC LED Driver	95.6%

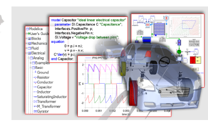
Motivation

- new California residential buildings to be ZNE by 2020
- all commercial buildings by 2030
- solar PV generation, batteries, and most loads natively DC
- many efficient DC devices should be encouraged
- *less power quality problems & improved reliability-resilience with DC*
- *islanding microgrid buildings facilitated by DC*



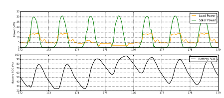
Research Goal

- use Modelica simulations to determine efficiency improvements
- estimate economic benefits of DC distribution
- model medium size Los Angeles office and other buildings
- include realistic profiles for solar output and load
- use converter efficiency curves, and detailed battery and wiring models



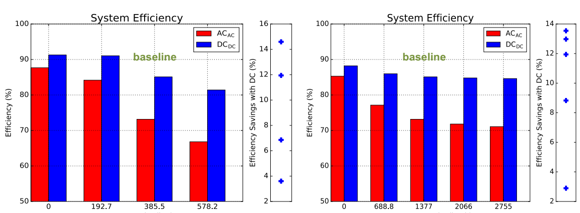
Modelica

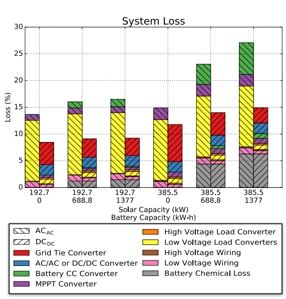
- object oriented modeling language with GUI provided by Dymola
- popular for building, automotive, and other engineering simulation
- useful for complex systems that include mixed electrical, thermal, etc.



Results

DOE Reference Building Model of Medium Office in Los Angeles, CA

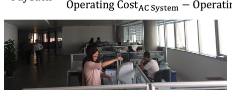




Description	Network	Average LCC Savings (US$)
Total First Cost ($)	AC	252,000
	DC	301,000
Net Annual Electricity Consumption (kWh/yr)	AC	177,000
	DC	101,000
Average LCC Savings ($)	AC vs. DC	61,000
% Cases with Net Benefit	AC vs. DC	>90%
Average Payback Period (yr)	AC vs. DC	~1

$$\text{LCC} = \text{First Cost} + \sum_{y=1}^{\text{Lifetime}} \frac{\text{Operating Cost}(y)}{(1+\text{Discount Rate})^y}$$

$$\text{Payback} = \frac{\text{First Cost}_{\text{DC System}} - \text{First Cost}_{\text{AC System}}}{\text{Operating Cost}_{\text{AC System}} - \text{Operating Cost}_{\text{DC System}}}$$



All DC floor in the XingYe HQ building in Zhuhai, China

Parametric Experiments

- solar Experiment – baseline is amount of solar capacity needed to power a ZNE building
- battery experiment – baseline is half the amount of battery capacity needed for a ZNE building to store all daily excess solar (= generation – load)

Efficiency Results

- 12% baseline efficiency savings with DC
- DC is more efficient with high solar and battery capacity

Loss Analysis

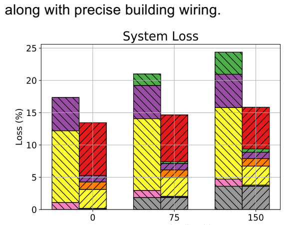
- AC building loss is dominated by the poor efficiency of load packaged rectifiers (wall adapters)
- AC buildings with lots of storage see loss in the battery inverter
- DC building loss dominated by the grid tie inverter
- particularly heinous with high solar capacity and no storage (fourth pair of bars at left)
- both buildings suffer significant battery chemical loss

Techno-Economic Analysis

- results determined from market cost data, grid tariffs, and Monte-Carlo analysis
- first cost is higher for DC
- given the enormous efficiency savings, the payback period is less than a year
- end use costs, installation costs, and other soft costs not considered in techno-economic analysis

IBEW ZNE Building, San Leandro CA

The DC analysis model is used to scope the feasibility of DC distribution in a ZNE office building. The simulations are run with actual solar and load profile data, along with precise building wiring.



Future Research

Experimental and Field Testing

- experimentally estimate efficiency savings of identical AC vs. DC networks
- verify the savings of removing the rectification stage in various loads
- design and construct a DC microgrid, meter and measure the savings
- collaborate with DC demonstrations in Europe and Asia

Analysis and Modeling

- develop a generic DC efficiency modeling tool for commercial use
- improve the techno-economic analysis and create future projection models
- develop advanced control algorithms for load shedding in DC buildings
- study the non-energy benefits of DC for power quality, resiliency, etc.

BERKELEY LAB
ENERGY TECHNOLOGIES AREA

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ABBREVIATIONS & ACRONYMS:

CEC – California Energy Committion
EV – electric vehicle
GUI – graphical user interface
LCC – life cycle cost
U.S. DOE – U.S. Department of Energy
ZNE – zero net energy