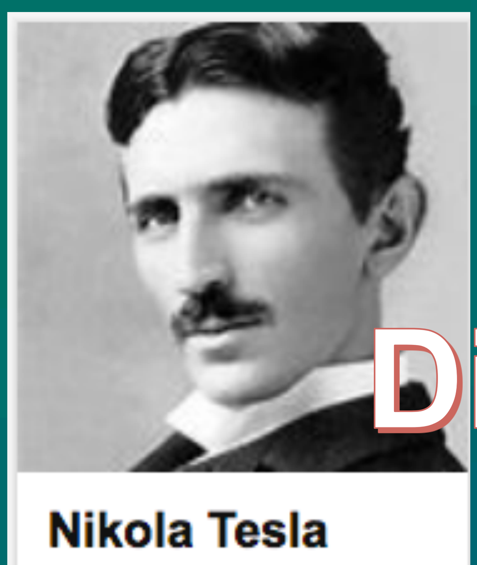
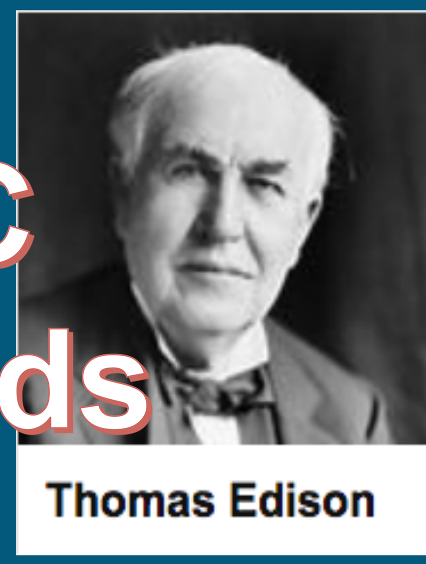


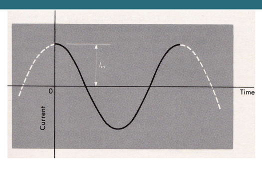

# An Efficiency Comparison of AC versus DC Distribution in Commercial Building Nanogrids

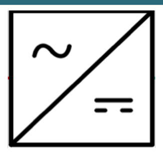



## AC & DC Power Background

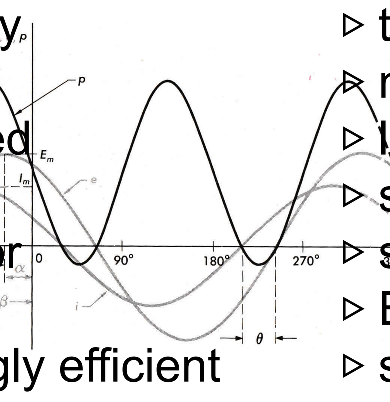
Research and demonstrate technical viability of DC building distribution. Simulate and measure its potential energy efficiency savings and other benefits (renewable integration, reliability, resilience, power quality, etc.), and enhance benefits through communication, using low voltage (<600 V) DC directly integrated with renewable energy technologies and storage in buildings.

**alternating current**

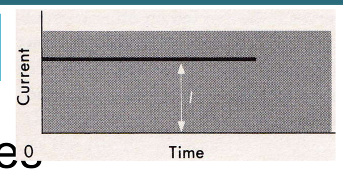




- ▹ the *building* power we're all accustomed to
- ▹ has huge advantage of easy voltage changes
- ▹ enables long distance transmission with local safety
- ▹ voltage and frequency cycles at fixed frequency
- ▹ when working well, energy is always being delivered
- ▹ approach is closely related to rotating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

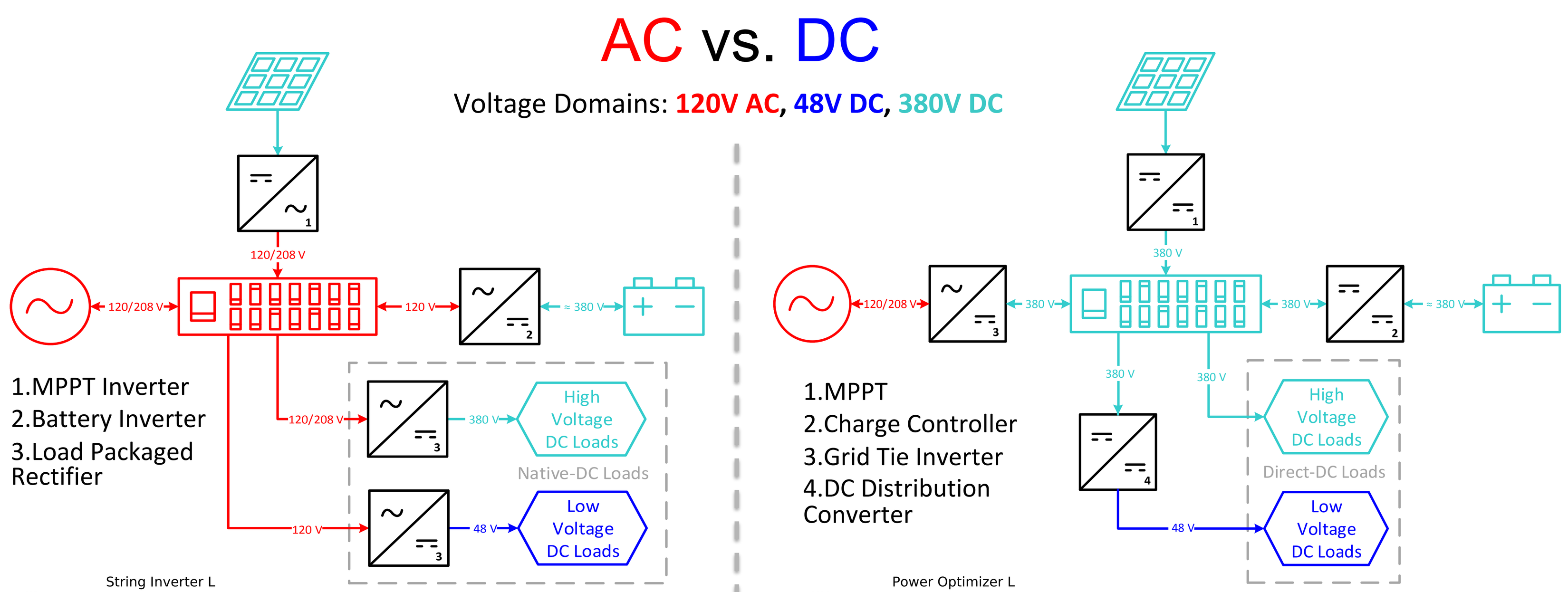


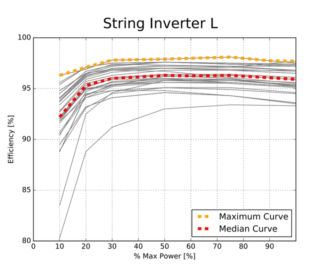
**direct current**




- ▹ the *vehicle* power we're all accustomed to
- ▹ common in modern commercial building devices
- ▹ third-half of load including efficient devices, e.g. LED lighting
- ▹ many sources, e.g. PV, and batteries, e.g. EVs, also DC
- ▹ less losses with all DC & many less power quality challenges
- ▹ simpler systems should be cheaper, more reliable & resilient
- ▹ should create a favorable environment for efficiency and EVs
- ▹ EVs and heat pump heating could add significant DC load
- ▹ safety and other standards needed and a formidable barrier
- ▹ connection to electronics permits smart distribution

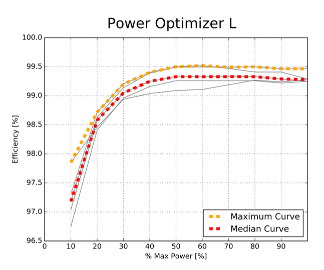
## Analysis Approach




Efficiency data from product curves

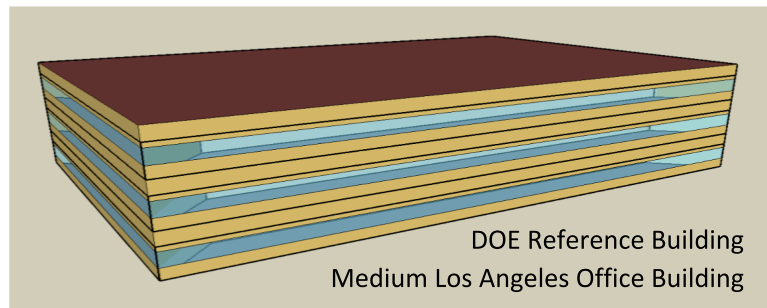
| AC Product | CEC Efficiency |
|---|---|
| String Inverter | 96.0% |
| Battery Inverter | 92.1% |
| Low Power Rectifier | 89.9% |
| High Power Rectifier | 90.8% |
| AC LED Driver | 90.2% |




| DC Product | CEC 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% |

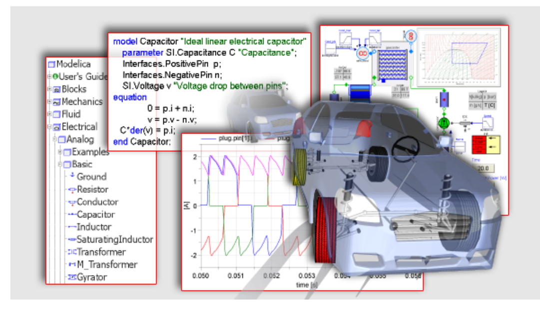
### Motivation

- California requires all new residential buildings to be zero net energy (ZNE) by 2020, and all commercial buildings by 2030. Can DC distribution help?
- Solar PV generation, battery storage, and most loads are natively DC. Islanding microgrid buildings may also have huge benefits from DC



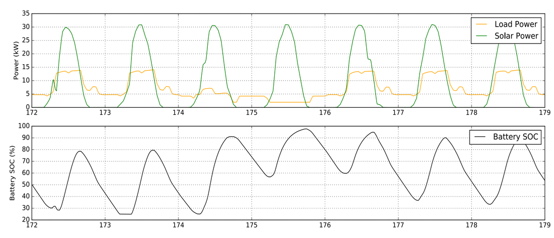

### Research Goal

- Use parametric Modelica simulations to determine the efficiency savings with DC distribution
- Scope is a modeled medium size office building in Los Angeles
- Include realistic profiles for solar and load, converter efficiency curves, and detailed models for battery and wiring

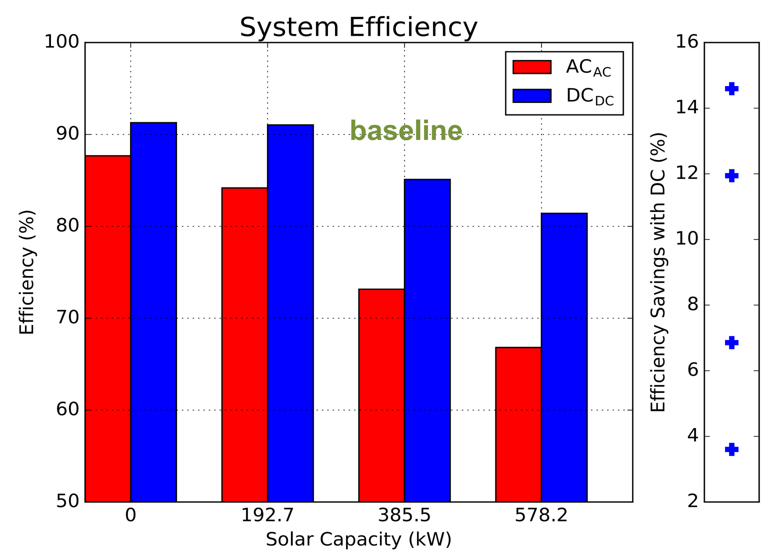
### Modelica

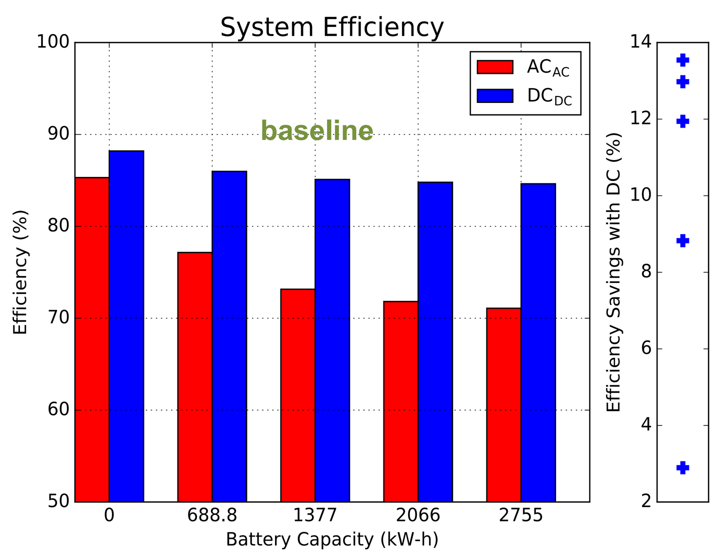
- Object oriented modeling language with GUI provided by Dymola
- Popular for building and automotive simulations
- Useful for complex systems that span electrical, thermal, etc.



## Results

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



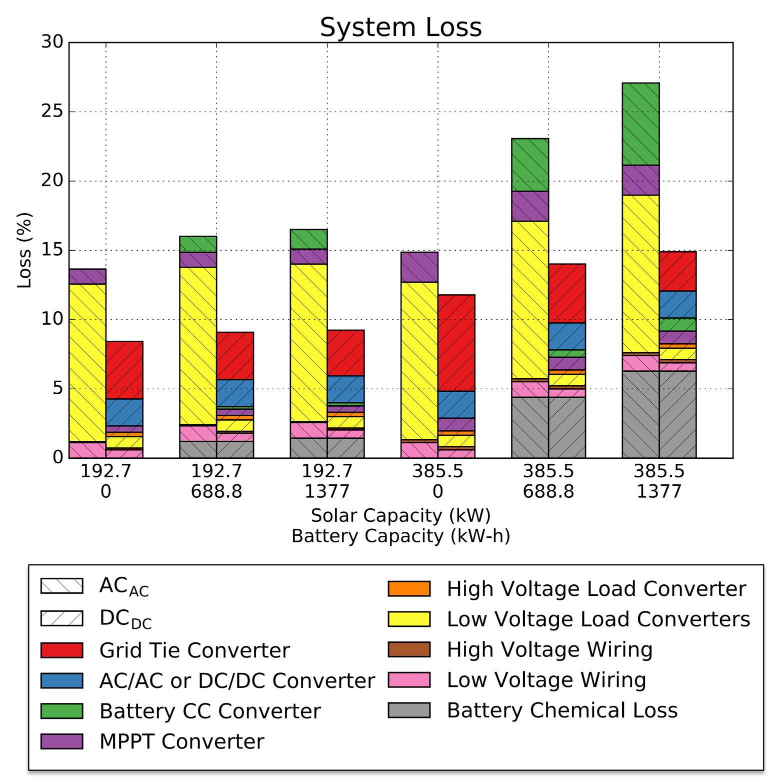




TABLE II. LCC AND PBP RESULTS FOR BASELINE SCENARIO

| Description | Network | Value |
|---|---|---|
| Total Installed Cost ($) | $AC_{AC}$ | 252,098 |
| | $DC_{DC}$ | 301,155 |
| Net Annual Electricity Consumption (kWh/yr) | $AC_{AC}$ | 176,775 |
| | $DC_{DC}$ | 100,656 |
| Average LCC Savings ($) | $AC_{DC}$ vs. $DC_{AC}$ | 61,487 |
| % Cases with Net Benefit - DC Network | $AC_{DC}$ vs. $DC_{AC}$ | >90% |
| Average PBP - DC Network (Years) | $AC_{DC}$ vs. $DC_{AC}$ | 0.7 |

$$LCC = Total\ Installed\ Cost + Lifetime\ Operating\ Cost$$

$$PBP = \frac{Installed\ Cost_{DC\ System} - Installed\ Cost_{AC\ System}}{Operating\ Cost_{AC\ System} - Operating\ Cost_{DC\ System}}$$

#### 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 much more efficient with high solar and battery capacity

#### Loss Analysis

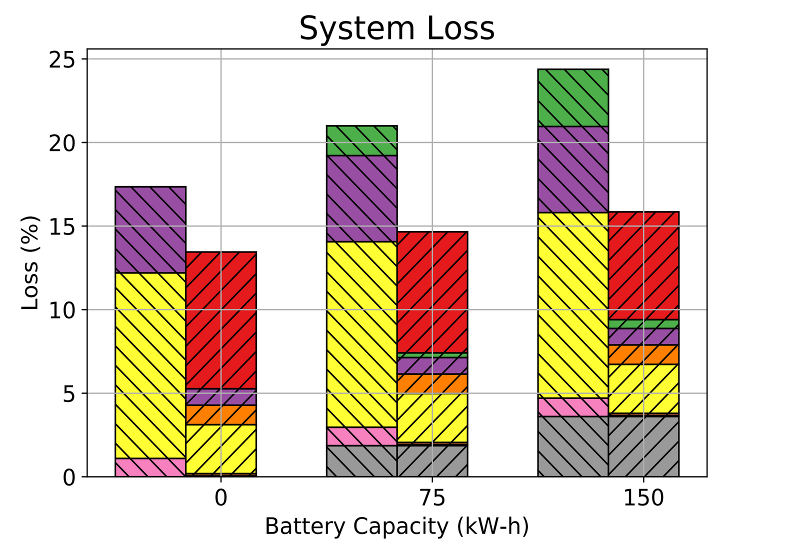
- AC building loss is dominated by the poor efficiency of **load packaged rectifiers** (wall adapters)
- AC buildings with lots of storage see loss in the **battery inverter**
- DC building loss dominated by the **grid tie inverter**. This loss is particularly heinous with high solar capacity and no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

#### Techno-Economic Analysis

- Results determined from market cost data, grid tariffs, and Monte-Carlo analysis
- Upfront cost is higher for DC
- Given the enormous efficiency savings, the payback period is less than a year

### IBEW/JTAC Building, San Leandro CA

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




## Future Research

### Experimental and Field Testing

- Experimentally study the efficiency savings of identical loads in AC or DC configuration
- Verify the savings of removing the rectification stage in various loads
- Design and construct a DC microgrid. Meter out and measure the savings

### Analysis and Modeling

- Increase scope of buildings, and 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 power quality and DC microgrid disconnect

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