ENERGY INSTITUTE

COLORADO STATE UNIVERSITY

DC
For Buildings & Minigrids

Daniel Zimmerle

DC… Useful

Worlds Apart

DC in commercial buildings to improve effiency

- ✓ HVAC
- ✓ Lighting
- ⇨ Miscellaneous Electric Loads (MELs)

⇨ **DC in minigrids to lower cost**

- Low cost distribution
- Basic electric services

Developed World

Developing World

Developed World: DC Design and Scoping Tool

Science

Education

Industry

Advocacy


Steve Frank
NREL


Rois Langner
NREL


Rich Brown
LBNL

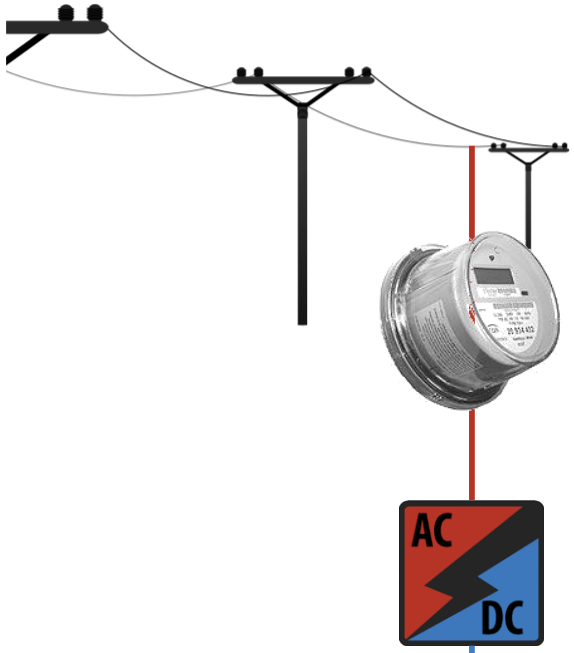

Michael Wetter
LBNL


Dan Zimmerle
CSU


Jim Cale
CSU


Sandy Vanderstoep
PVI

DC Design and Scoping Tool



It's a Direct Current World Out There

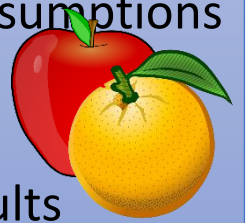
DC distribution systems can **save both energy and money…**

…but **how much?**

To answer that question, industry needs **rigorous and accurate** analysis tools

Existing Studies

- Inconsistent assumptions
- Lo-fi models
- Dubious claims
- Conflicting results




Computing Equipment


Consumer Electronics

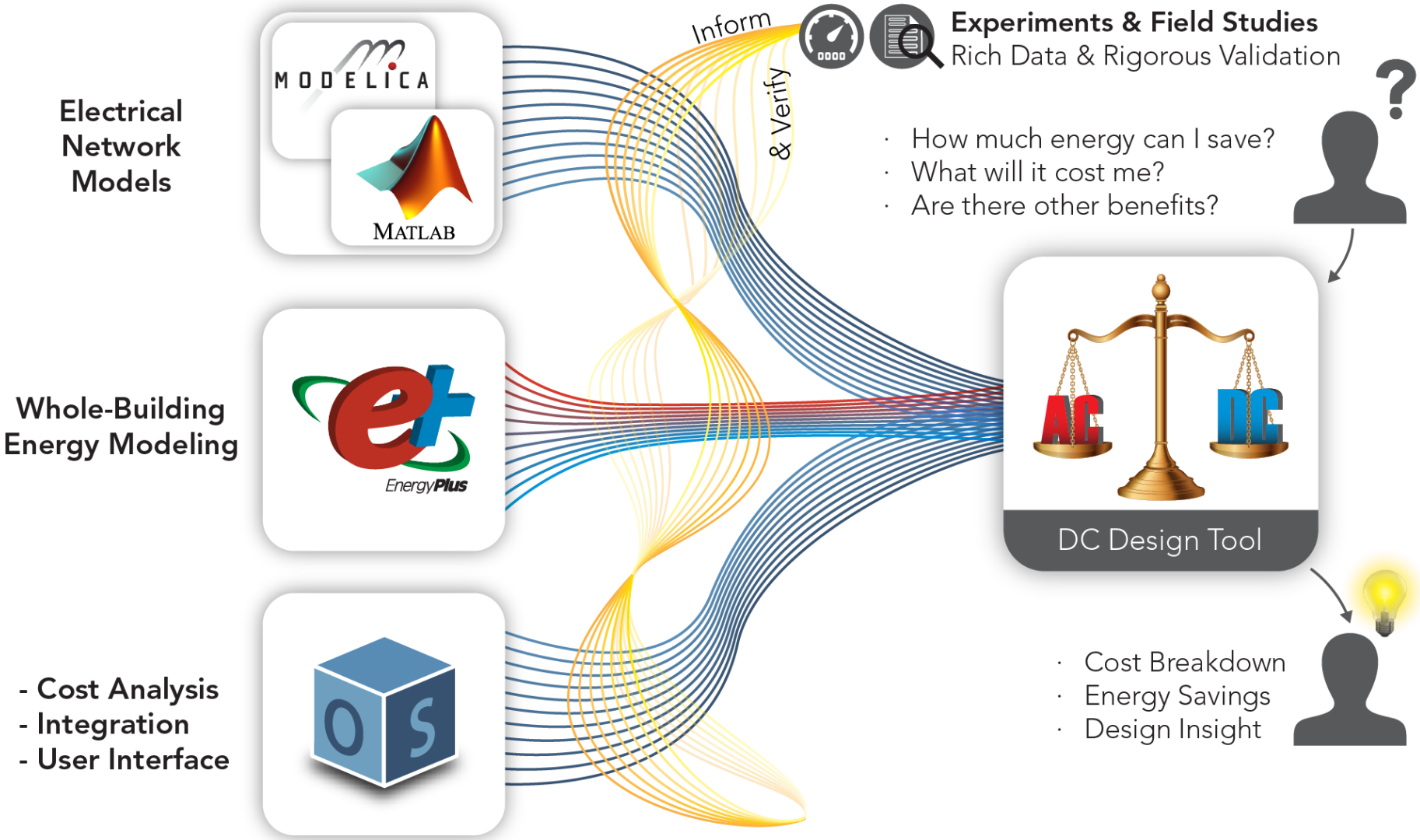

Motor Drives


Electric Vehicles

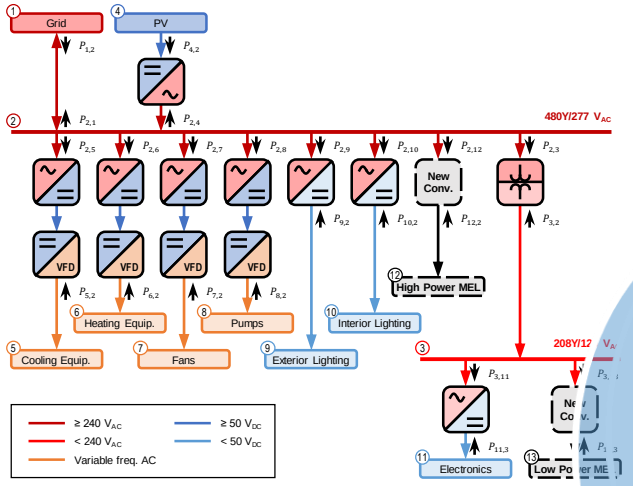

Energy Storage

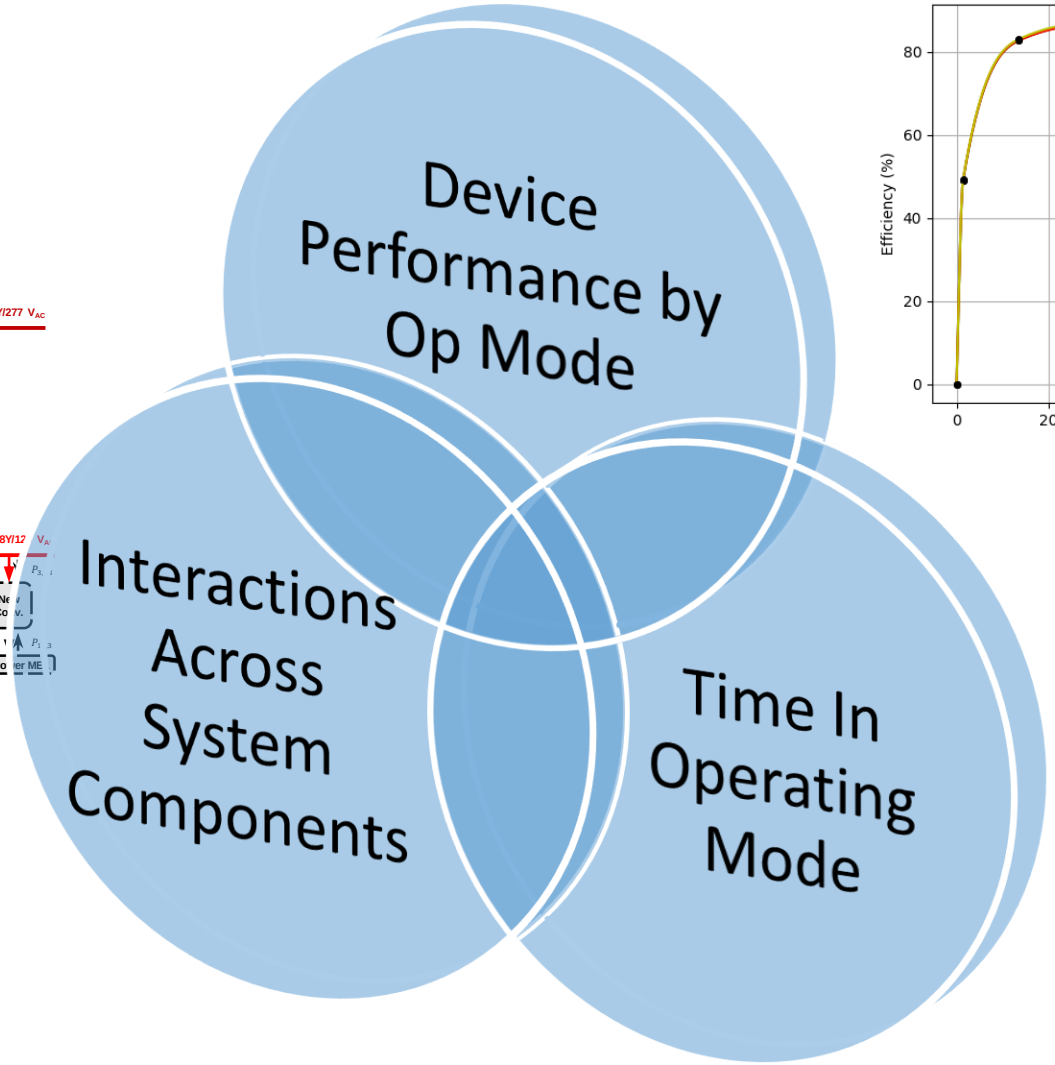

Onsite Generation

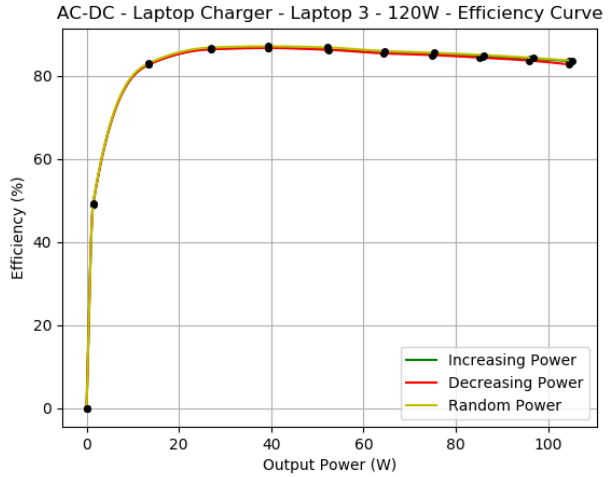
DC Design and Scoping Tool

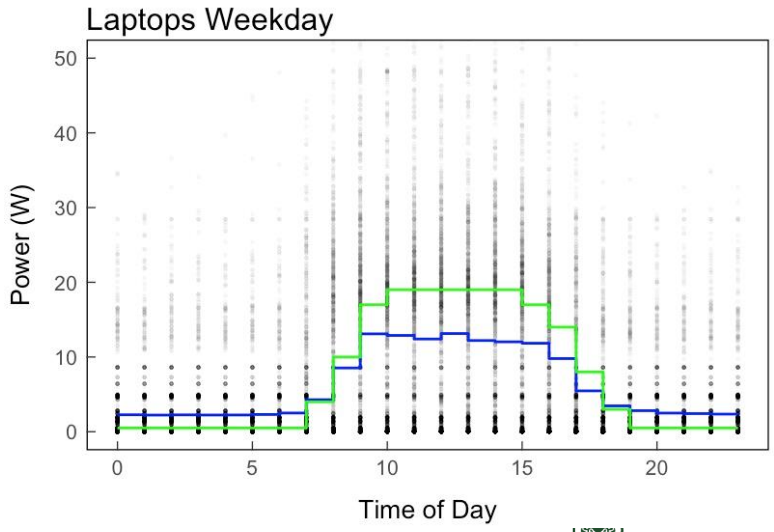


Performance Tool Requirements

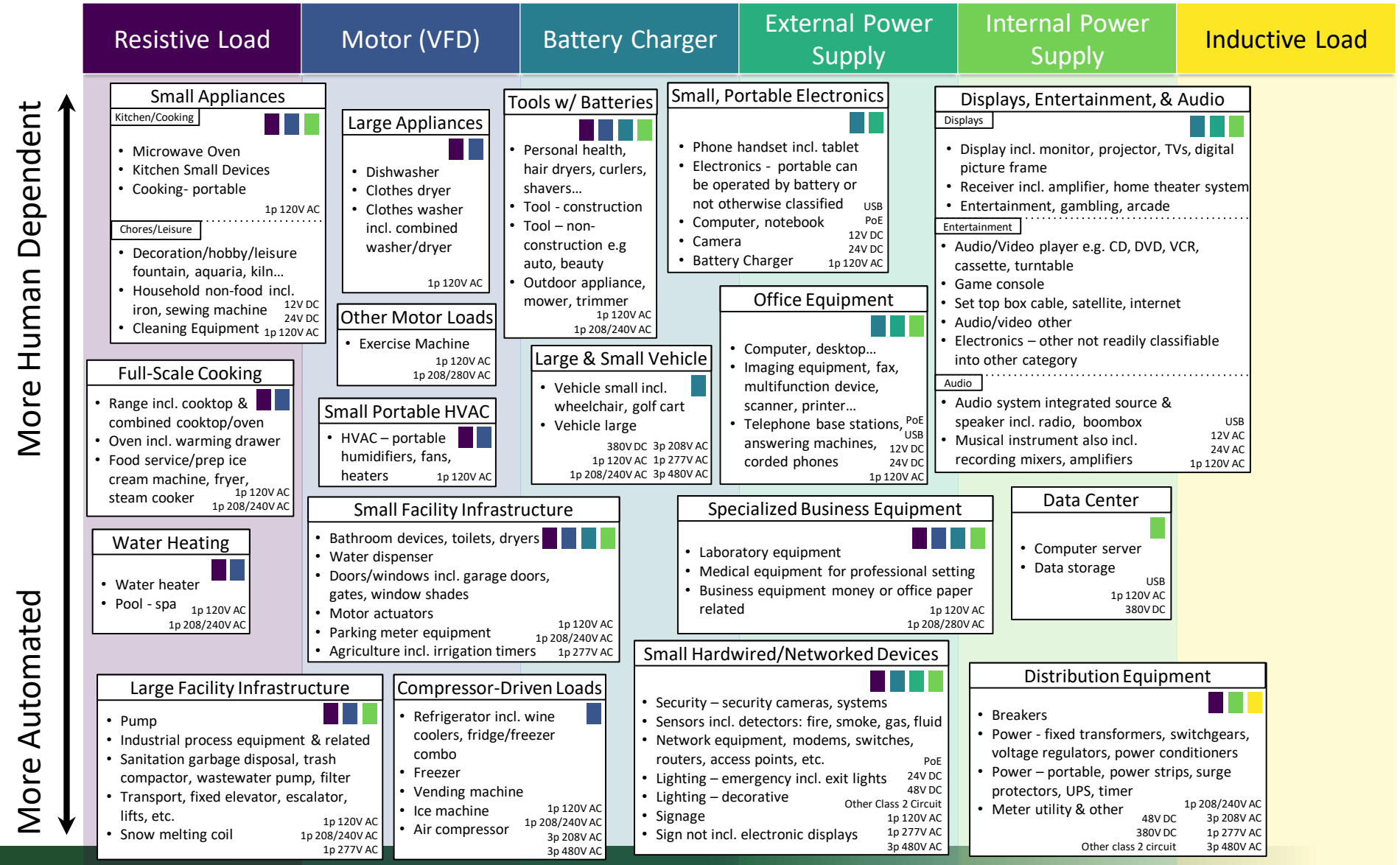








DC MELs Device Groups



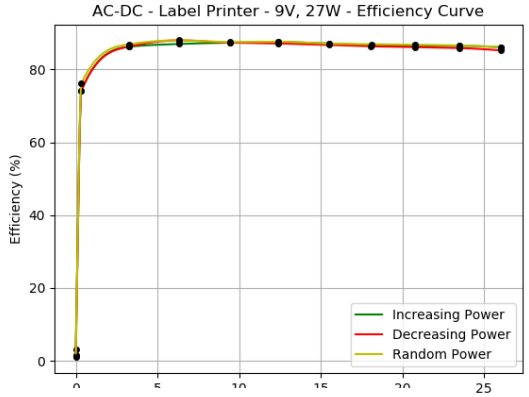
Device Characterization: Performance by Mode

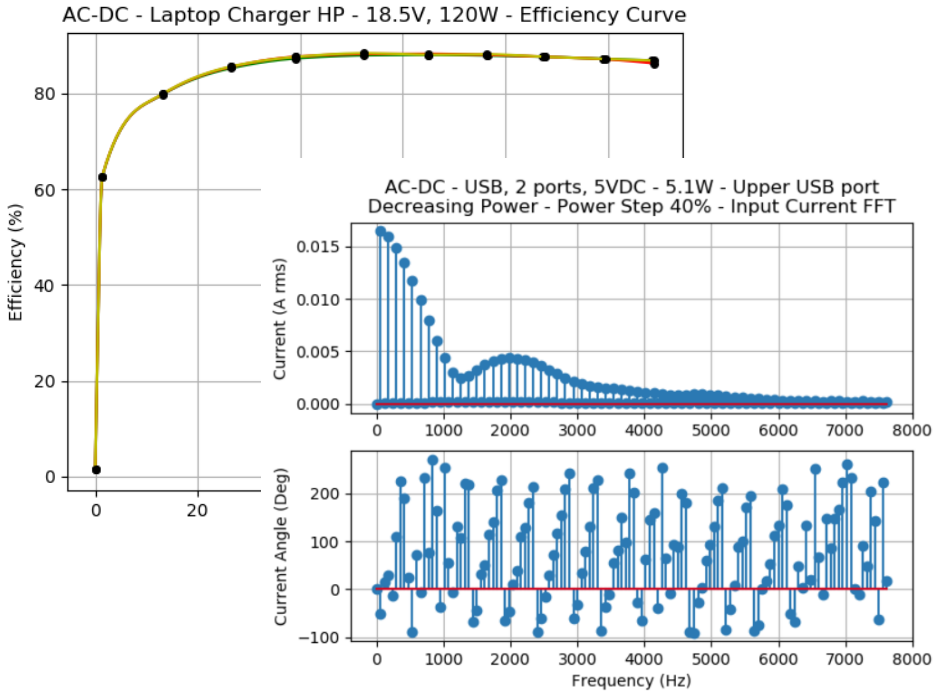
Characterization Experiments:

i. Measure converters that have both sides accessible
ii. Measure appliances that have only the input side of the converter available
iii. Purchase similar converters in the market for the appliances tested and measure them to serve as a proxy

Controllable Load Bank, 20V, 400W.

Power Analyzer PA2203A

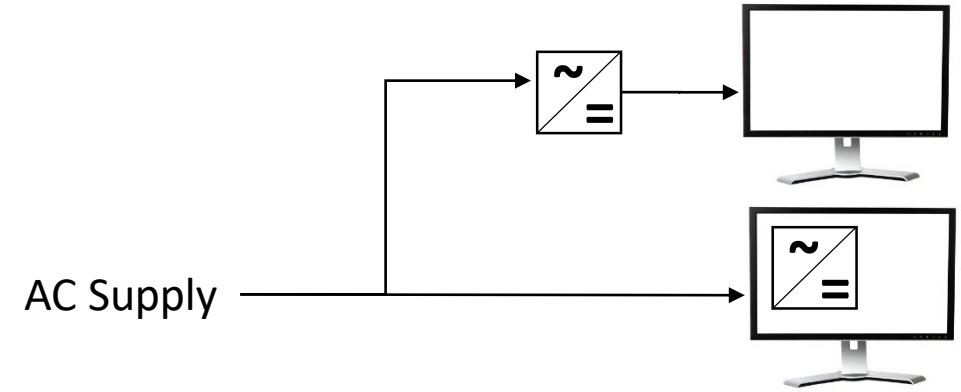




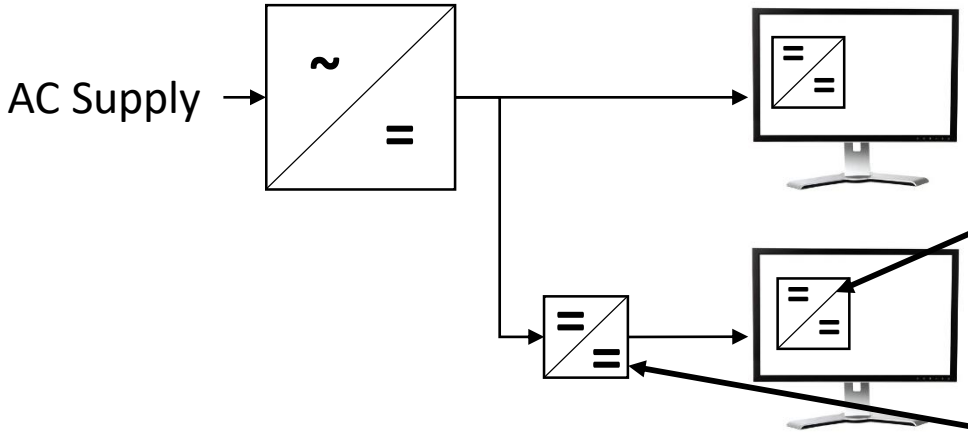
Devices Characterized

- **MELs Tested To Date:** 30 power converters, 38 appliances
- **Data Collected:** power in/out, harmonics, efficiency curves

Switch to DC: What Does this *Really* Look Like?

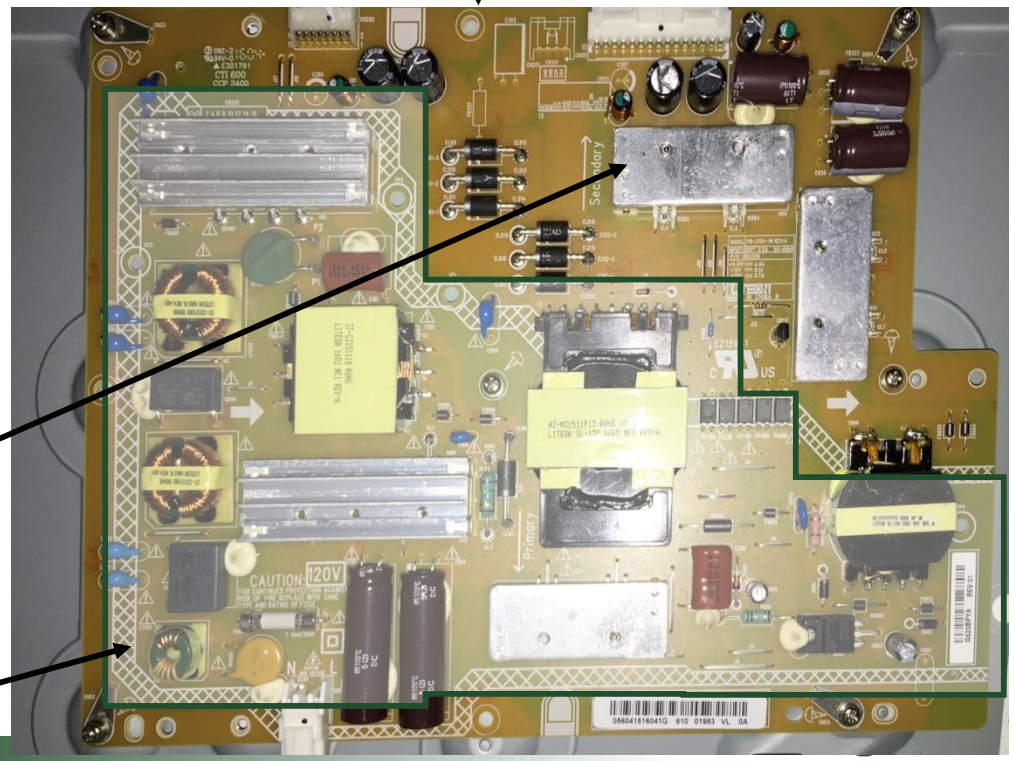


Theory



Practice

Power Supply



Secondary Supplies

Primary Supply

Building-Level Simulation: Harmonic Power Flow

- Assess efficiency of pure AC, DC, and hybrid AC/DC electrical distribution systems.

- **Requirements**
  - Enable fast, yet sufficiently accurate, simulation.
  - Capture losses resulting from harmonics and nonlinearities and unbalanced conditions.
  - Enable co-simulation of electrical and thermal effects.

- **Solution**
  - Simulation library implemented in Modelica modeling language.
  - Frequency domain analysis using harmonic power flow
  - Including nonlinearities and unbalanced conditions.
  - Modeling nonlinear transformer and converter impedances.

Library View and Example Circuit

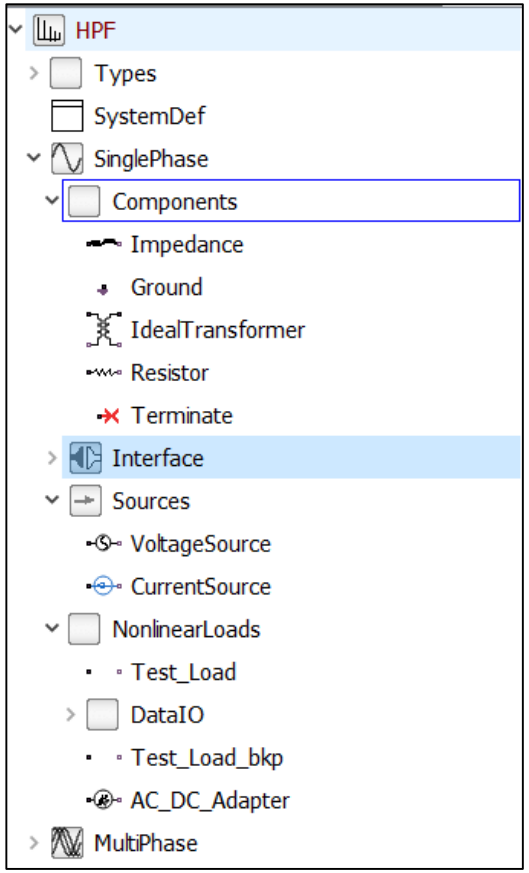


Fig. 1. Expanded view of library.

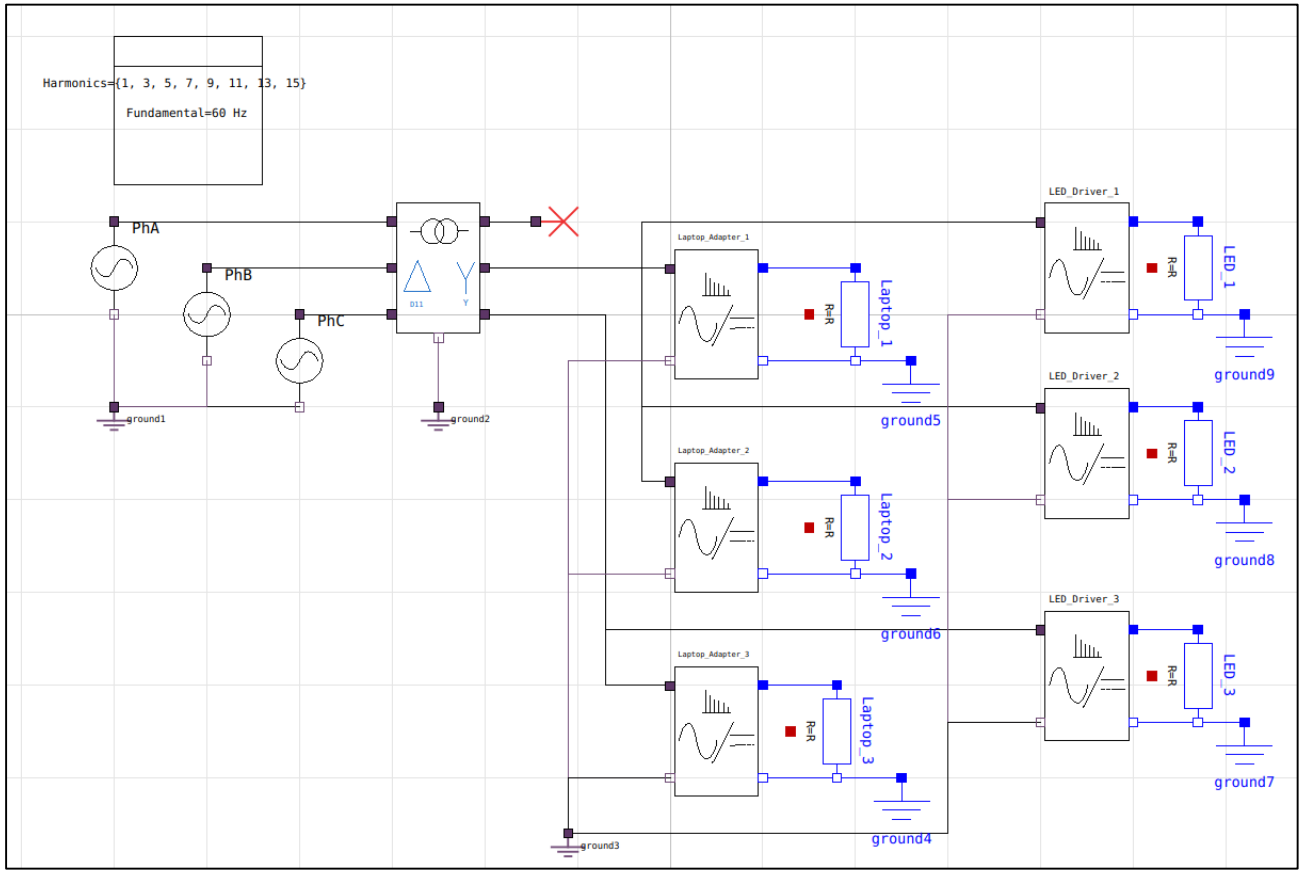


Fig. 2. Example circuit simulation for unbalanced transformer distribution.

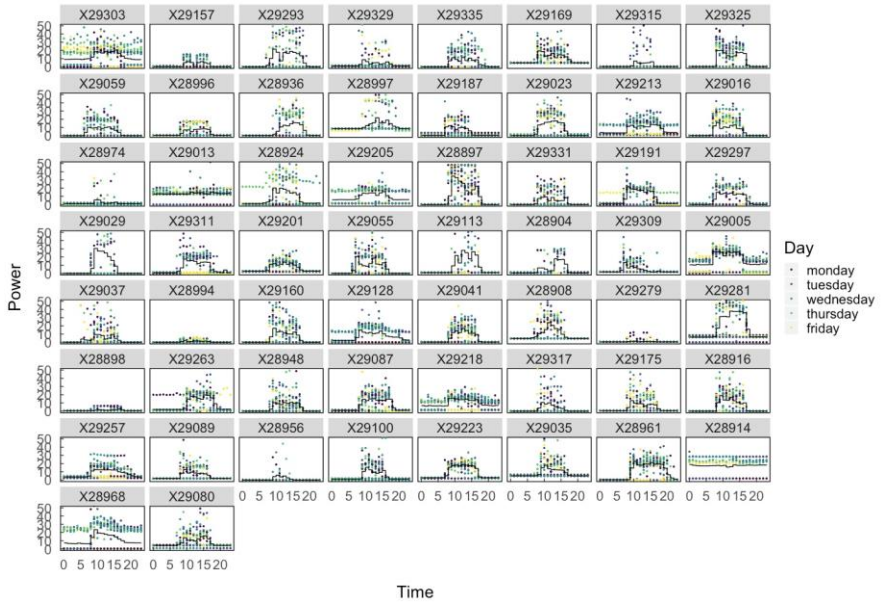
- Example circuit from the microgrid testbed constructed at CSU Powerhouse (unbalanced transformer).

Efficiency Change is a Mode X Time in Mode

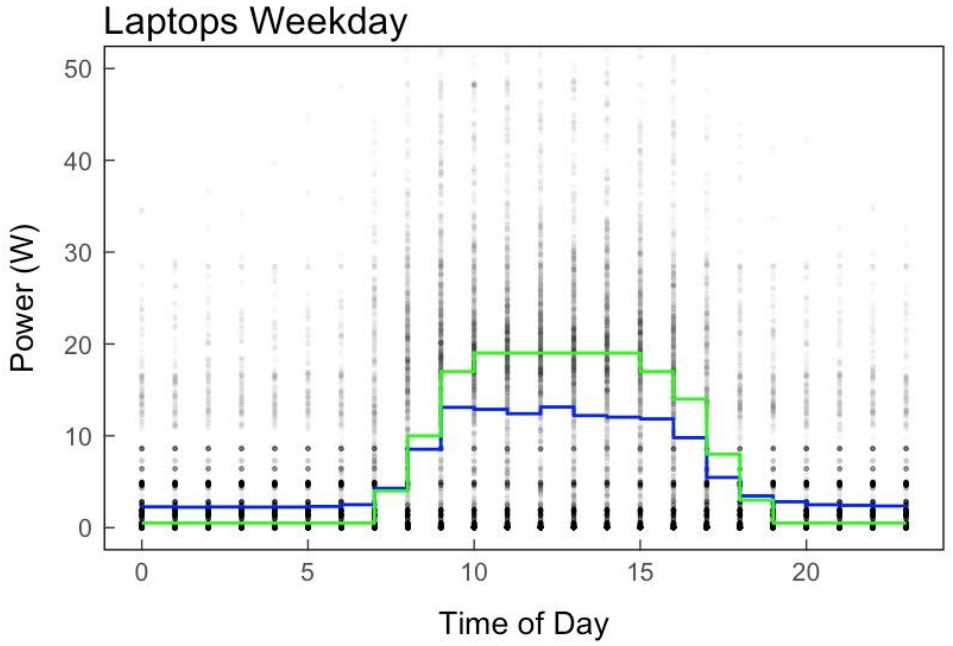
Sources for load profiles:

1. Smart plug data from NREL office building and a Walmart field study
2. New recordings in study buildings (locally networked WEMO plug meters)
3. Literature

Example of load profile development for Laptops:



First, look at all data for each device individually.



Then look at aggregated data and determine a load profile that makes sense. Blue is the average of all data; green is the manually selected load profile.

What Are We Seeing?

- Solid efficiency gain from converting MELs to DC (5-15%)
- No standards
  - No agreed voltage standards for distribution
  - No agreed power quality standards
  - No plug standards

Small AC/DC converters inject high harmonics into AC power systems (THD > 100%)

- Very immature market
  - Few appliances – have very few examples we can test
  - Resistance to installing

D. L. Gerber, V. Vossos, W. Feng, C. Marnay, B. Nordman, and R. Brown, "A simulation-based efficiency comparison of AC and DC power distribution networks in commercial buildings," Applied Energy, vol. 210, pp. 1167–1187, Jan. 2018.
V. Vossos, D. Gerber, Y. Bennani, R. Brown, and C. Marnay, "Techno-economic analysis of DC power distribution in commercial buildings," Applied Energy, vol. 230, pp. 663–678, Nov. 2018.
(additional conference presentations @ ICDCM 2019)

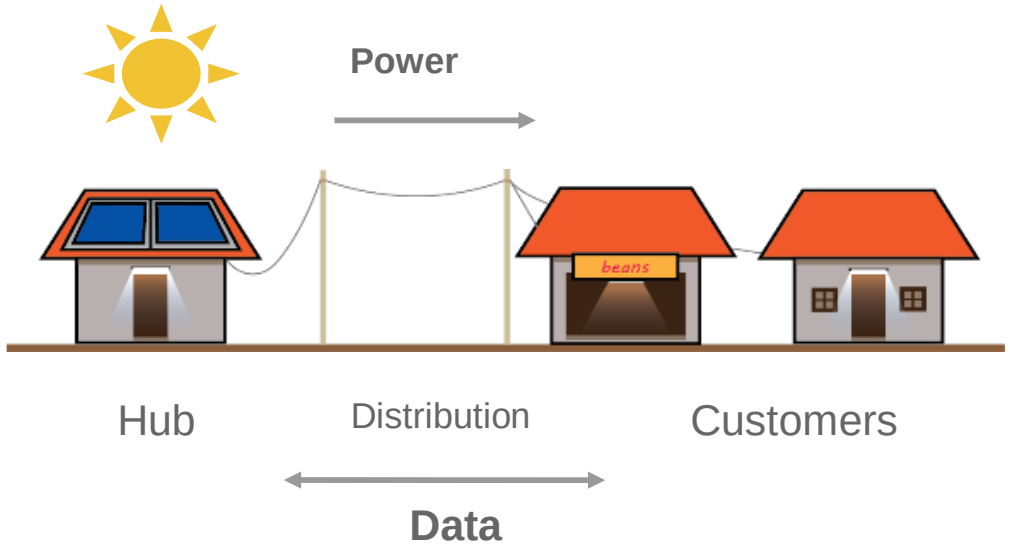
Developing World: Same Story / More Urgent

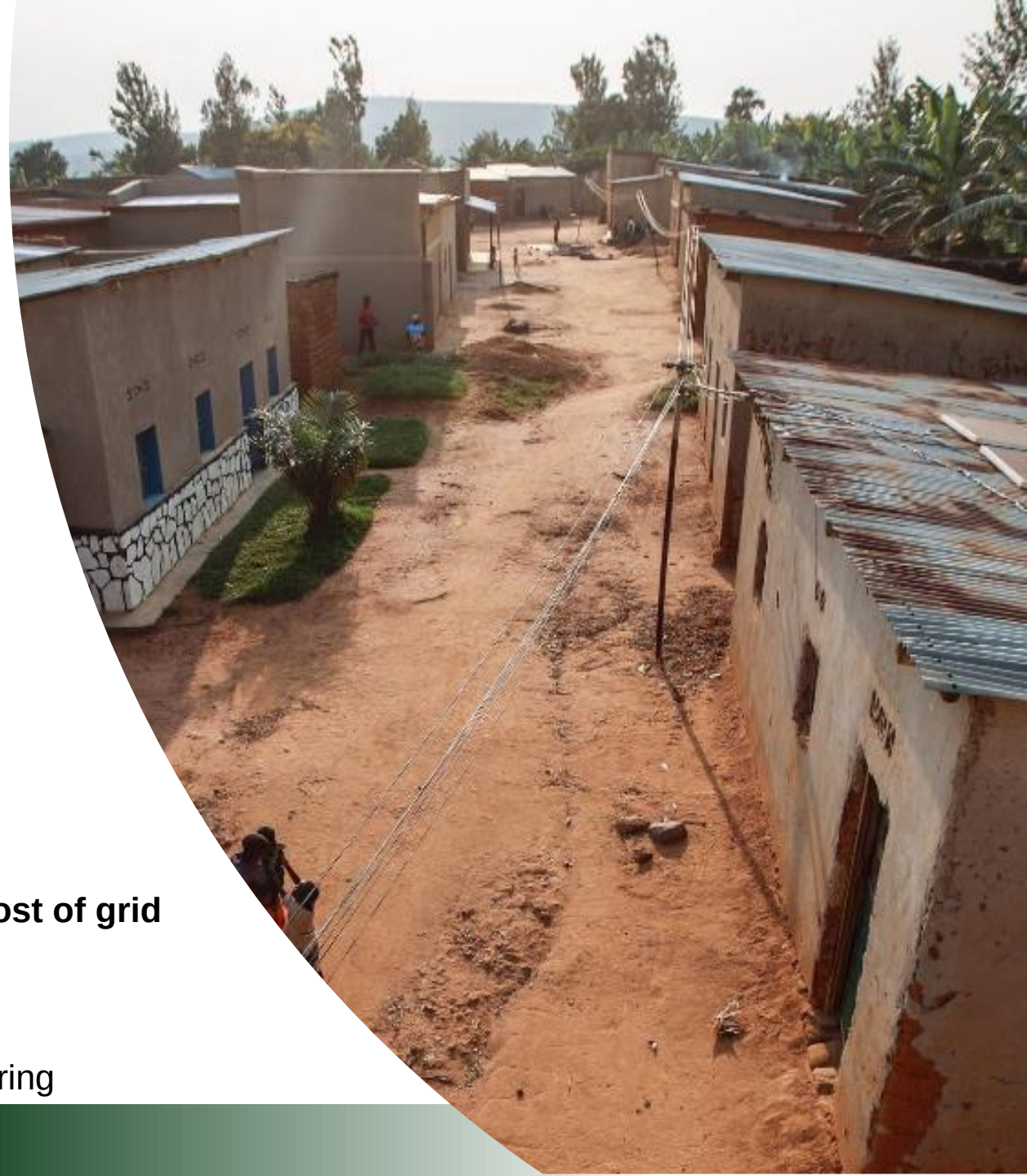
“ almost half of consumers are currently using **less than 20 kWh** per month … when a consumer would need to use approximately **130 kWh** per month in order to fund the cost of their own connection “

- Rural Electrification Strategy, Rwanda, 2016

And …. typical grid extension cost: $800-1200/connection

Low Cost / Low Voltage DC



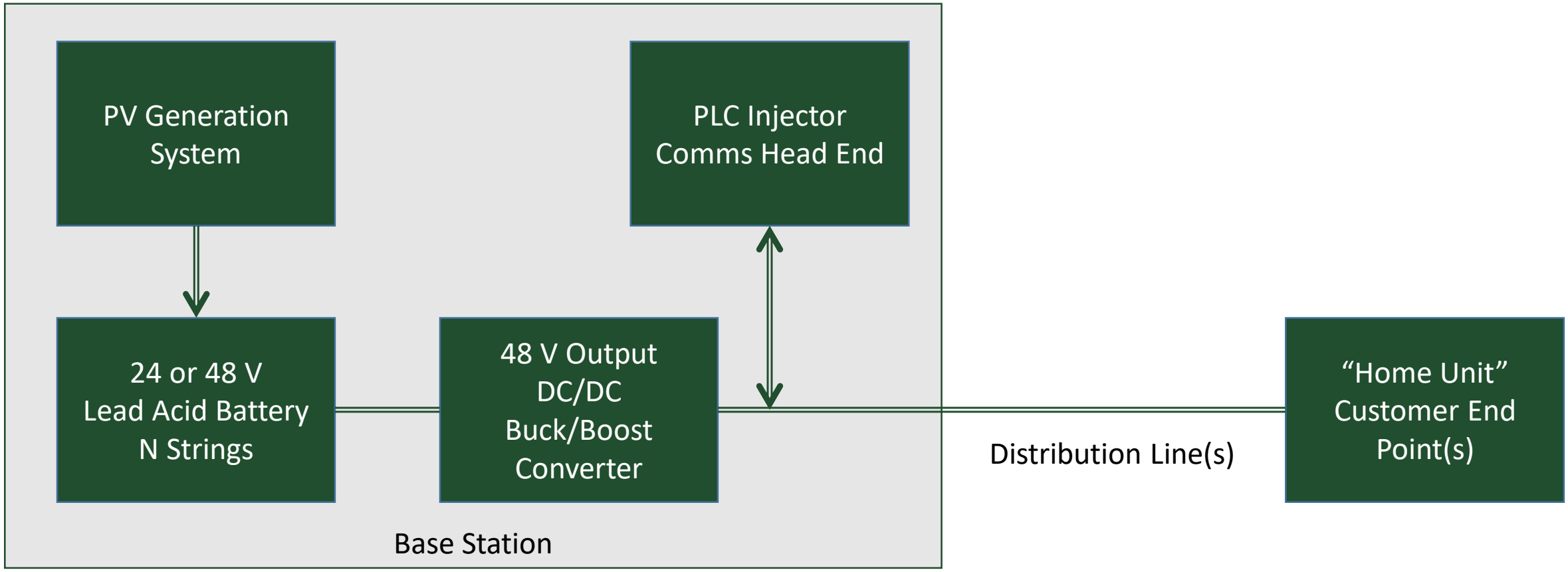


Smart, internet connected solar DC micro-grids ≈ 1/10th the cost of grid

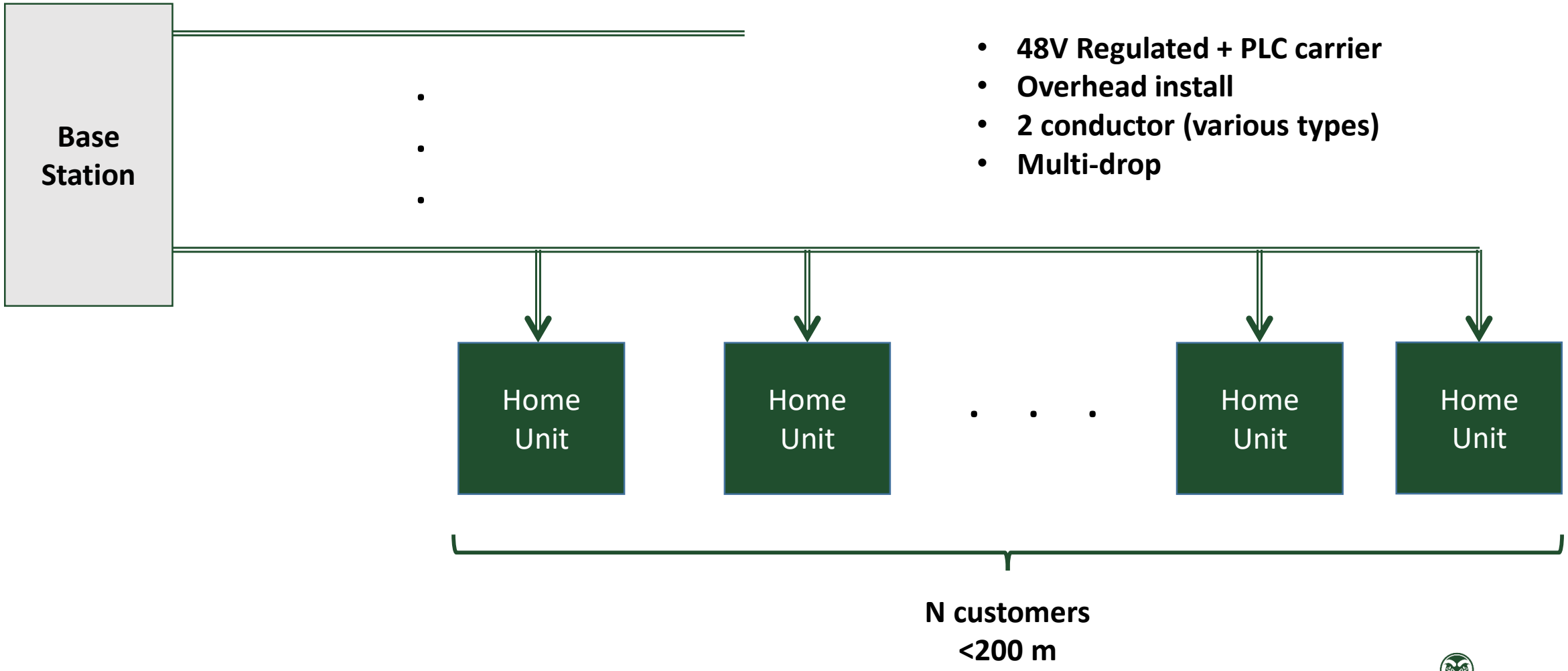
48V DC distribution – lower cost, touch safe, less complex

Electricity as a service – daily service fees instead of kWh metering

Basic System Architecture



Cabling Design



- 48V Regulated + PLC carrier
- Overhead install
- 2 conductor (various types)
- Multi-drop

Developing World? What are We Seeing?

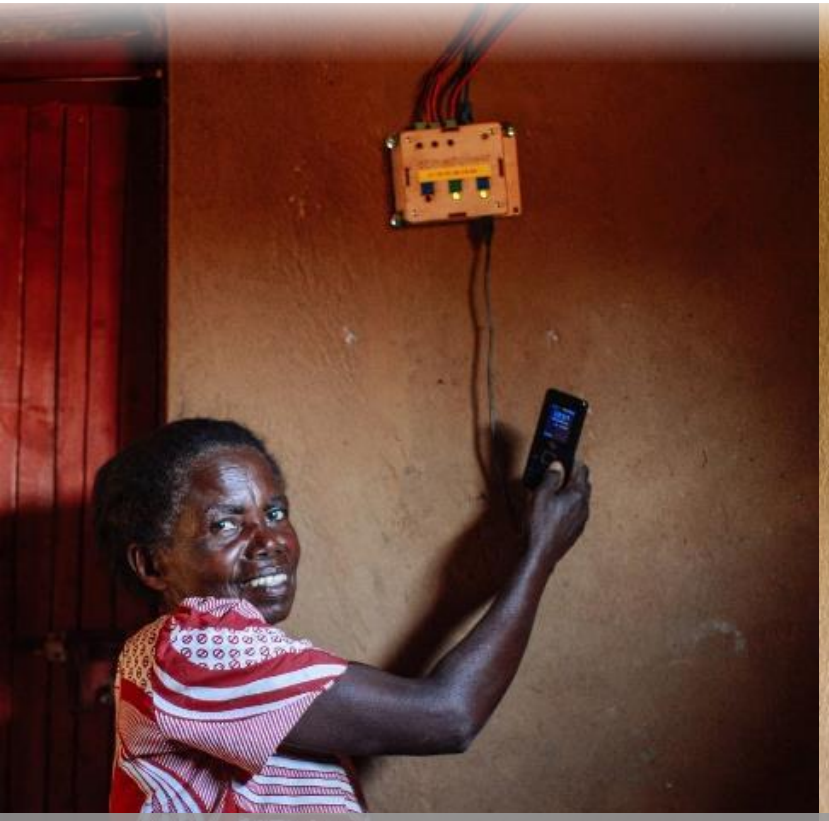
- Solid ~~efficiency~~ cost gain from converting to DC
  - $90/cx + lighting vs $300-400/cx for AC with no appliances

  … but limited power delivery
- Same problem of no standards: Increase appliance cost
  - No agreed voltage, power quality, or plug standards
- Very immature market
  - Few available appliances
  - ***Resistance to non-AC distribution by utilities …***

    poorly understood by utilities and their regulators

Hybrid AC/DC approach

A smarter micro grid that brings complete village connectivity at an unrivalled low cost



Low cost, 48V DC for households

- Electricity as a service
- Low cost connections
- Quick payback (2-3 years)

High power AC for productive uses

- Target high revenue connections
- Support economic development for future growth

Village-wide internet access for all

- Low cost revenue stream
- Long term resiliency, even with grid expansion

Thank You

Contact

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