The 3rd IEEE International Conference on DC Microgrids

May 20-23, 2019

Matsue, Japan

An Efficiency-Focused Design of Direct-DC Loads in Buildings

Daniel Gerber, Richard Liou, Richard Brown
dgerb@berkeley.edu
Berkeley, CA, USA

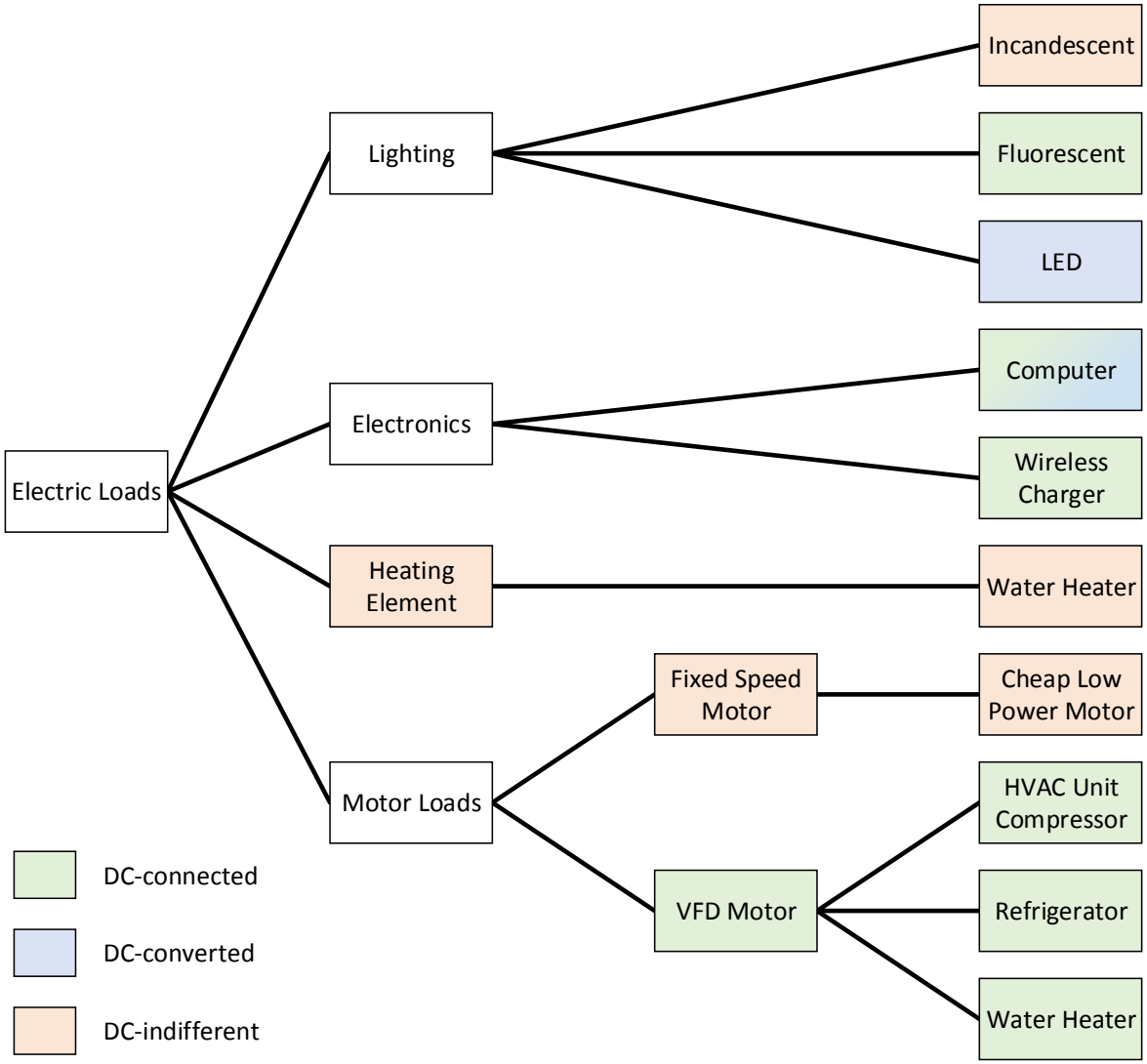
DC Microgrids in Buildings

Motivation

- DC buildings are efficient
  - Up to 14% more efficient than AC
  - Most loads are internally DC
- Barriers to entry
  - Lack of DC loads on the market
  - Many 380 V DC demonstrations use loads that are not designed for 380 V
- This work explores how DC loads can be designed to leverage the benefits of DC distribution

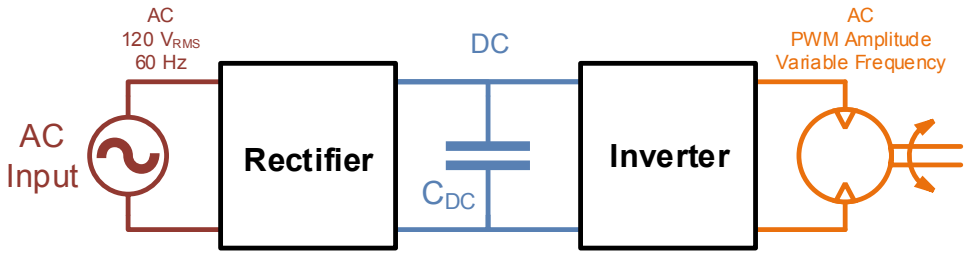
Categories of Loads

- **DC-connected:** Internal DC stage of these loads can be connected or hardwired directly to the DC distribution
- **DC-converted:** Requires a DC/DC converter in order to connect to the DC
- **DC-indifferent:** Equivalent benefits with AC or DC input

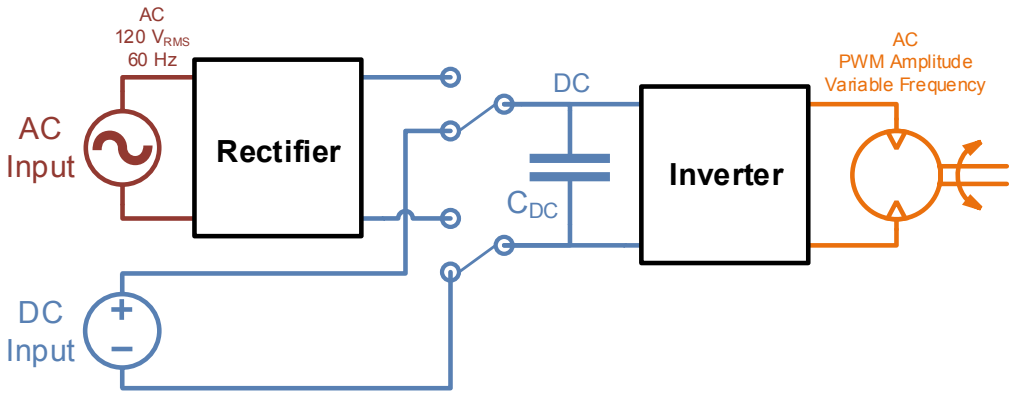


Motor Loads – BLDC Motors

- The most efficient motor loads use variable speed drive brushless DC (BLDC) motors
- AC BLDC motors have a rectifier, internal DC capacitors, and inverter
- The internal DC caps can connect directly to DC distribution, avoiding the rectification stage



AC BLDC Motor Load

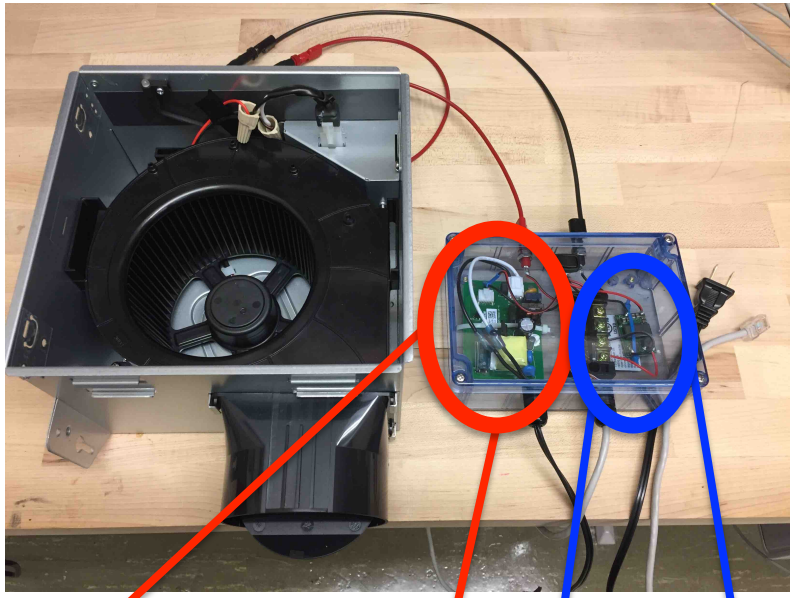


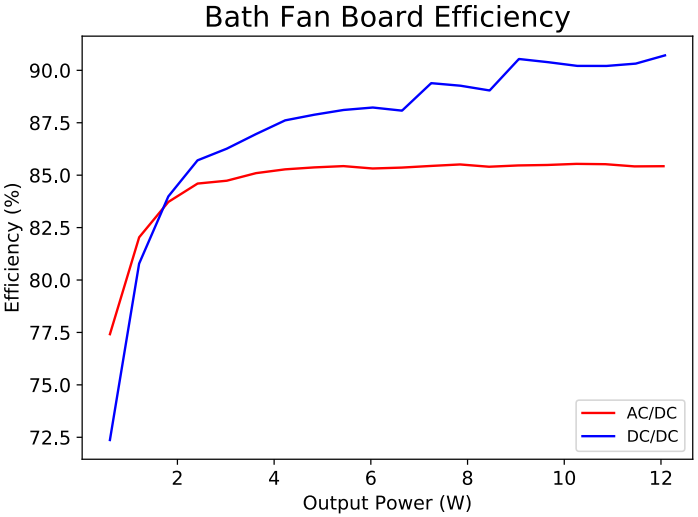
Internal DC Caps can connect to DC distribution

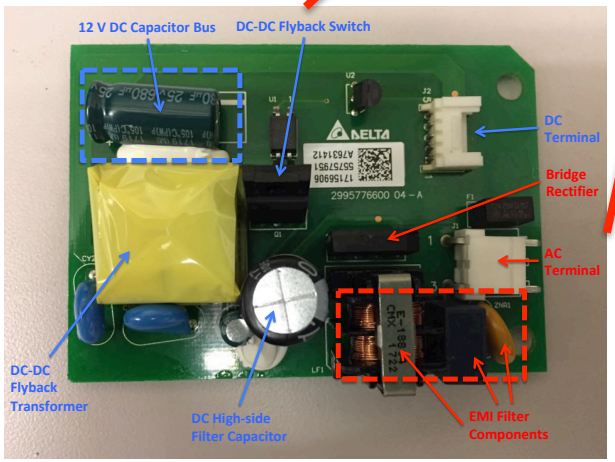
Motor Loads – Bath Fan

- Internal DC bus: 12 V
- Modify for 48 V PoE input

1. Use a 48/12 V DC/DC converter: -4% consumption
2. Redesign inverter/motor for 48 V: potentially -14% consumption

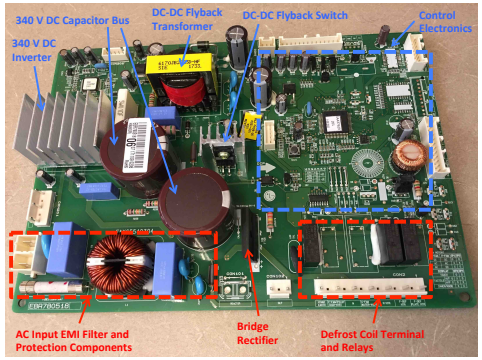




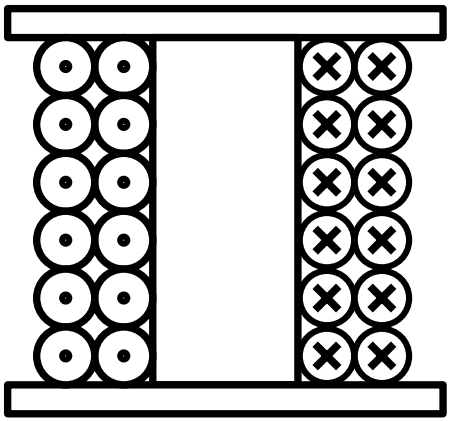


Motor Loads – DC Bus Voltage

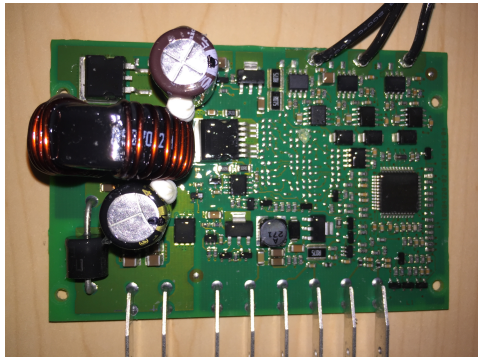
- No need for DC/DC converter if DC bus voltage equals DC distribution voltage
- BLDC motors can be redesigned for any DC bus voltage
  - Replace inverter if needed
  - High-voltage motors will use thinner wire and more turns on the stator coil
  - Winding area and loss is equivalent



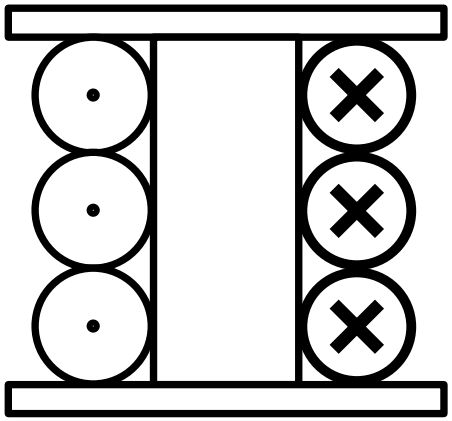
340 V Inverter Board



High-voltage DC bus



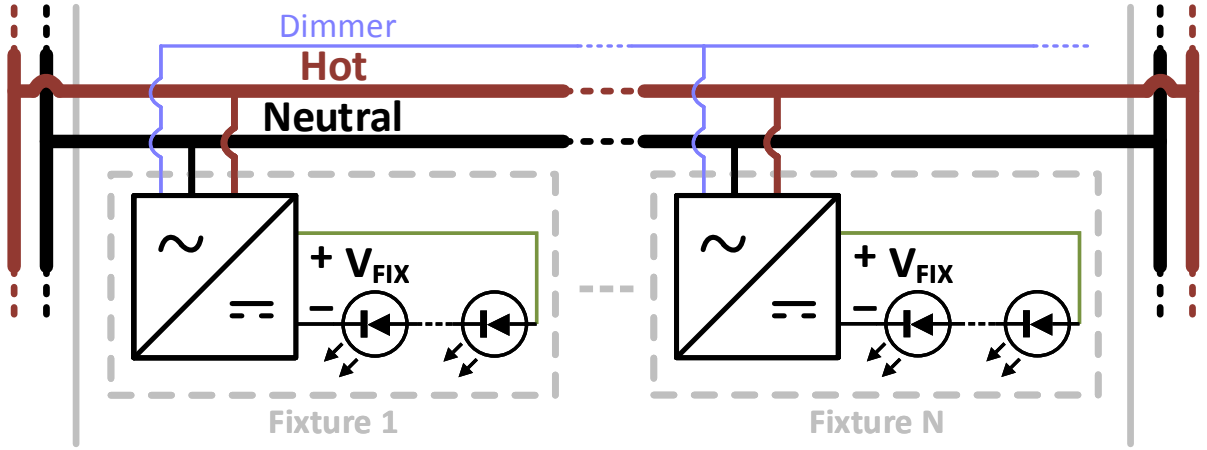
24 V Inverter Board



Low-voltage DC bus

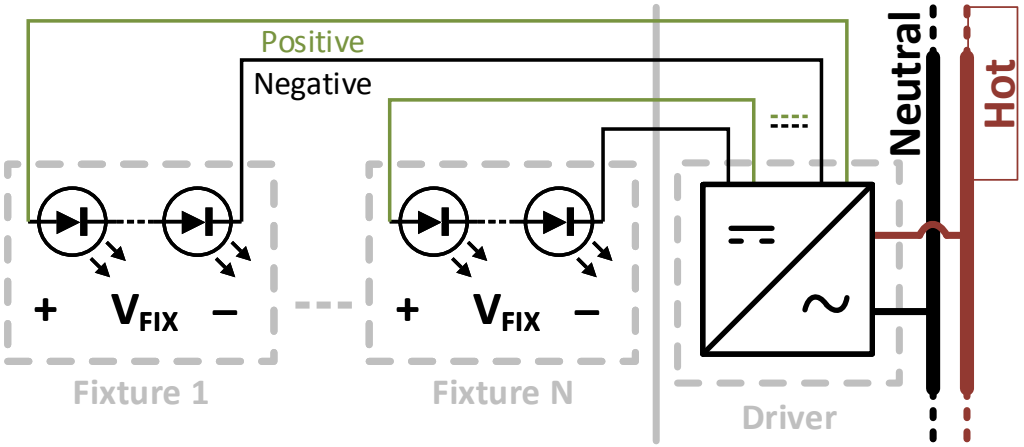
Lighting – Today's Integration Paradigm

- Most LED drivers are integrated into bulb, allows plug-and-play
  - Pros:
    - Plug-and-play compatibility
  - Cons:
    - High conversion ratio is inefficient
    - Components must tolerate high voltage: bulky and expensive
- The problems of integration are even worse at 380 V DC
- We propose (1) remote drivers, (2) series fixtures



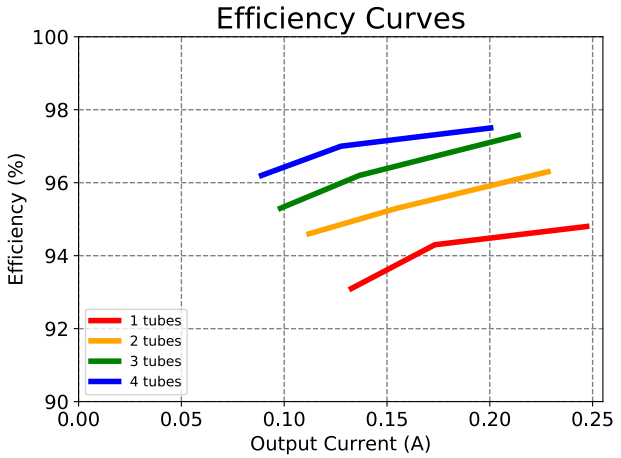
Lighting – Why Remote Drivers?

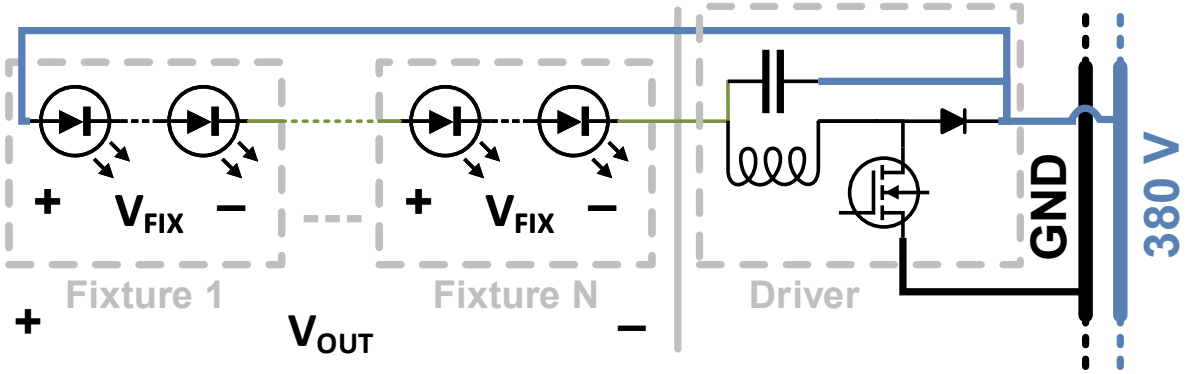
- Reduces life-cycle cost by up to 58%
  - Separating the driver from the fixture doubles the fixture's life span (40%)
  - Clever driver placement reduces maintenance costs for replacing light bulbs, especially in high bay (30%)
- Easy to add ancillary services
  - Wireless dimming
  - Battery backup
- Most remote drivers on the market wire fixtures in parallel



Lighting – Why Series Fixtures?

- Reduces life-cycle cost (10%-20%)
  - One driver powers many fixtures
- Improves efficiency (>98%)
  - Can stack fixtures such that N*V_{FIX} is close to 380 V
  - In prototype, adding extra bulbs increased efficiency from 94% to 98%





Conclusion

- Design DC loads to avoid unnecessary conversion stages
- Motor loads can be easily redesigned with any DC bus voltage
- Zone lighting at 380 V can benefit from series remote drivers

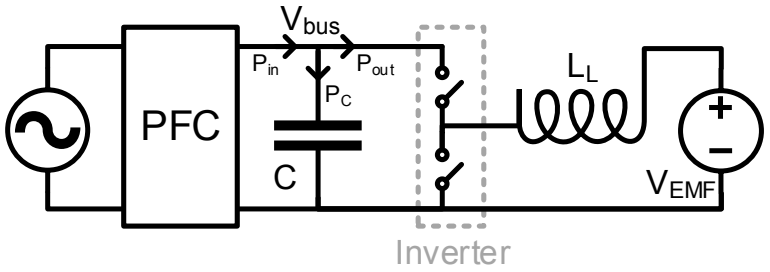
Thank you!

Project Goals

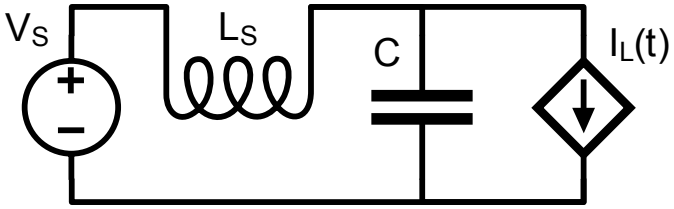
- Categorize loads based on how they benefit from DC
- Modify several AC loads for DC input and demonstrate reduced consumption
- Determine how to optimally design various classes of loads for DC input

Motor Loads - Sizing the DC Capacitors

- Reasons for DC capacitors
  - Filter PWM ripple (20-100 kHz)
  - Provide a buffer for transients in load current
  - Filter 120 Hz AC ripple from the DC bus
- DC loads do not need to filter 120 Hz AC ripple
- DC loads allow for smaller DC capacitors for both motor loads and lighting



Model to analyze AC and PWM ripple

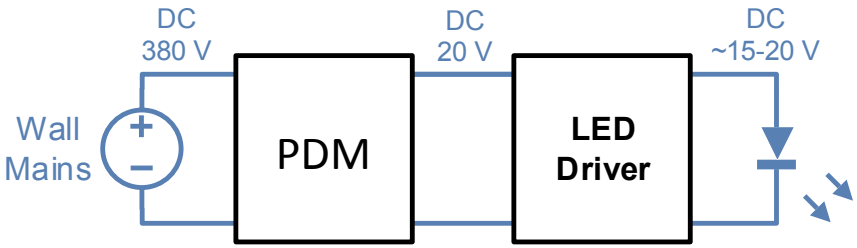


Model to analyze load transients

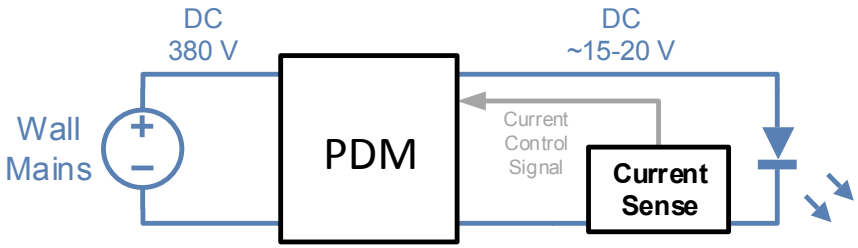
C (uF)	AC Ripple (V)	PWM Ripple (V)	Transient Ripple (V)
10.0	78.02	3.32	0.82
100.0	7.8	0.33	0.26
1000.0	0.78	0.03	0.08

Lighting – Low Voltage

- Many task lamps or PoE fixtures have their own integrated LED drivers
  - Two conversion stages: power distribution module (PDM) and LED driver
- Allowing the PDM to act as an LED driver reduces conversion stages
- USB task lamp
  - USB charging station acts as LED driver
  - Uses Qualcomm quick charge to control current



Fixture with integrated LED driver



PDM acts as LED driver

Bypass Circuit