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

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

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LBNL BTUS Brownbag Seminar
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

![Diagram of categories of loads](image)
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
Motor Loads – Bath Fan, Refrigerator

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Motor Load Components:
- 12 V DC Capacitor Bus
- DC-DC Flyback Transformer
- Bridge Rectifier
- EMI Filter Components
- DC Terminal

Motor Load Boards:
- Fan AC/DC Board
- AC/DC Components
- Fan DC/DC Board
- 340 V DC Refrigerator
- 24 V Refrigerator Board

Motor Load Diagrams:
- Refrigerator
- Fan

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Lighting – Task Lamp, Zone Lighting

Task Lamp
USB charger acts as LED Driver

Zone Lighting
Series fixtures improve efficiency by 6%

Wall Mains
DC 380 V

Desktop USB-C Charging Station
Current Sense

DC ~15-20 V

Fixture 1
+V_{\text{FIX}} -

Fixture N
+V_{\text{FIX}} -

Driver

V_{\text{OUT}}

380 V
Conclusion

• Design DC loads to avoid unnecessary conversion stages
• DC-connected is best, DC-converted is also ok
• Motor loads can be easily redesigned with any DC bus voltage
• Task lamps can use power supply as LED driver
• Zone lights can be strung in series for savings
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 – 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

Bath Fan Board Efficiency

![Graph showing efficiency vs. output power for AC/DC and DC/DC converters]

Motor Diagram:
- Components labeled: 32 V DC Capacitor Bus, DC-DC Flyback Switch, DC Terminal, Bridge Rectifier, DC-DC Transformer, EMI Filter Components.
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
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

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<th>Transient Ripple (V)</th>
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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

![Diagram of LED lighting system]

DC 380 V
PDM

DC 20 V
LED Driver

DC ~15-20 V

Wall Mains

Fixture with integrated LED driver

PDM acts as LED driver

DC 380 V
PDM

Wall Mains

Current Sense

Current Control Signal
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 $N \times V_{\text{FIX}}$ is close to 380 V
  – In prototype, adding extra bulbs increased efficiency from 94% to 98%

![Diagram of series fixtures](image)

![Efficiency Curves Graph](image)
Bypass Circuit

\[ + \quad V_{\text{FIX}} \quad - \]