Center for Power Electronics Systems
Bradley Department of Electrical and Computer Engineerung
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CPES Initiative on Sustainable Buildings and Nanogrids

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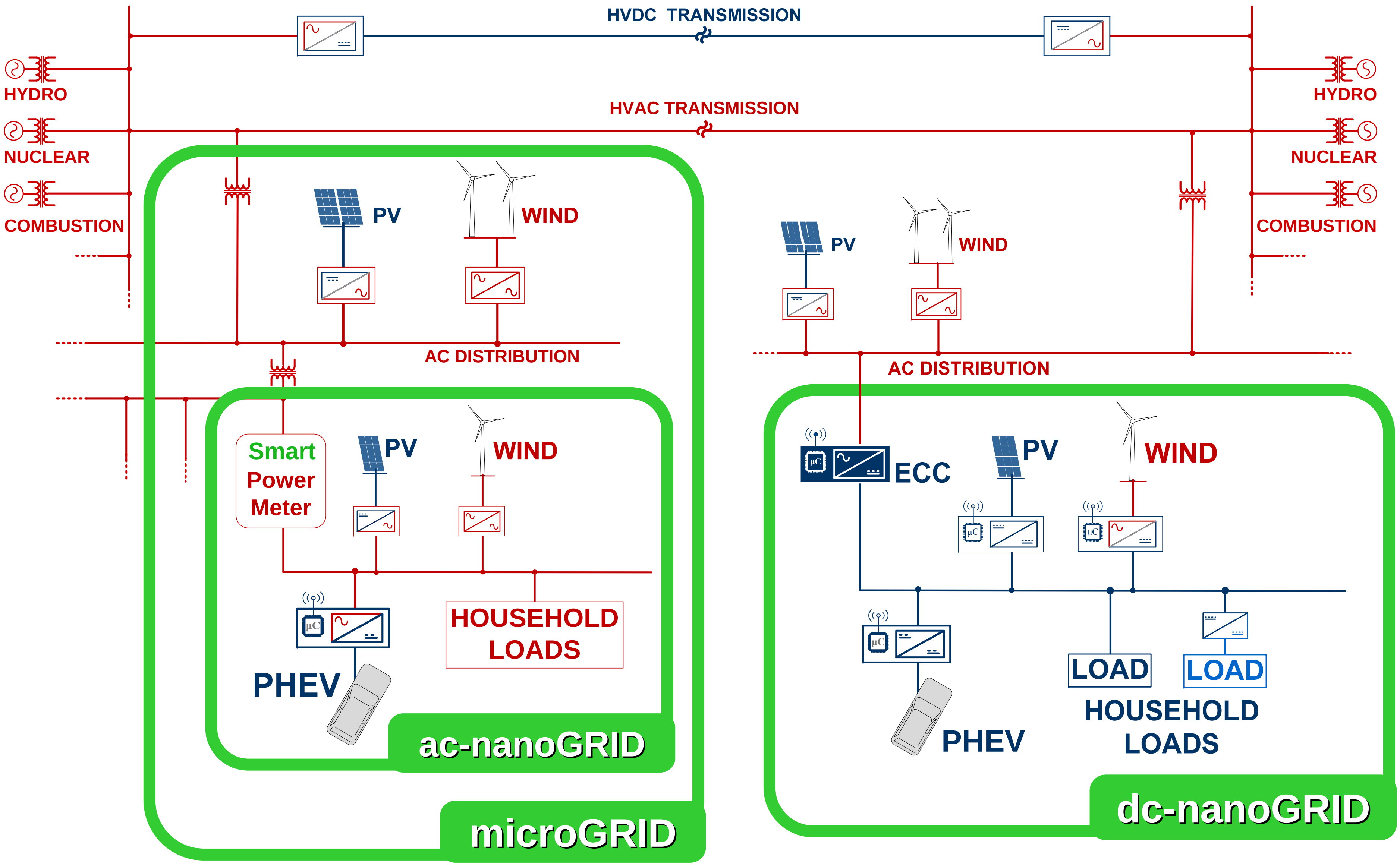
presentation to

2011 APEC: Special Presentation Session on

Power Electronics and Alternative Energy

DC-based Nanogrid System



Sustainable Buildings

Objective

Apply power electronics to future residential and commercial buildings to enable

major improvements in

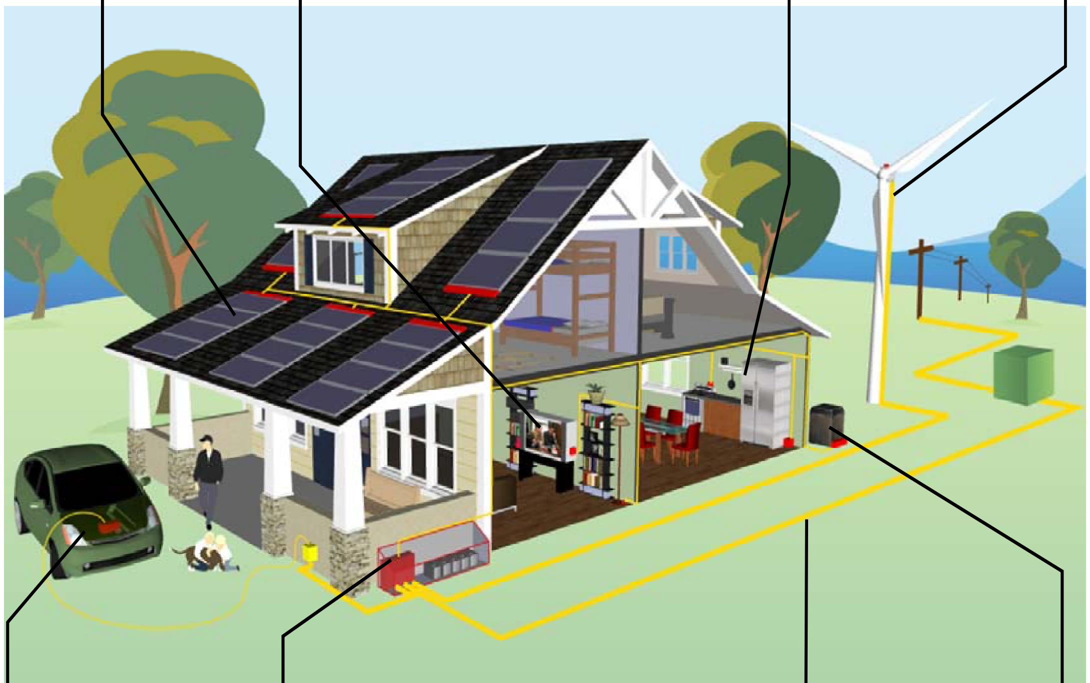
energy efficiency and sustainability

while

minimizing cost and maximizing reliability.

CPES

Mini-Consortium for
Renewable Energy and Nanogrids (REN)



Work Scope

- PV System
- Plug-in Hybrid Electric Vehicles / Battery Storage
- Wind Power
- Energy Management for the Nanogrid
- AC Nanogrid
- DC Nanogrid
- Solid State Lighting

Current Principal Plus Members in this area:

DELTA, CEI, NISSAN, GE Energy, SIEMENS

Research Sponsors

CPES Industry Consortium, NSF, BOEING, VPT Energy Systems, VirginiaTech College of Engineering, ICTAS, Whirlpool, NATIONAL INSTRUMENTS, CLEANFIELD ENERGY

CPES

Mini-Consortium

Power Management Consortium (PMC)

(1998 – present)

Chicony POWER TECHNOLOGY

CRANE AEROSPACE & ELECTRONICS

DELTA

IOR International Rectifier

Work Scope:

- Devices and Magnetics
- Modeling and control (analog & digital)
- 3D integration
- High performance VRM/POL converters
- DC/DC converters and Bus converters
- EMI and PFC
- Power architecture and management

intersil

NXP

LITEON

mps Monolithic Power Systems

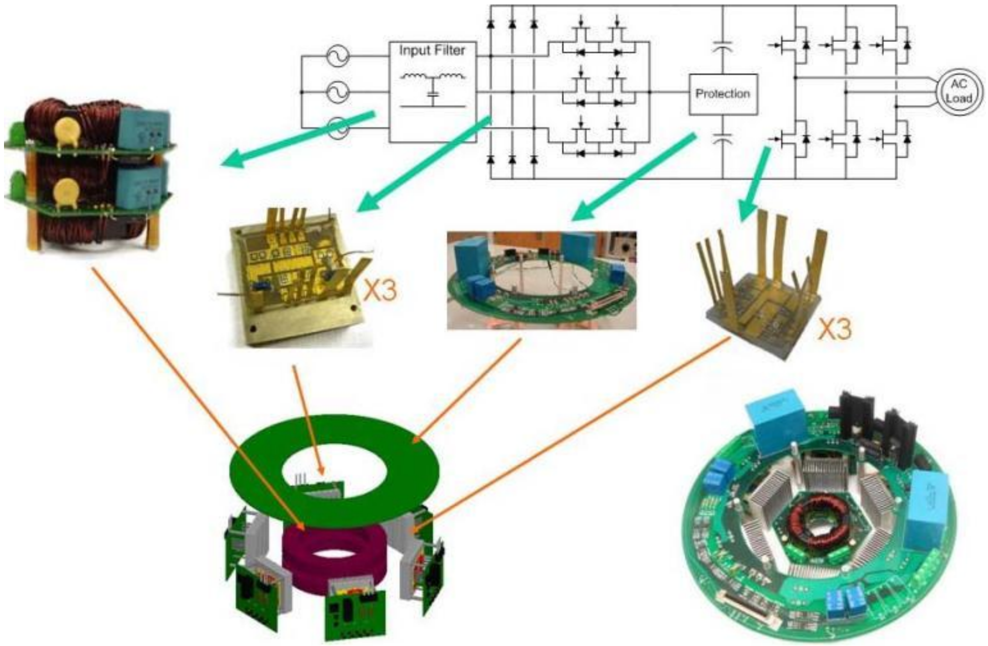
LINEAR TECHNOLOGY

RICHTEK

National Semiconductor The Sight & Sound of Information

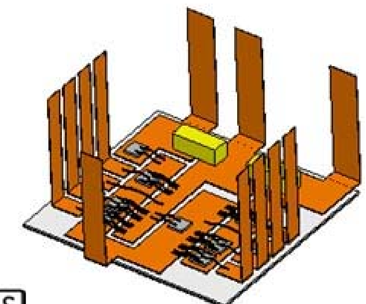
TEXAS INSTRUMENTS

Mini-Consortium for
High Density Integration (HDI)



Work Scope:

- High-Temperature Integration Technologies
- Components
- Module-Level Integration
- System-Level Integration



Current Principal Plus Members in this area:

ALSTOM
CRANE AEROSPACE & ELECTRONICS
SAFRAN
GE Global Research
ROLLS ROYCE
United Technologies Research Center

Research Sponsors

CPES Industry Consortium
NSF
ONR
BOEING
ROLLS ROYCE
GE Global Research
CRANE AEROSPACE & ELECTRONICS
arpa·e Advanced Research Projects Agency • ENERGY
United Technologies Research Center

Sustainable Building Design Initiative
Renewable Energy DC Nanogrid

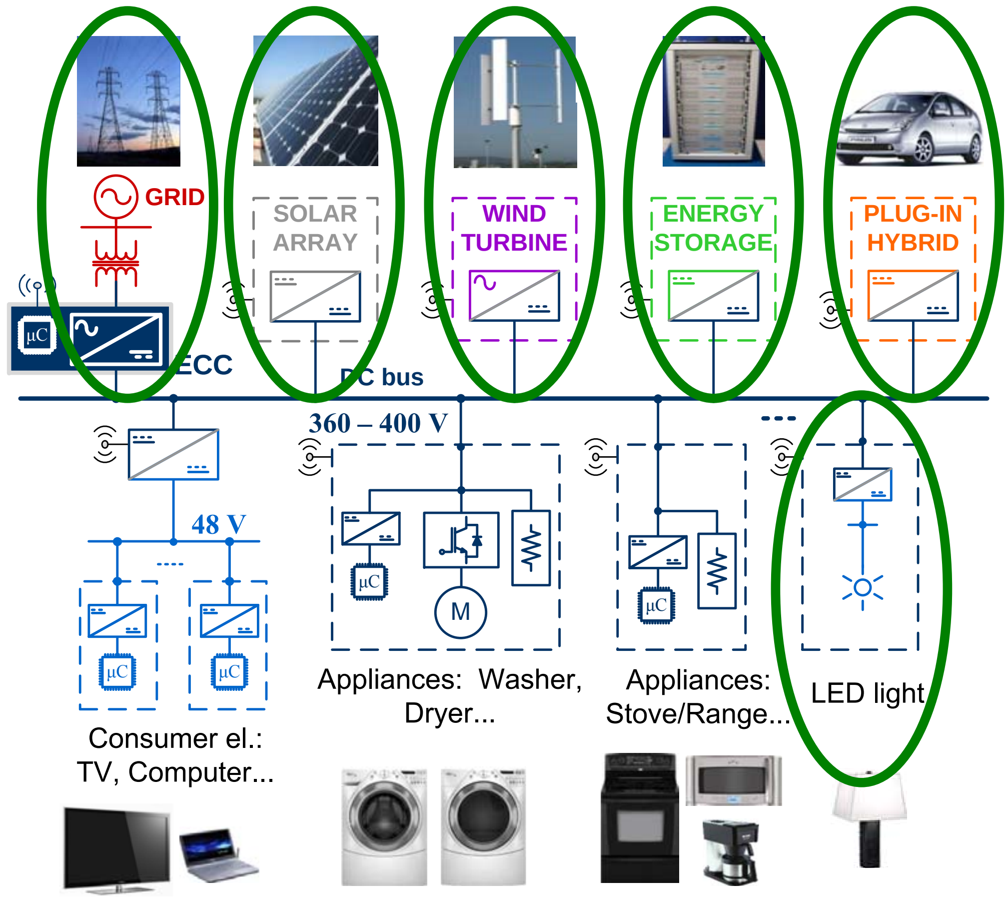
Objectives

- DC-based power architecture (bus structure)
- Decoupled dynamics from grid
- Islanded operation
- Bidirectional power conversion
- Zero-net annual energy cost
- Dispatchable generation / consumption

Challenges

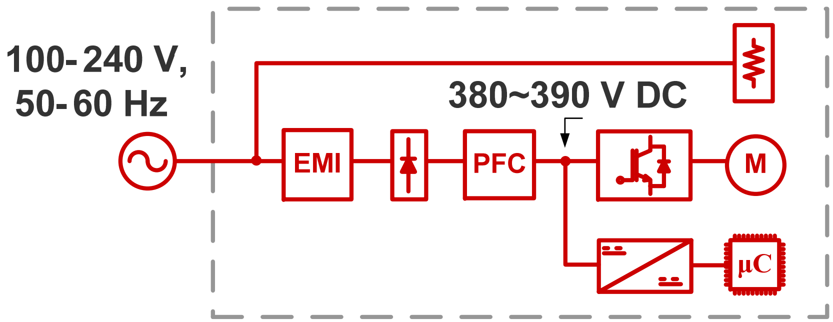
- Power management
- Wireless communication
- Integrated protection
- Breakerless system
- Grounding, EMI, & power quality
- Safety

Droop-based Continuous Power Sharing and Automatic Prioritized Energy Use Optimization



Safe, Efficient, Convenient, Aesthetic, and Enjoyable Appliances and Ambient

Voltage Levels in the DC-Nanogrid System

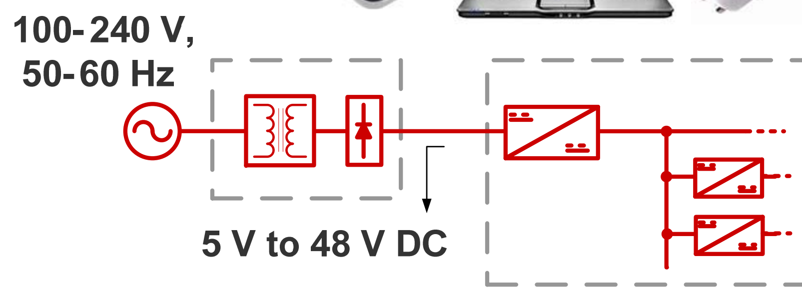


High power appliances:

Wide input voltage range 100 V to 240 V AC (Japan to Europe) →
Rectified max = 340 V DC →
PFC output ≈ 380 - 390 V DC

Chosen is **380 V** as the nominal voltage of the bus

Standard - EPRI ELECTRIC POWER RESEARCH INSTITUTE



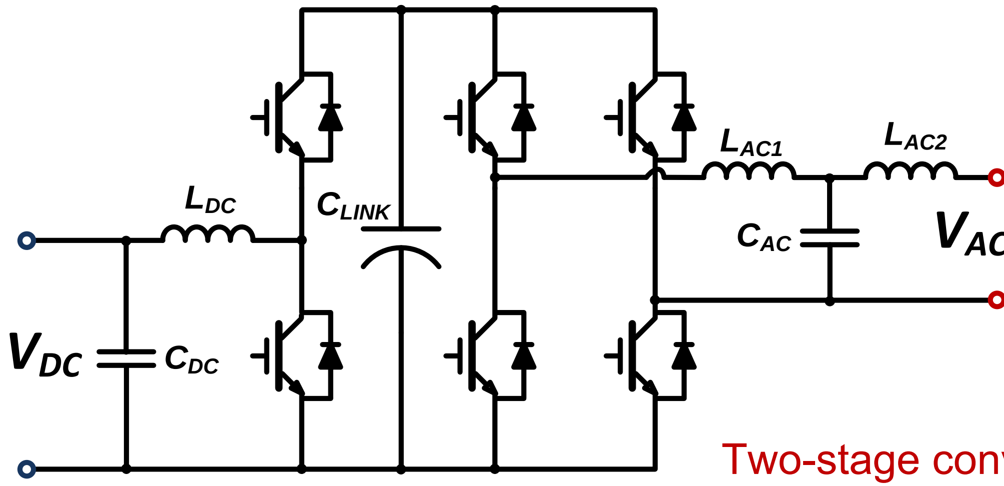
Low power consumer electronics:

Low, safe touch voltage < 50 V DC
…5 V,…19 V,… 24 V,… 48 V

Chosen is **48 V** as the nominal voltage for the low voltage local distribution

Standard - EMerge ALLIANCE

Bi-directional Grid Interface Converter



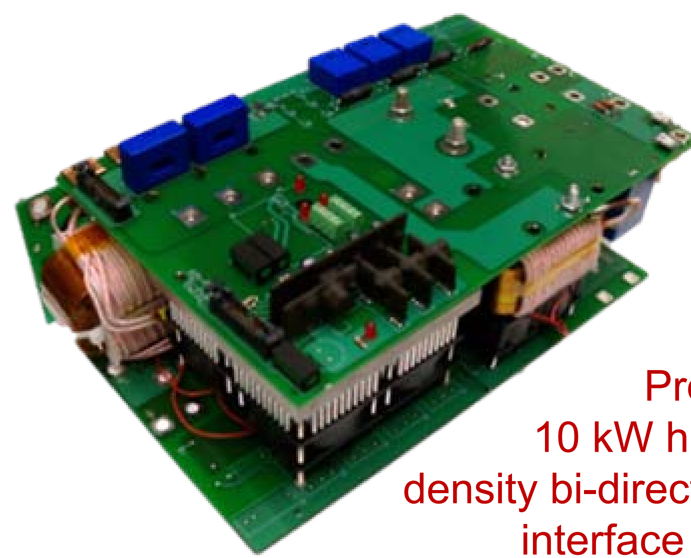
360-400 V DC Bus with droop regulation and short-circuit current limiting

240 V, 60 Hz, 1Φ Grid with dispatchable active & reactive power and short-circuit current limiting

Two-stage converter using low-cost 3Φ motor-drive IPM

Features

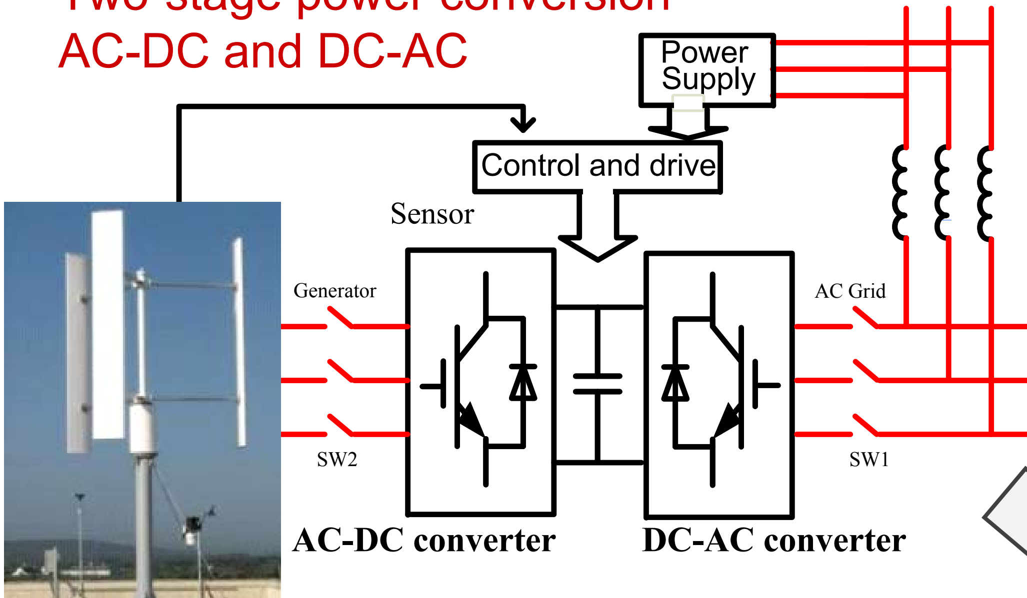
- Large dc-link voltage variation
- Small dc-link capacitor
- Soft-start on both sides
- High performance PLL
- Fast dc voltage & ac current control
- Full EMI compliance on both sides
- Small CM voltage on both sides



Prototype of 10 kW high power density bi-directional grid interface converter

Wind Turbine

Conventional structure:
Two-stage power conversion
AC-DC and DC-AC



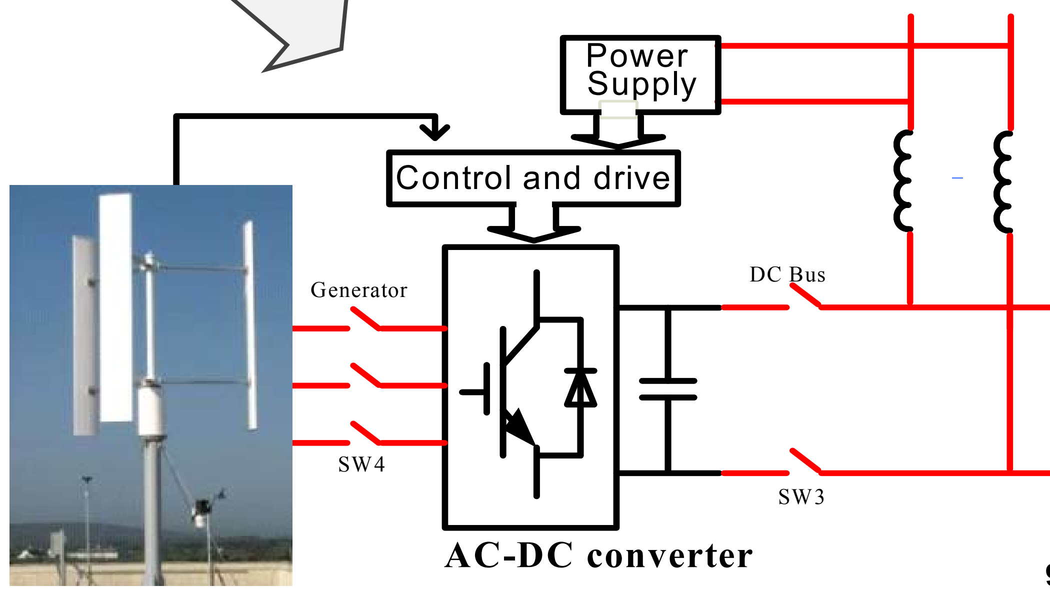
Vertical-axis Cleanfield Energy Wind Turbine

Turbine	Generator
Height: 3.11m Weight: 130kg 3 Blades	3-phase PMG Phase voltage: 120VAC Rated/max speed: 170/250 rpm Rated/max power: 3.5/5 kW

Feature

Ability to regulate output voltage in stand-alone (islanded) operation

New structure:
AC-DC converter
for the Nanogrid System

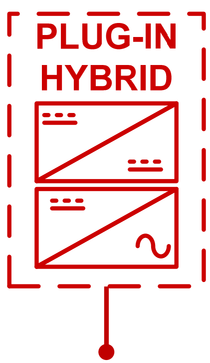


Sustainable Building Design Initiative

Plug-in Hybrid Electric Vehicle

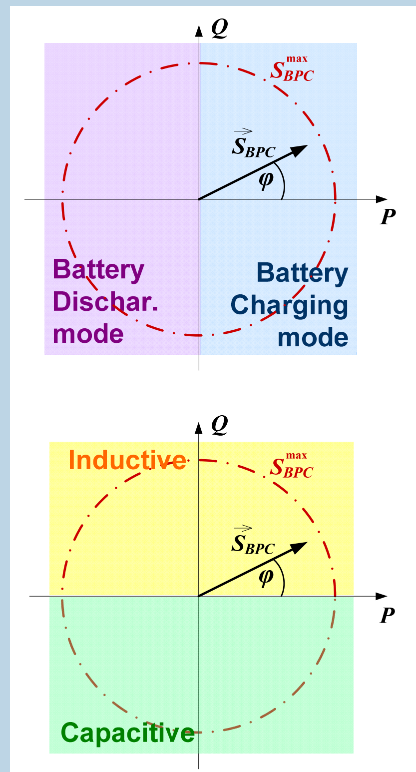
Demonstrated V2G technology in an AC Nanogrid System

Conventional structure:
Two stage bidirectional power conversion DC-DC and DC-AC

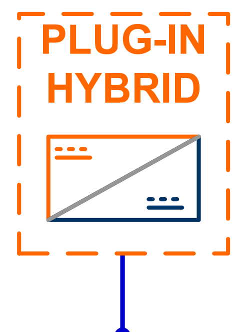


AC Grid

Dispatchable Active & Reactive power



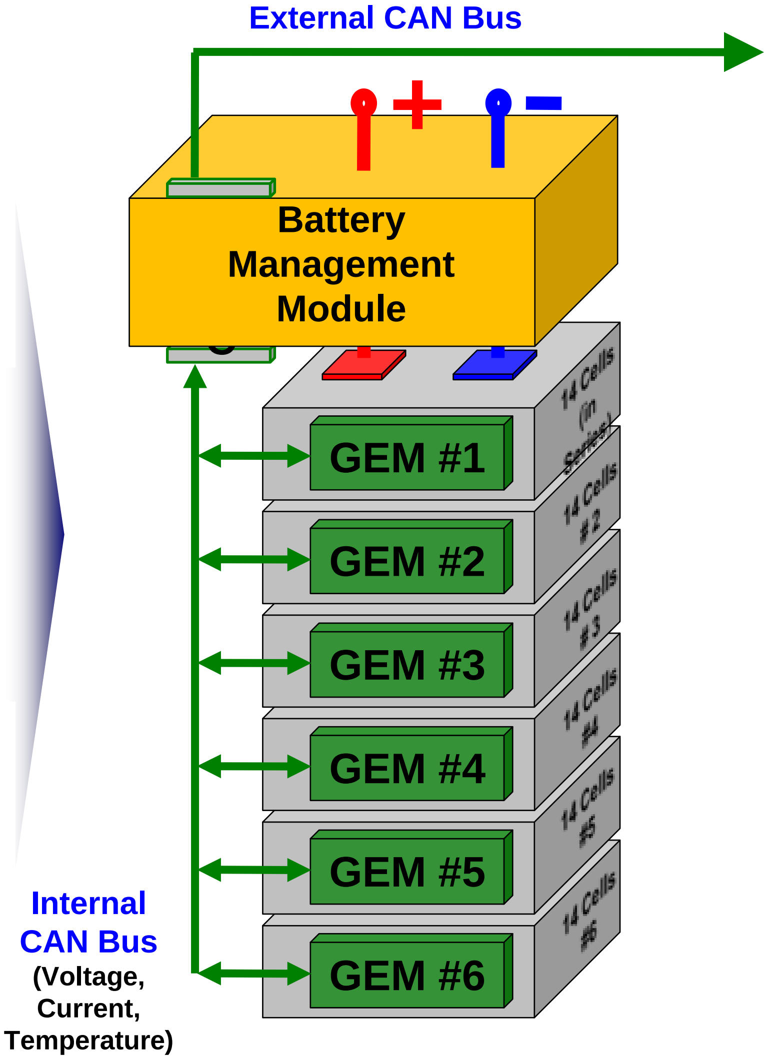
Future plans:
High Power Density Bidirectional DC-DC Converter

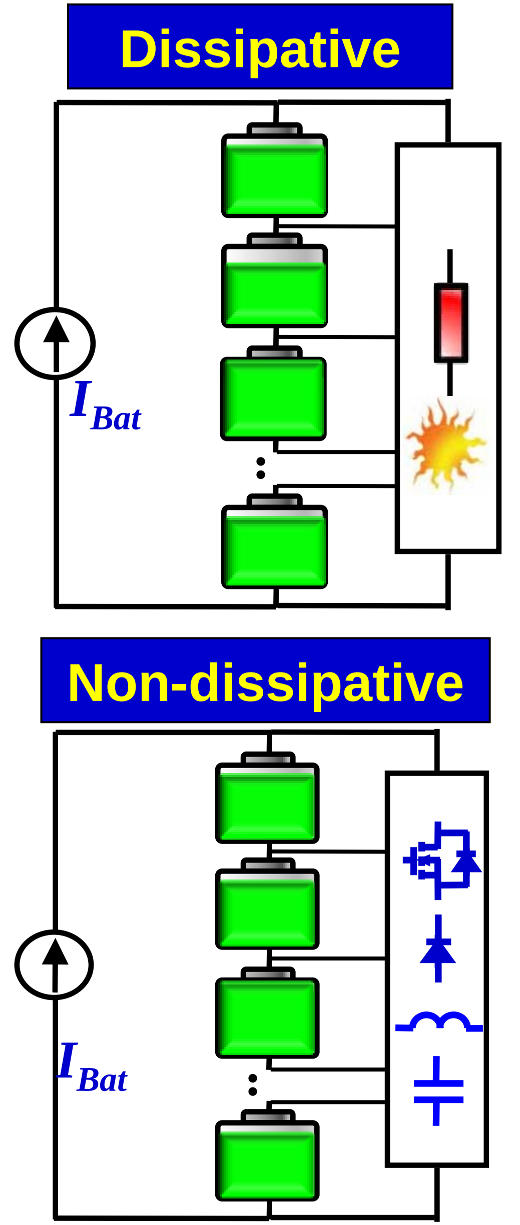


DC Nanogrid

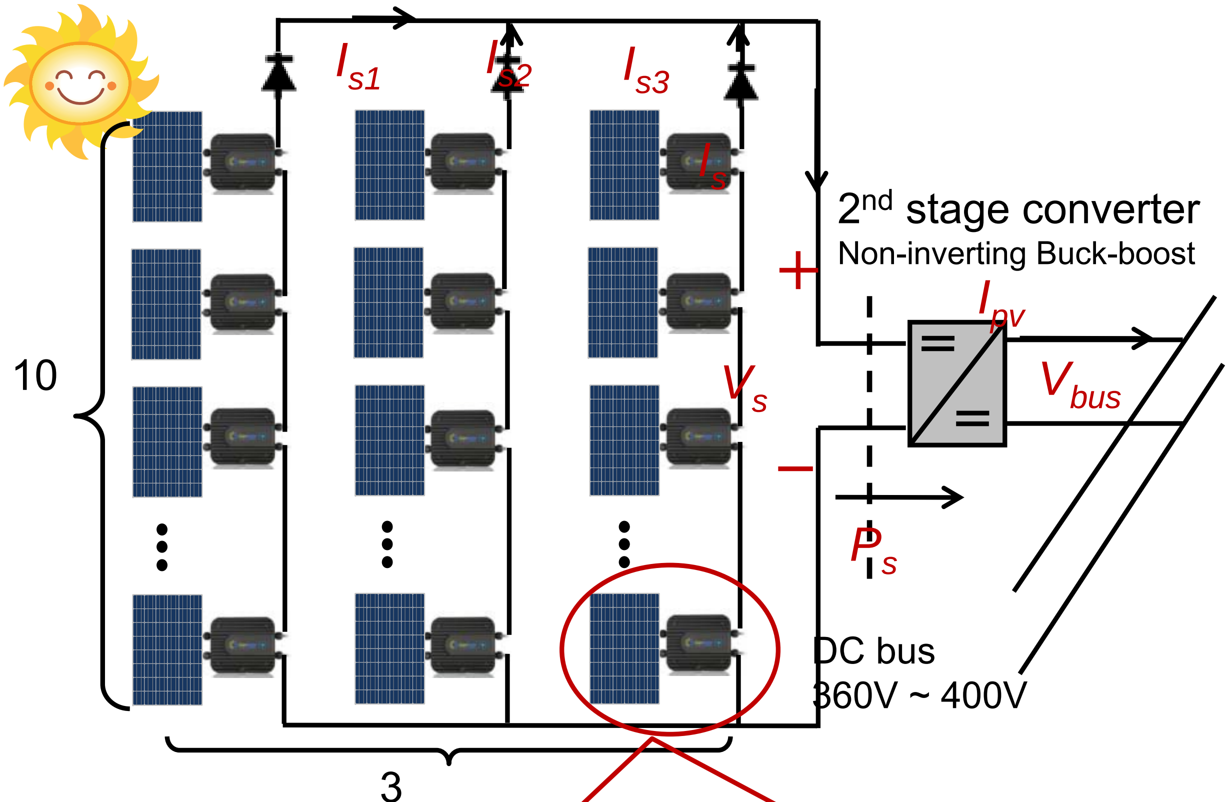
Sustainable Building Design Initiative
Battery Management System

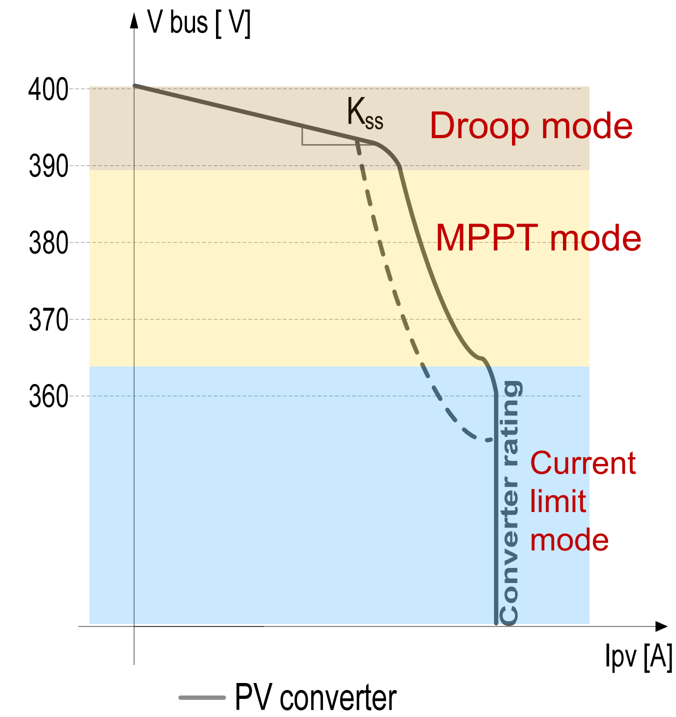
SAFT Lithium Ion Battery System

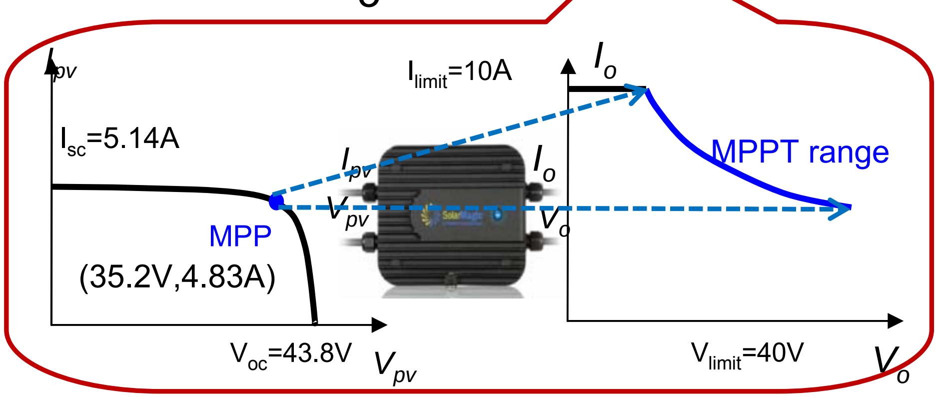




Photovoltaic Management System



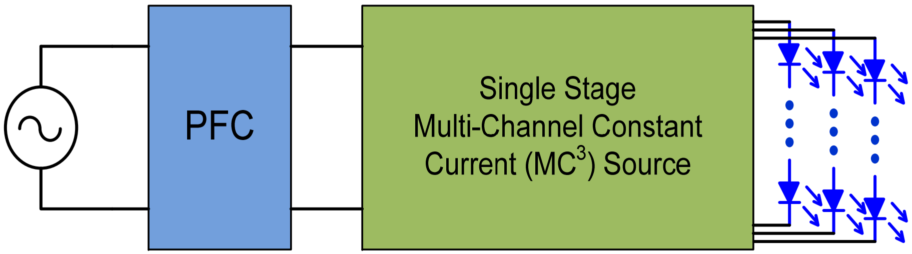




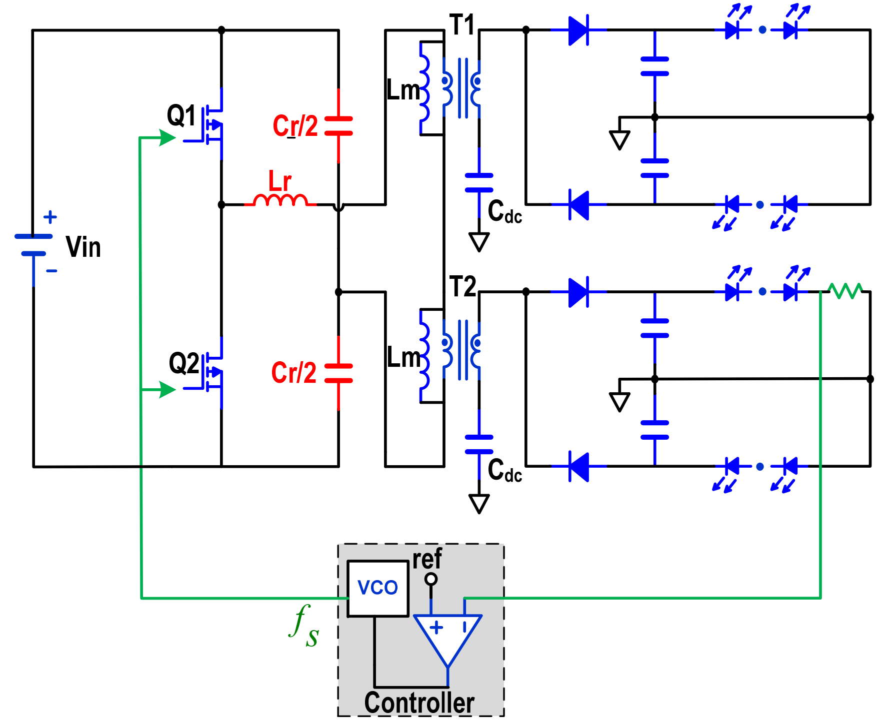
Solarmagic Power optimizer

- Smart PV panel
- Peak power tracking at the panel level
- Peak power tracking at the system level
- 20% more efficient than the centralized MPPT system

2-stage MC^3 LED Driver



Schematic of proposed multi-channel constant current source



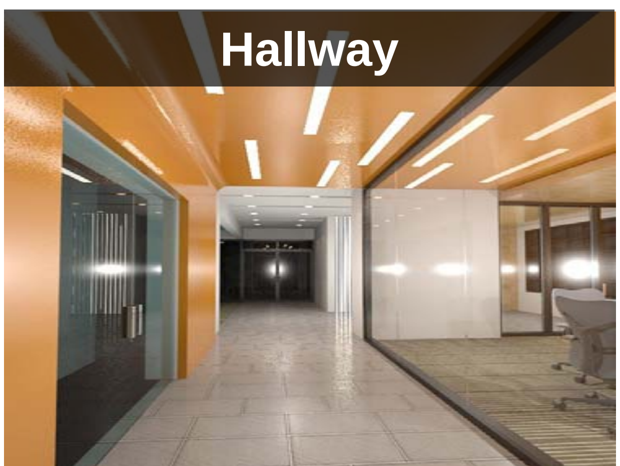
- LLC resonant topology
- Multiple outputs current source
- DC block cap balance the current of two strings
- Scalable for multiple LED strings

CPES

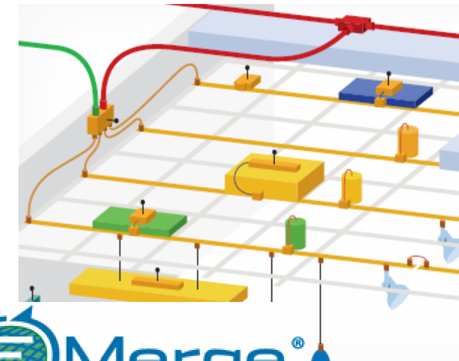
Integration of Technology into the Home Environment

- Synergy of power electronics and interior design

Design by: a+d School of architecture + design, Virginia Tech



Ceiling-based plug-and-play DC system

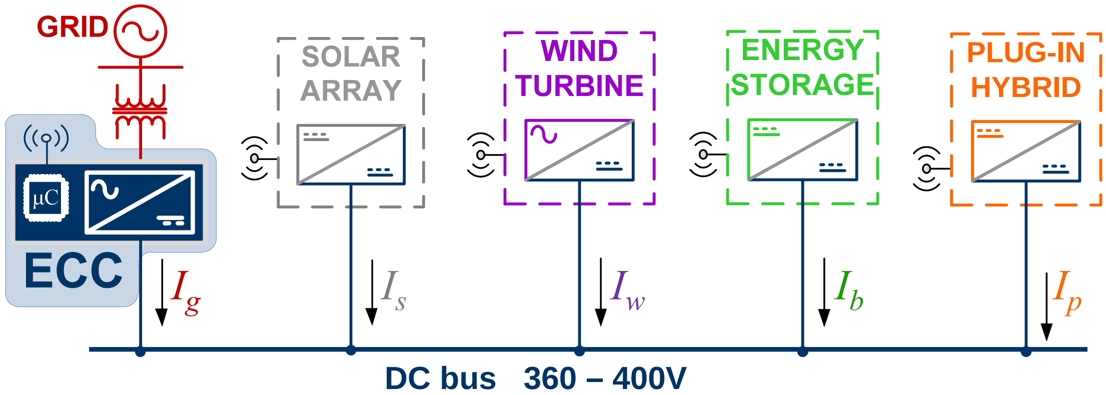


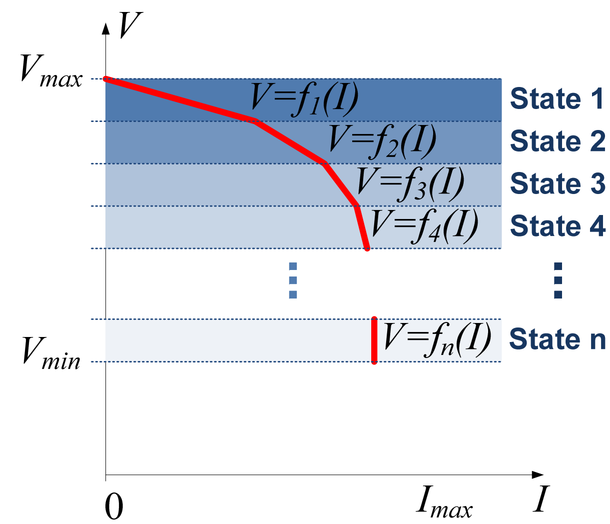
EMerge® ALLIANCE

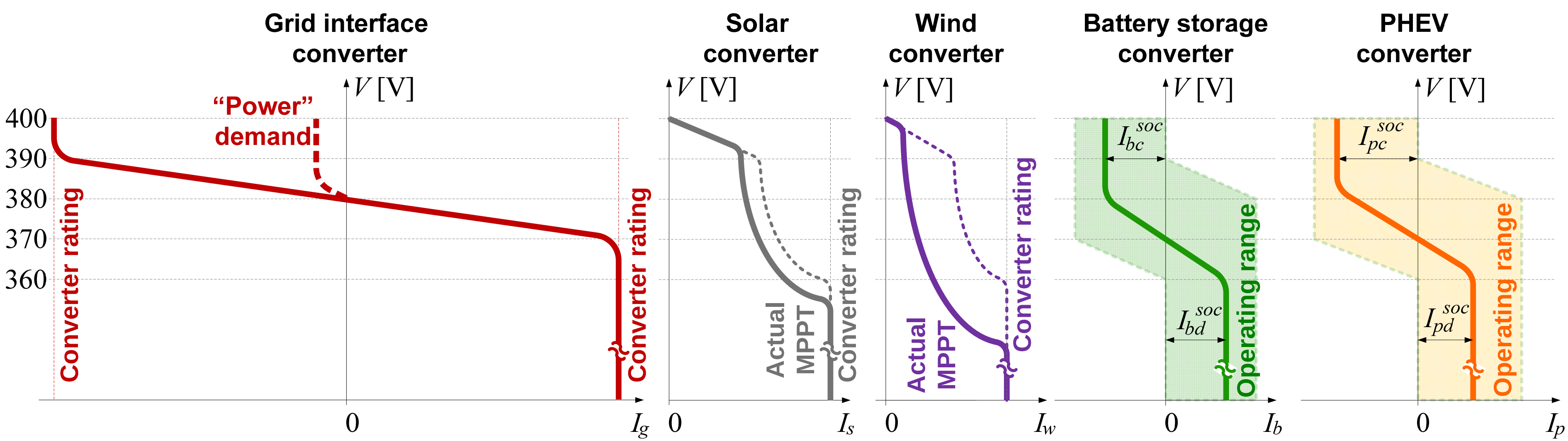
Armstrong

Integration of existing technology

Static (V-I) Characteristics of the System Components (dc-bus signaling technique*)

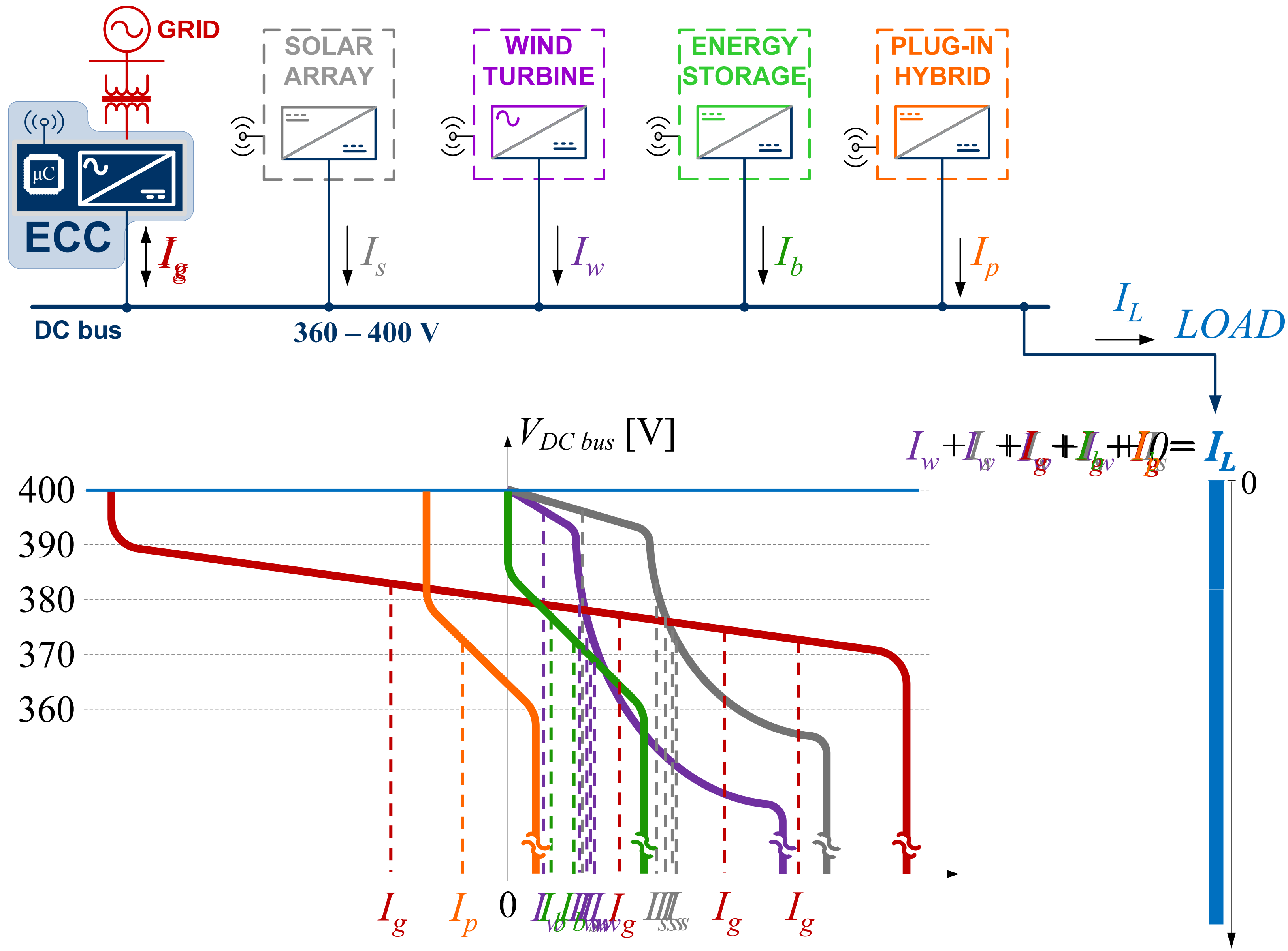




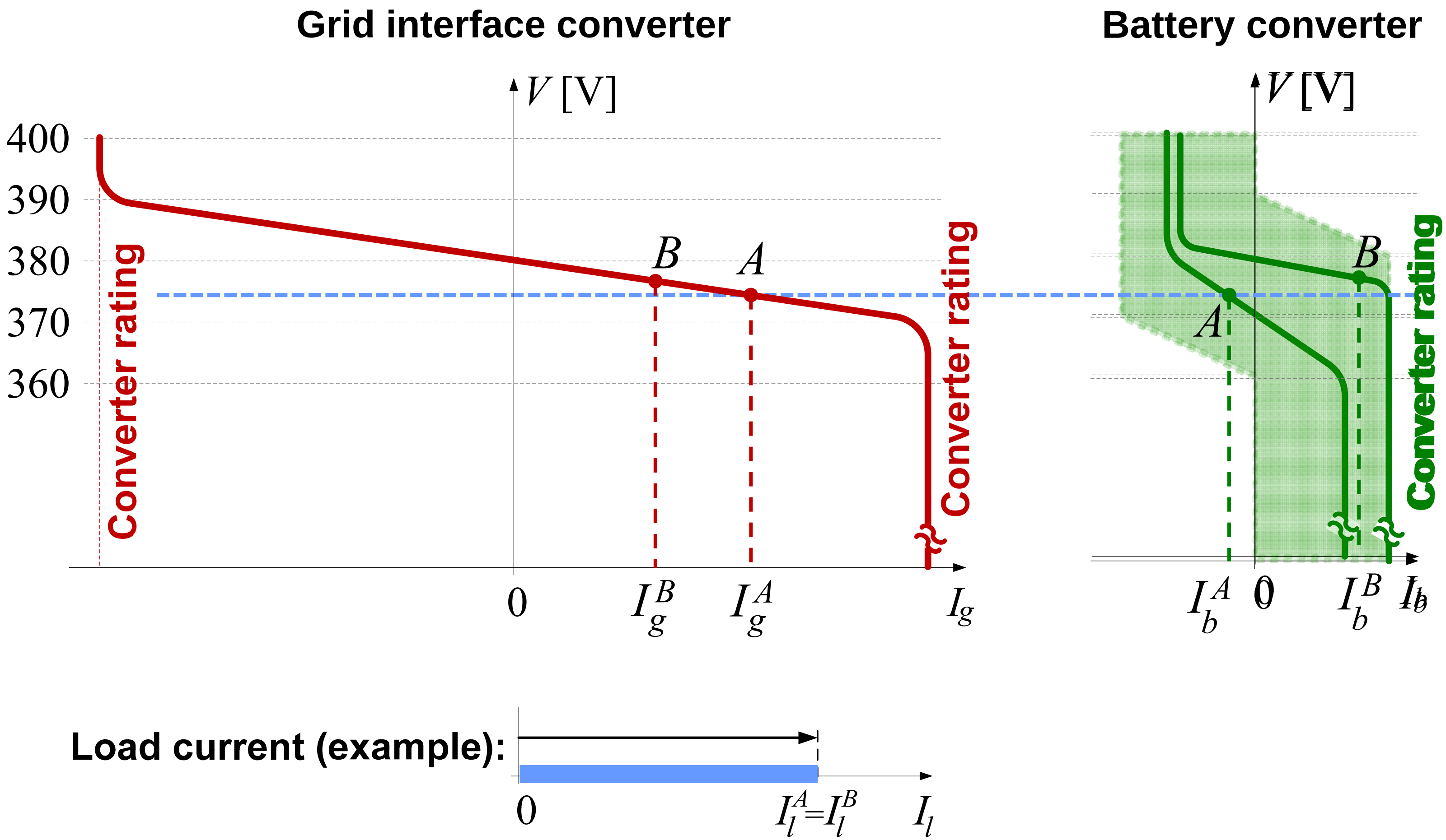


[*] J. Bryan, R. Duke, and S. Round, "Decentralized generator scheduling in a nanogrid using DC bus signaling," in *Power Engineering Society General Meeting, 2004. IEEE*, 2004, pp. 977-982 Vol.1.

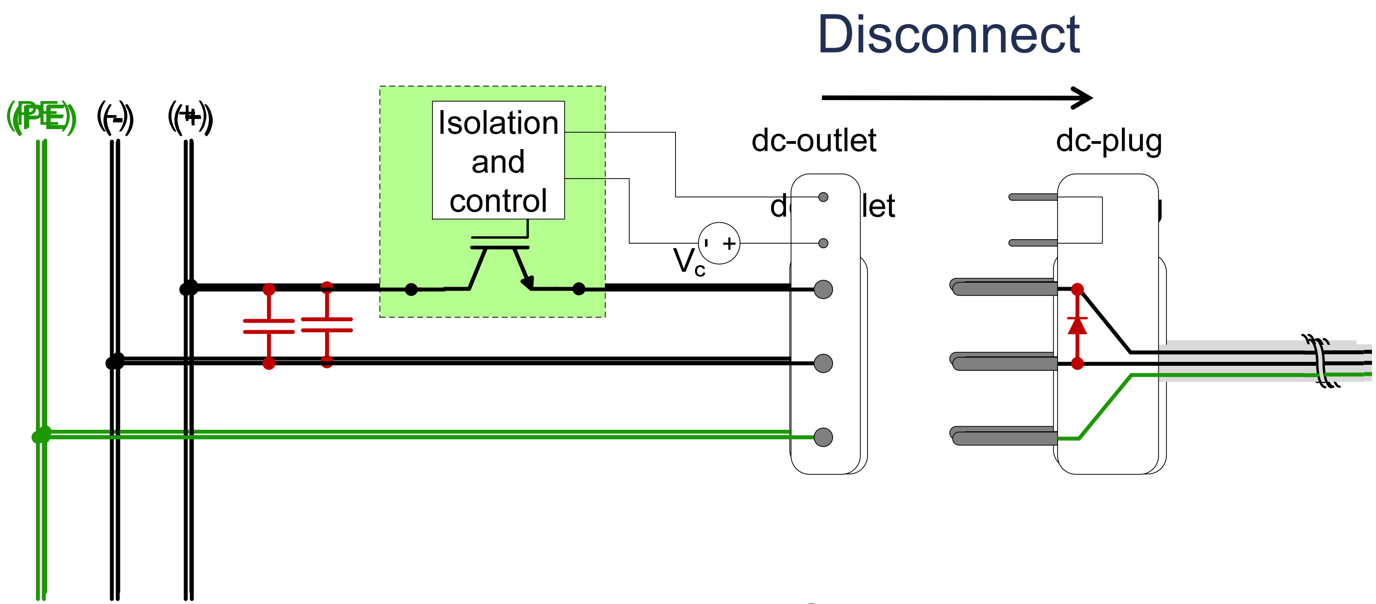
Static Operation of the DC-Nanogrid System



Optimization of the DC-nanogrid Operation

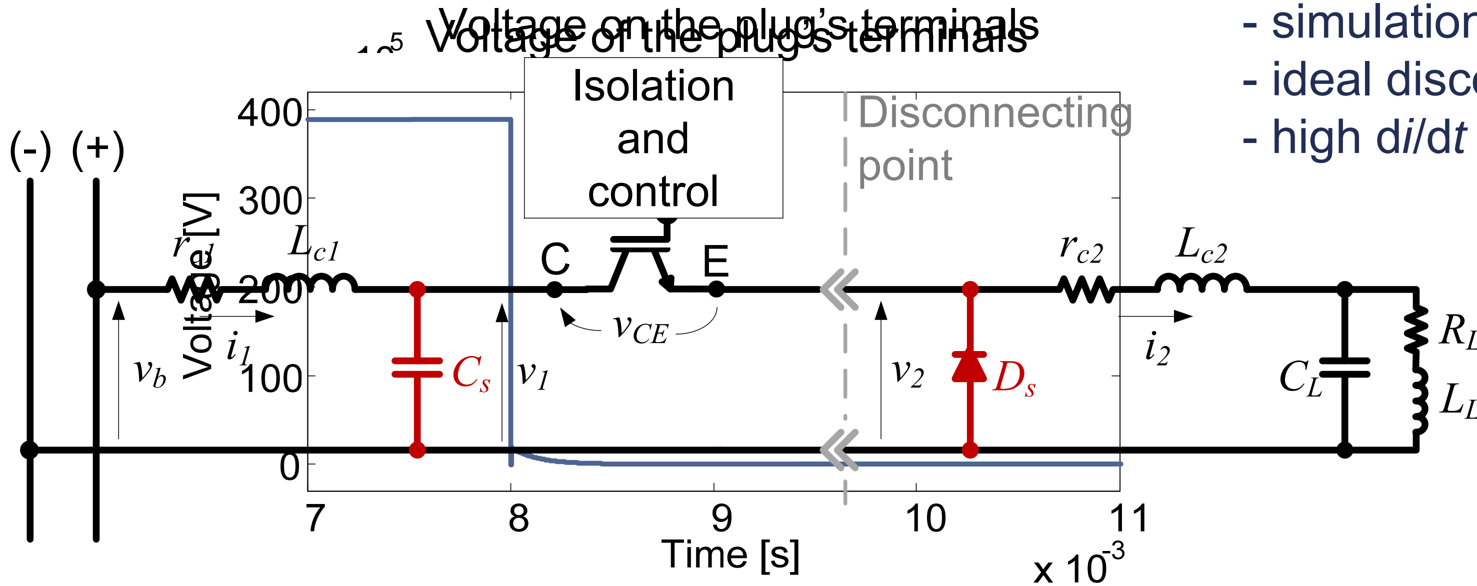


Power Socket/Plug for the High Voltage

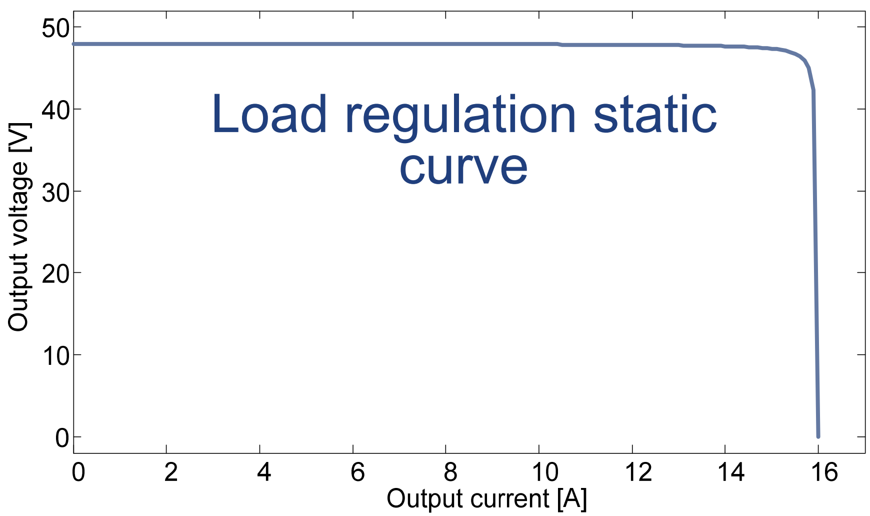


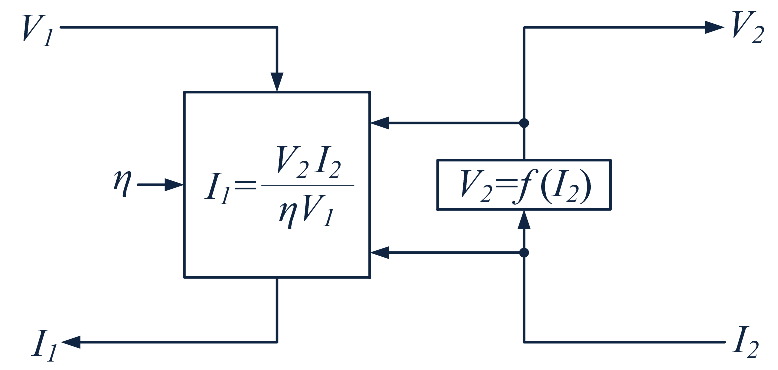
An equivalent circuit of the system above:

- simulation results
- ideal disconnect
- high d*i*/dt

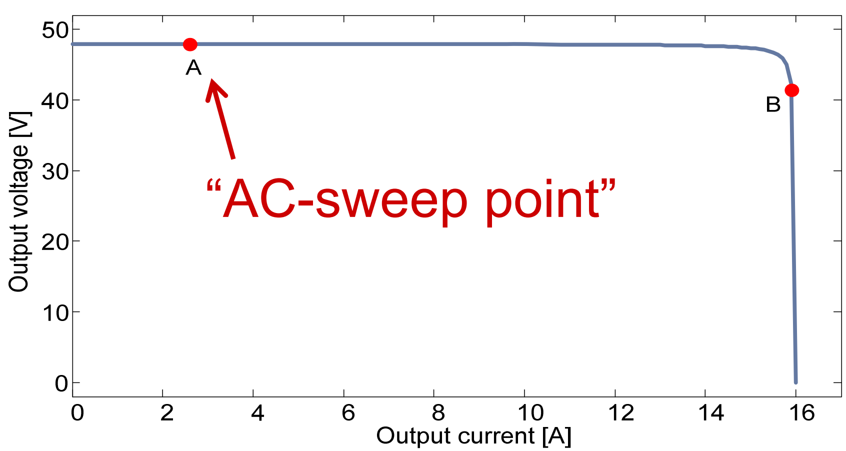


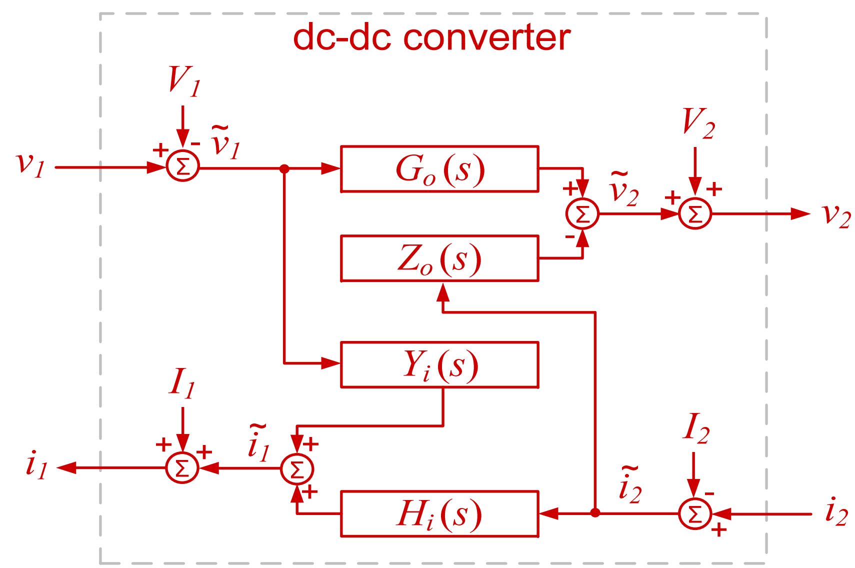
Building the Non-linear Static and Linear Dynamic Model





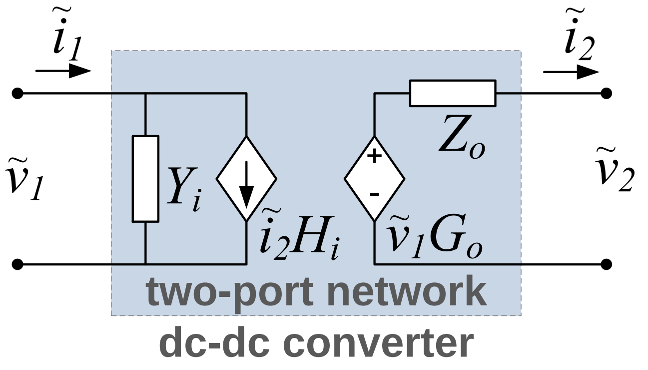
Non-linear static model





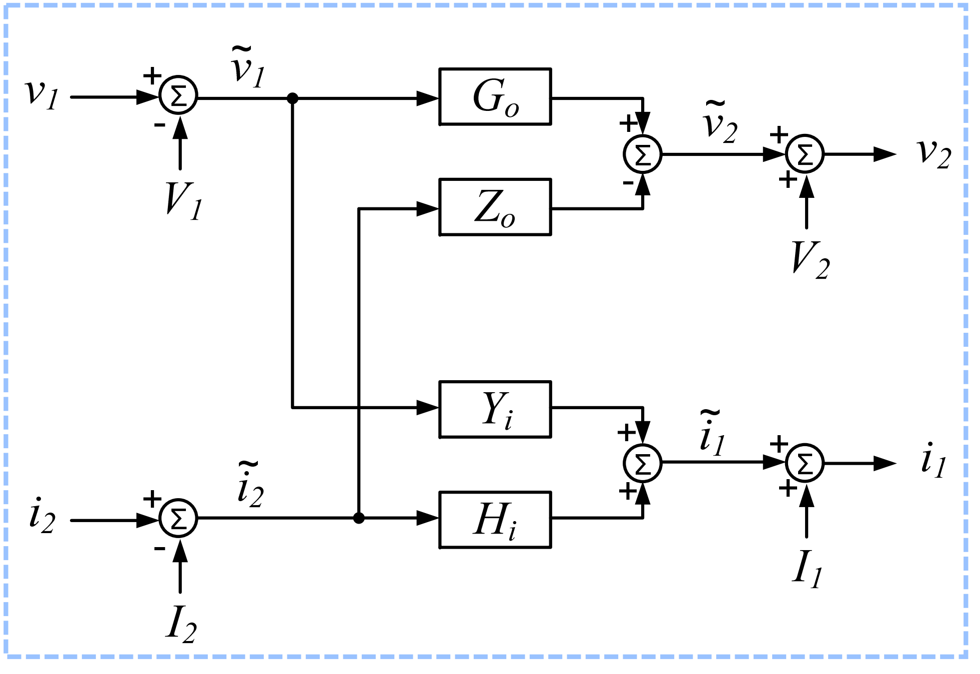
Linear dynamic model

Two port network behavioral model

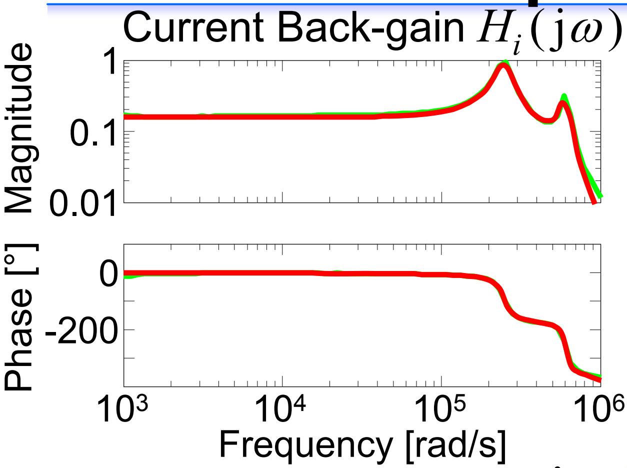


Small-signal model:

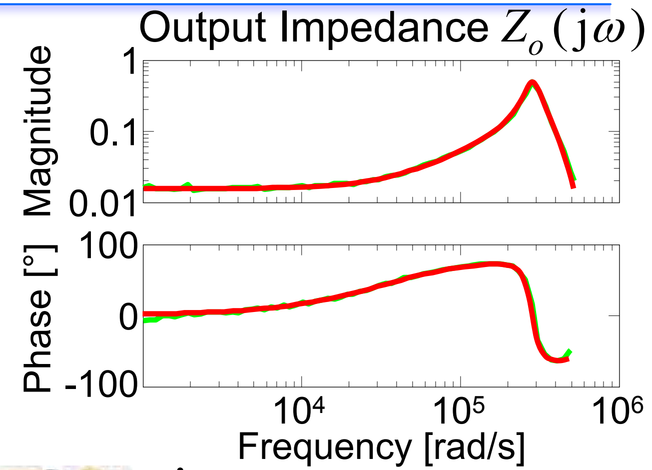
$$\begin{bmatrix} \tilde{v}_2 \\ \tilde{i}_1 \end{bmatrix} = \begin{bmatrix} G_o(s) & -Z_o(s) \\ Y_i(s) & H_i(s) \end{bmatrix} \cdot \begin{bmatrix} \tilde{v}_1 \\ \tilde{i}_2 \end{bmatrix}$$



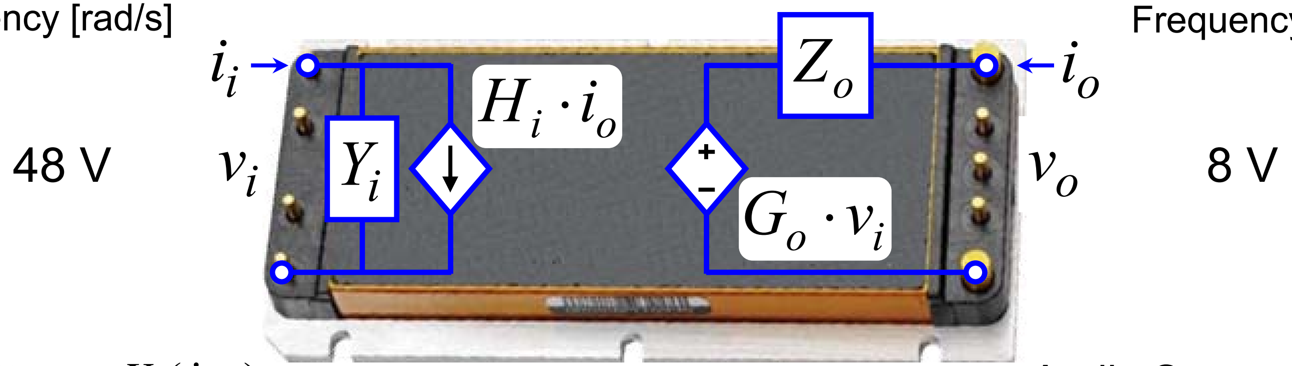
Modular Terminal Behavioral (MTB) Low-frequency Model of DC-DC Converter

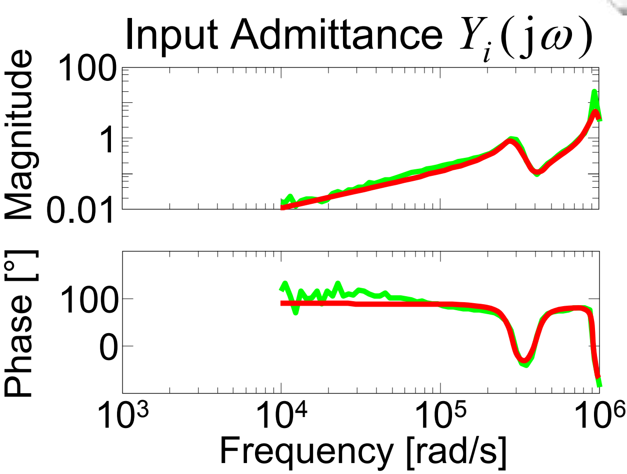


"Black Box" Modeling Example



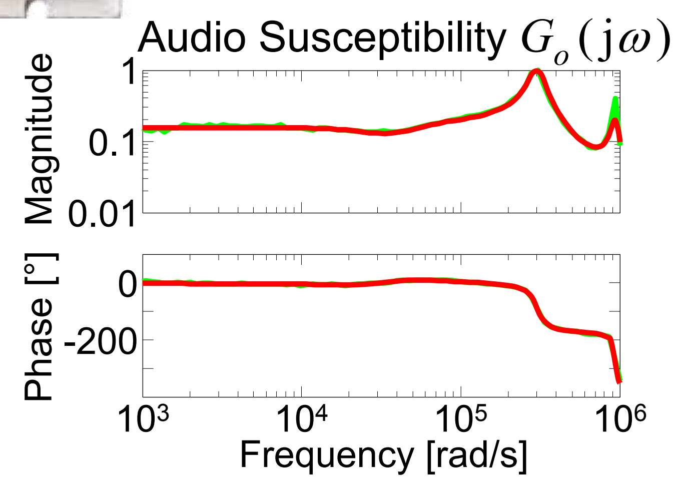
A commercial
60 W bus converter





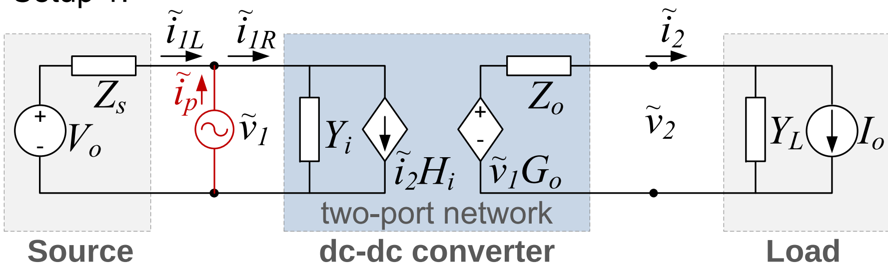
Measured frequency response functions

Curve-fitted, reduced order transfer functions

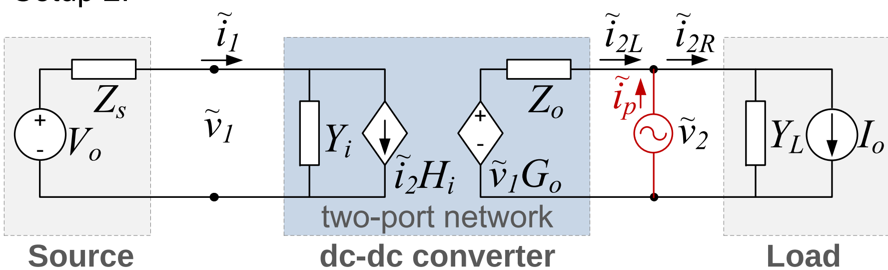


Obtaining un-terminated from the terminated transfer functions

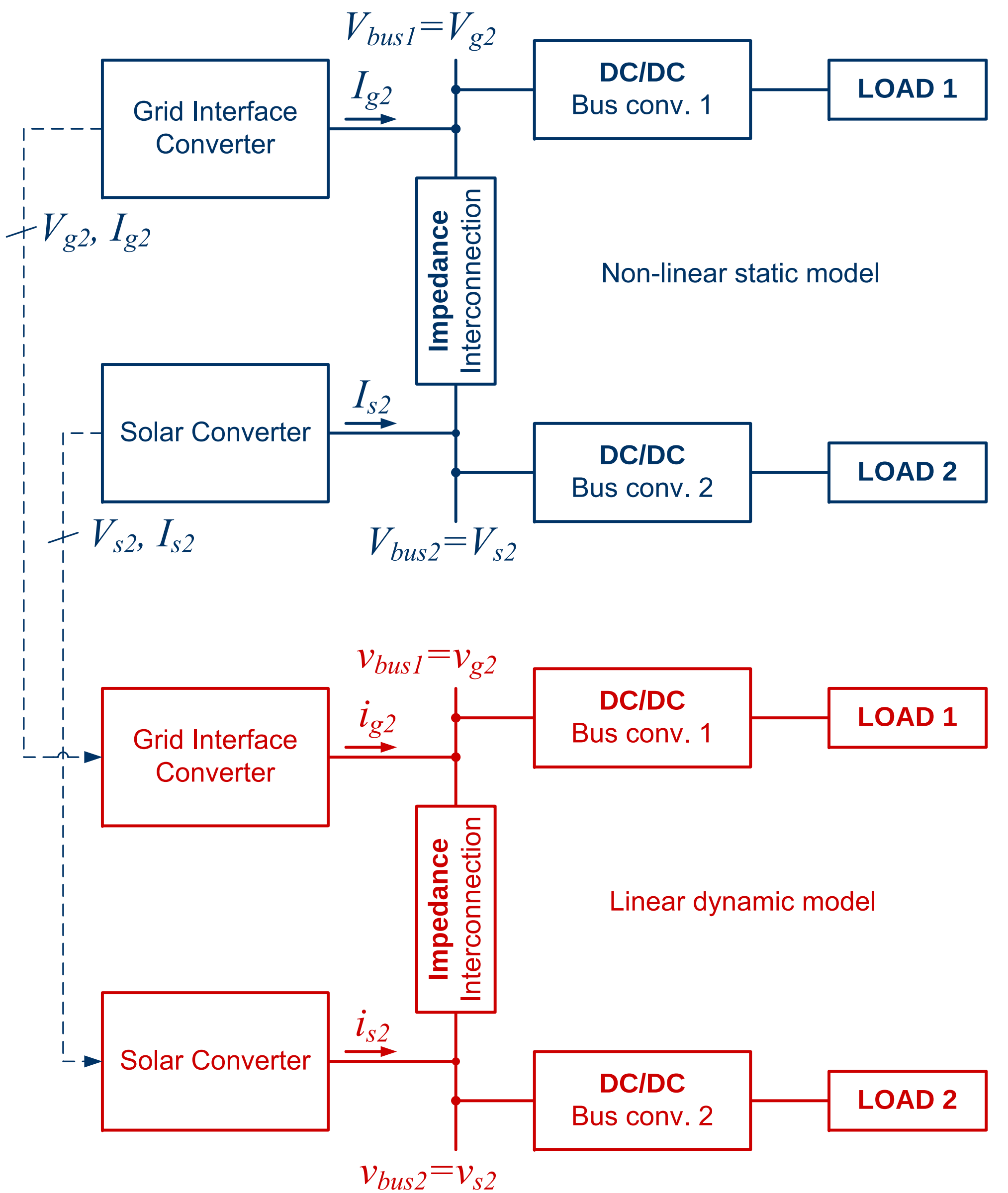
Setup 1:



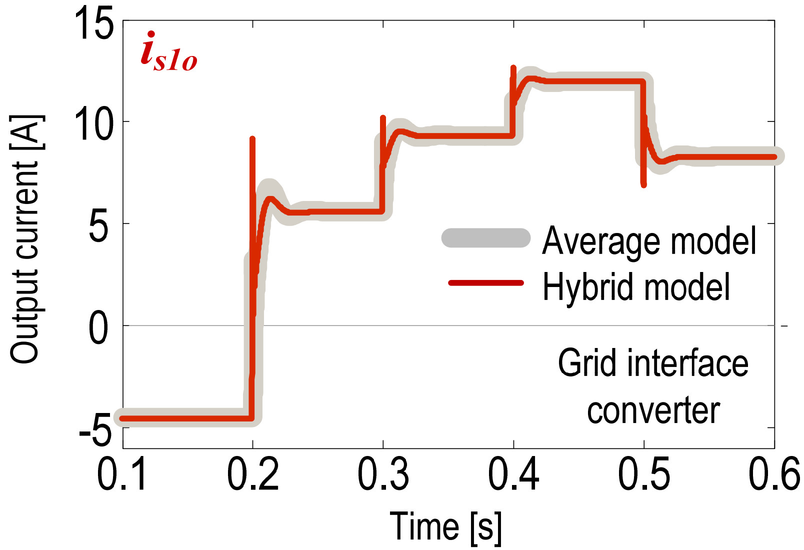
Setup 2:

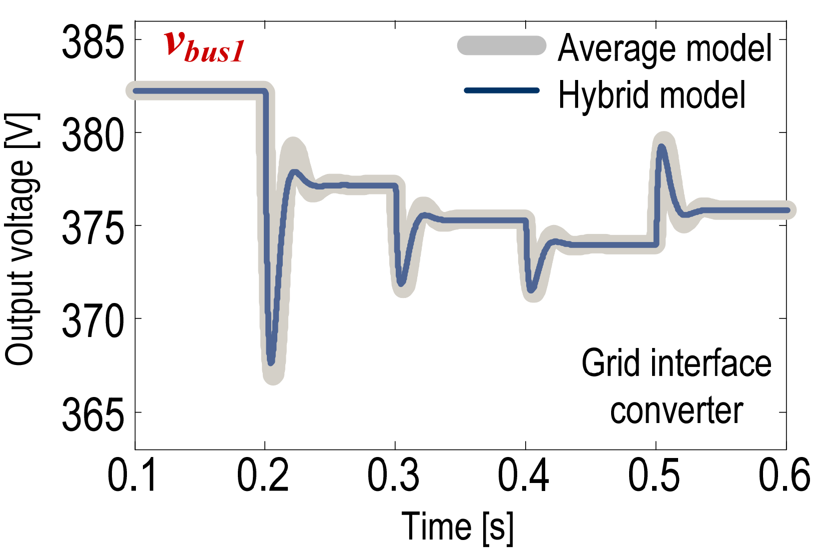


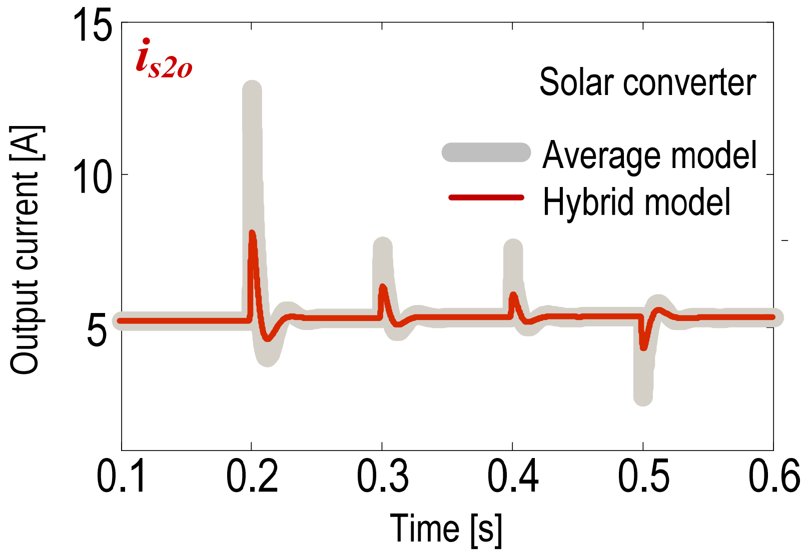
System-level Model Verification (Sample System)

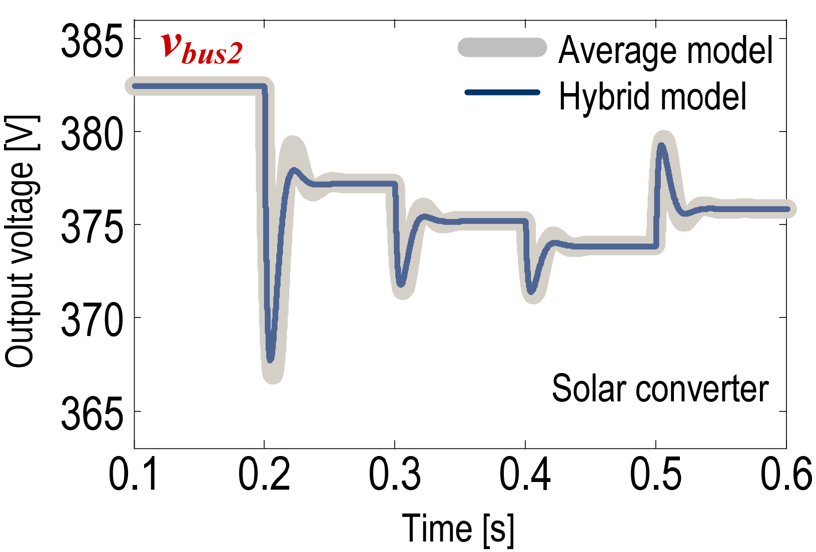


System-level Model Verification (Sample System)

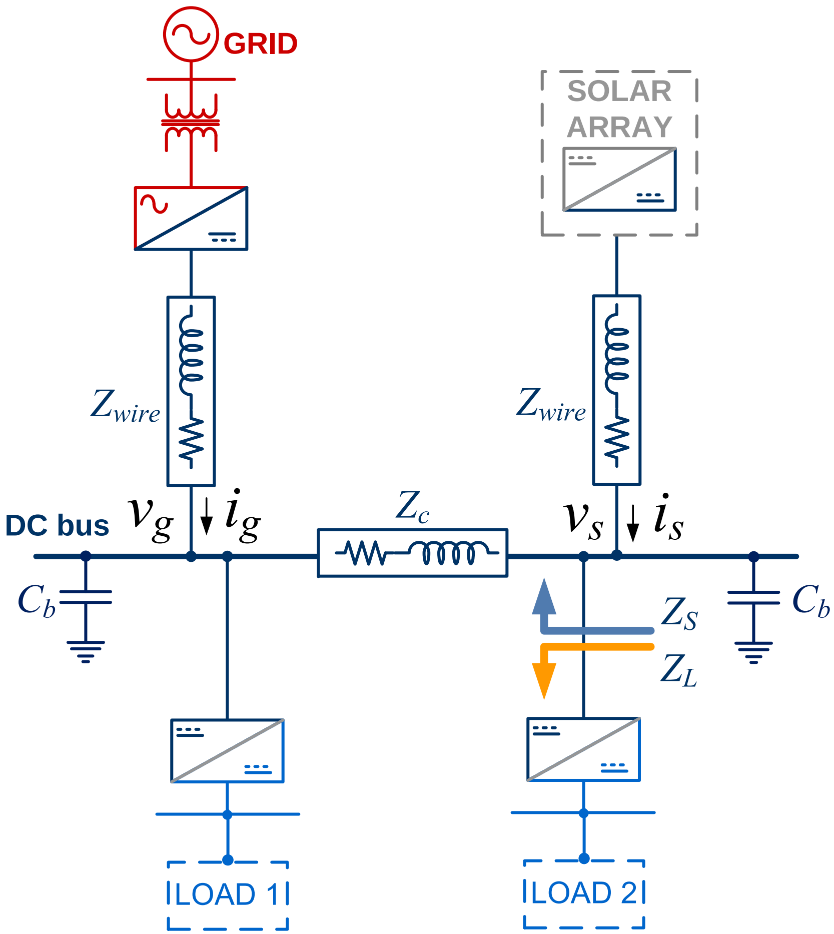


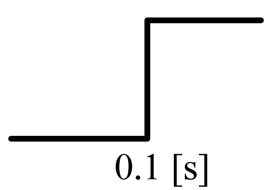


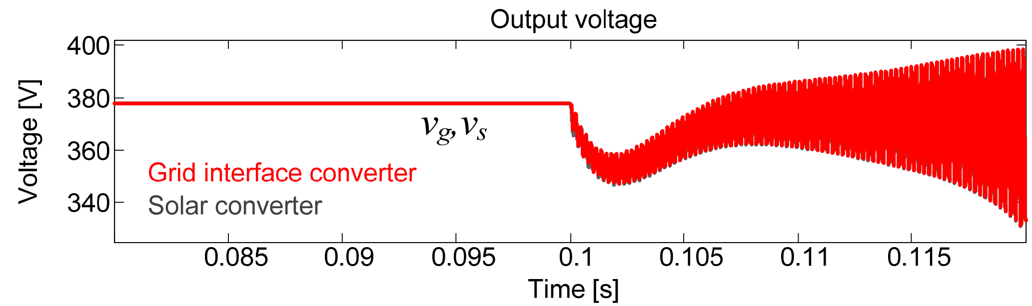


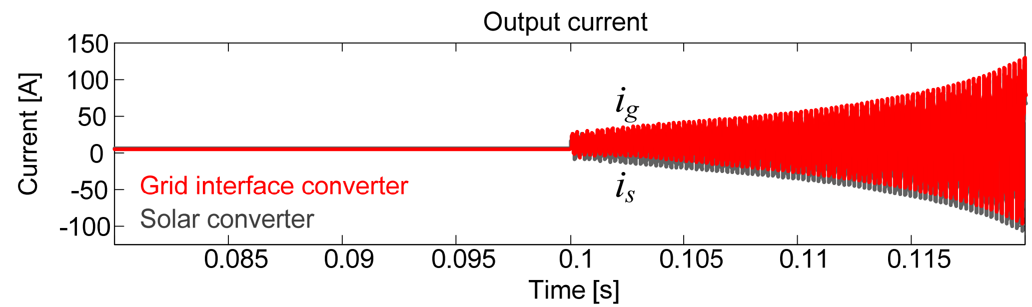


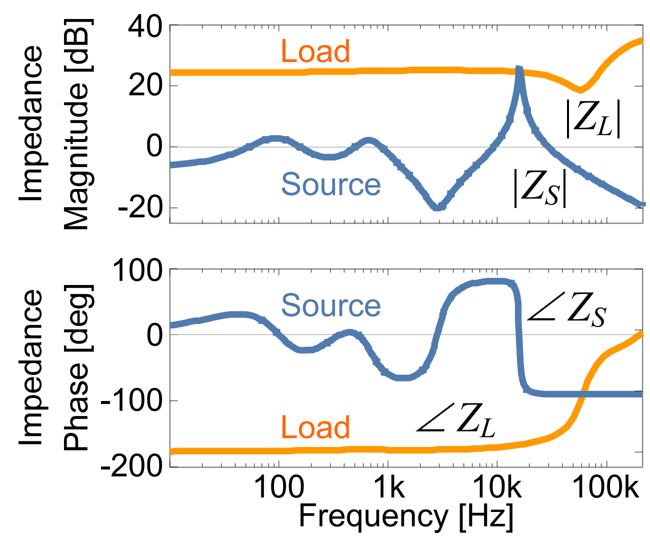
DC System Stability
(example with low bus capacitance C_b)



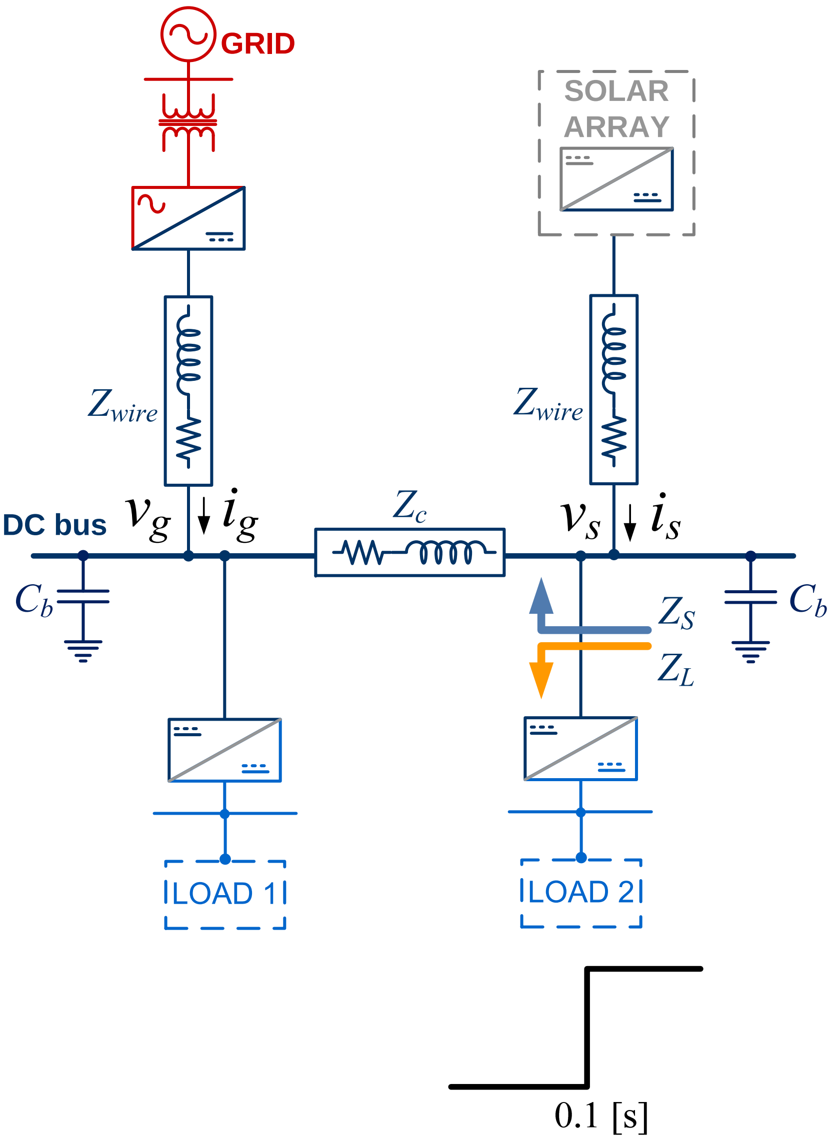


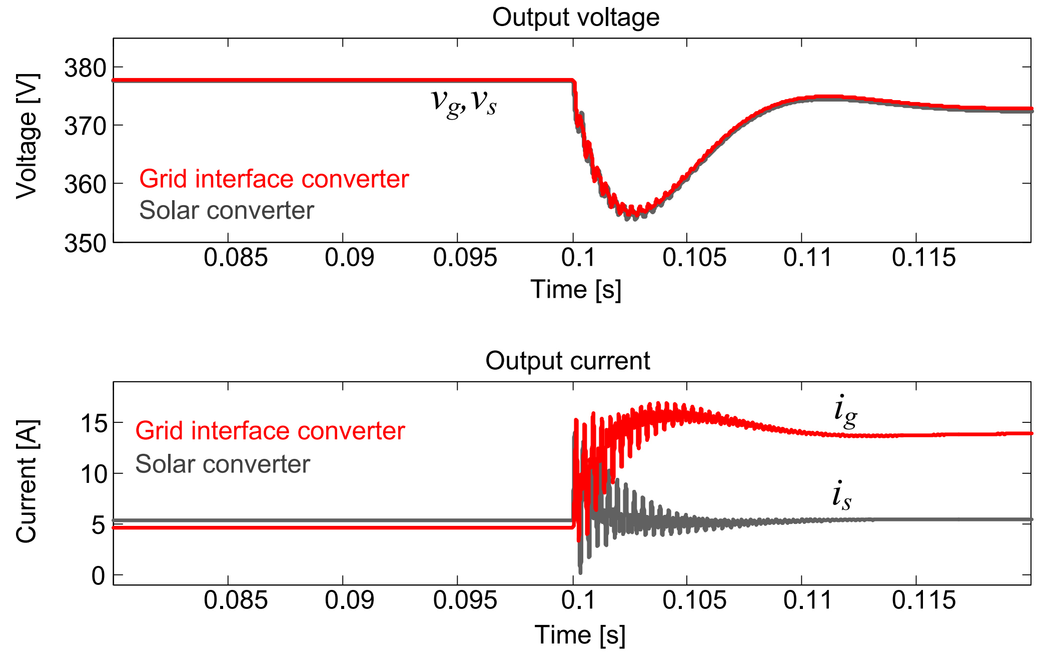


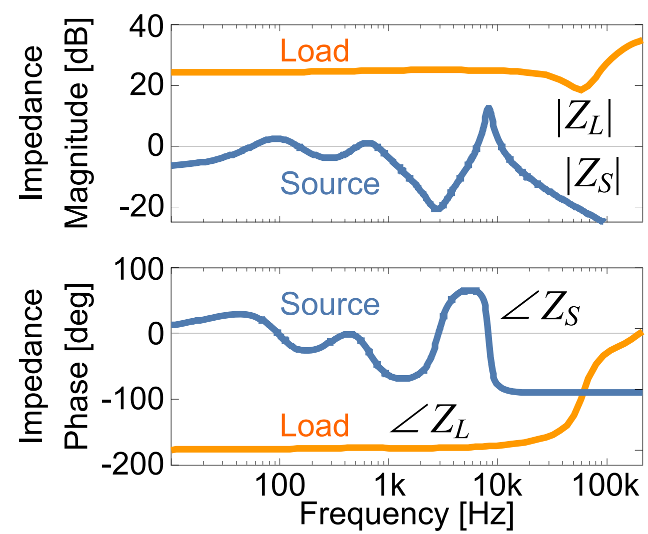




DC System Stability (value of C_b has increased)







Thank You

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Center for Power Electronics Systems

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Virginia Tech, Blacksburg, Virginia, USA