Power Electronic Converters for Advanced Electric Power Systems

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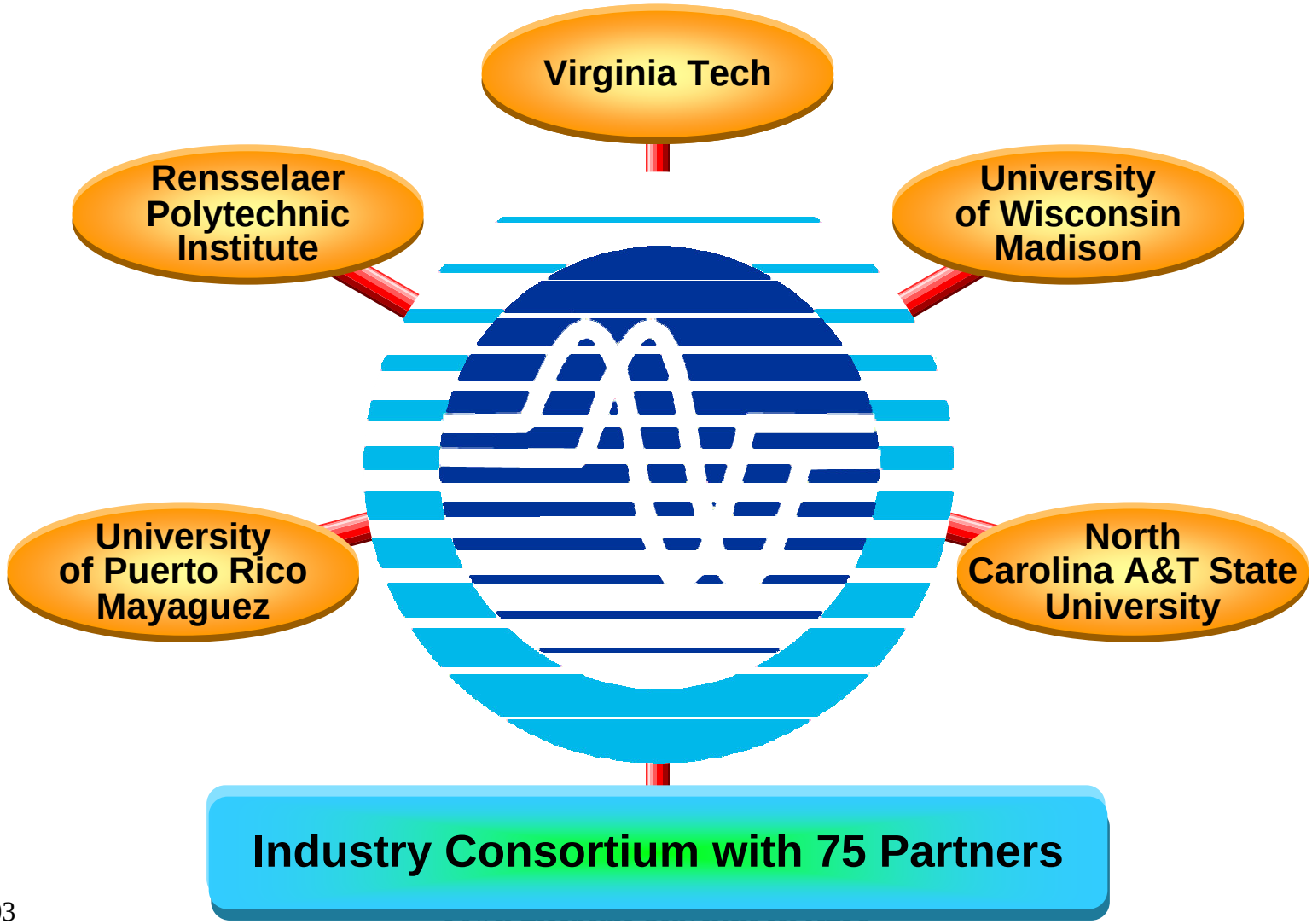
Outline

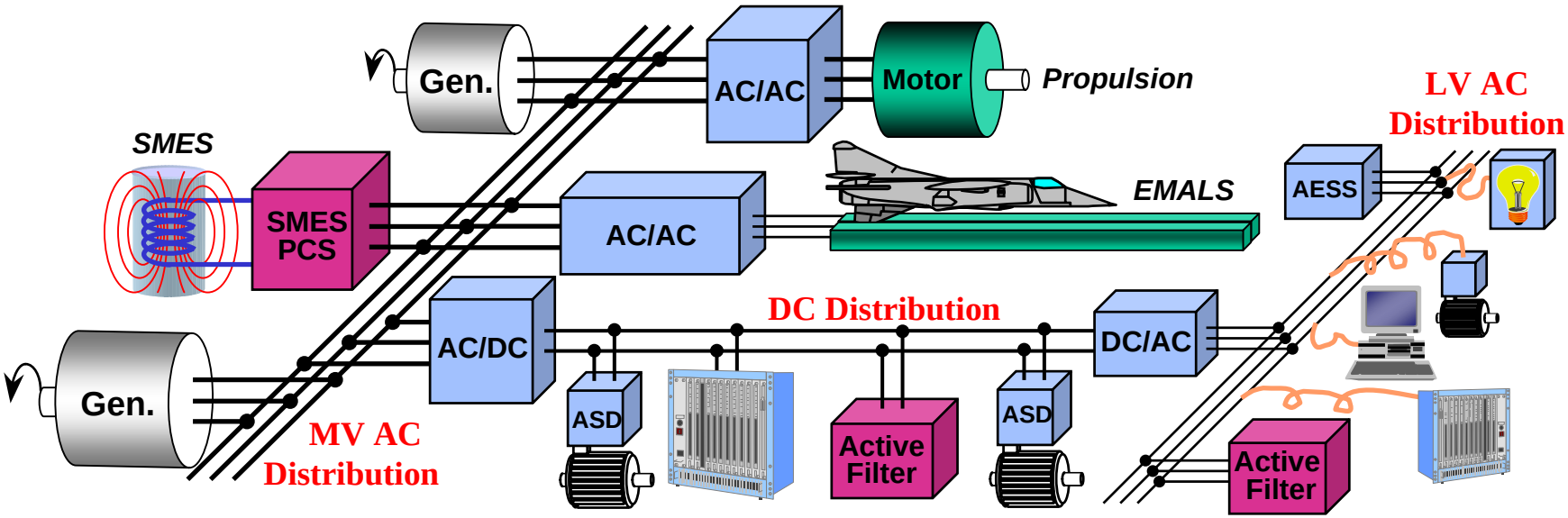
- Introduction
- Source and grid interface issues
- Modular converter design issues
- Standard-cell, open-architecture, electric power conversion systems

Center for Power Electronics Systems

A National Science Foundation Engineering Research Center



Power Electronics Building Block (PEBB) *and* Advanced Electric Power Systems

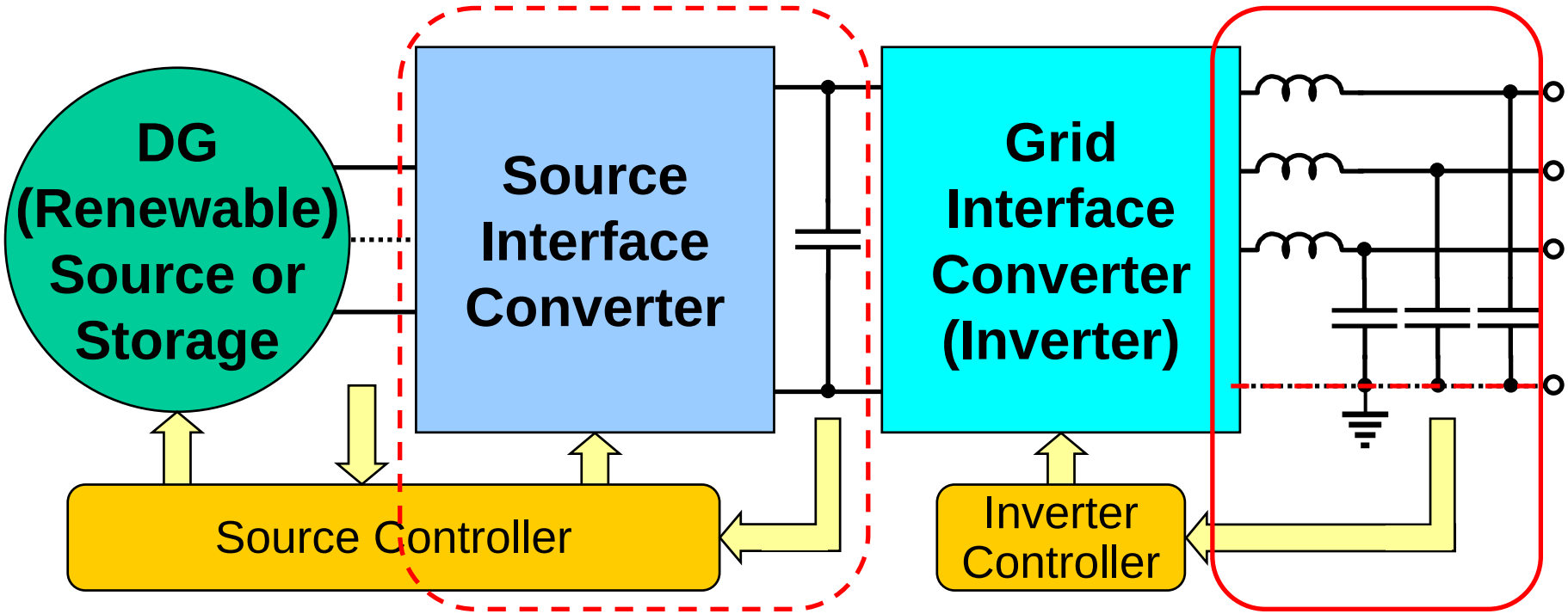


- **Most (all) sources and loads interfaced through power electronics converters:**
  - High system controllability, flexibility, and responsiveness
  - Increased availability
  - Reduced size and weight
  - Increased efficiency

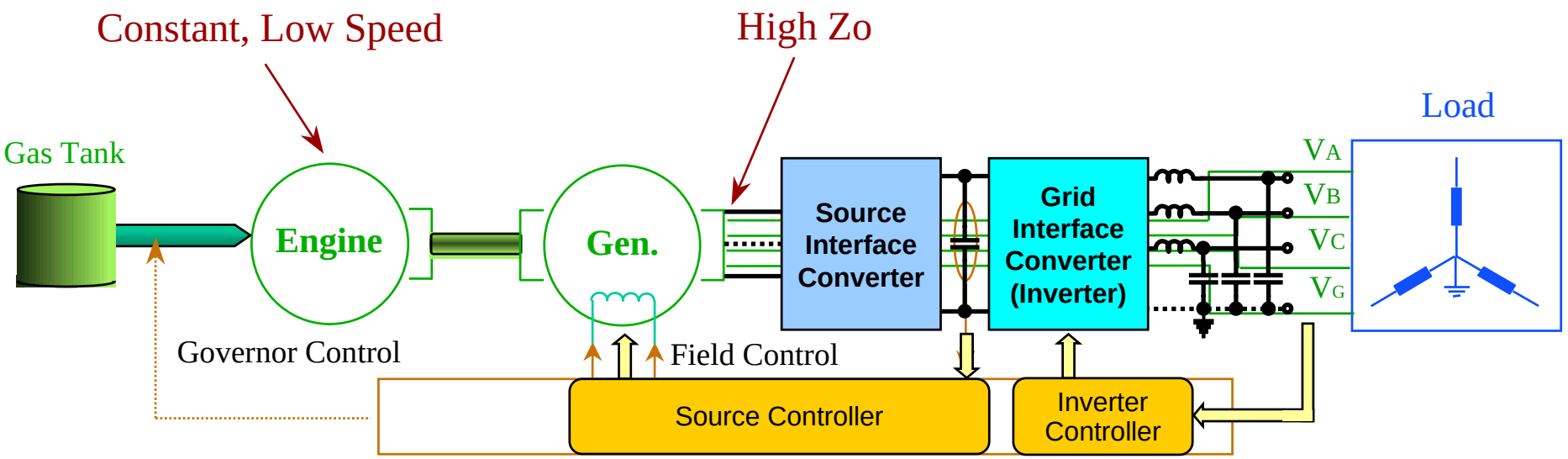
Commercial General Purpose Induction Motor Drives?

- 3-phase, 0-300 Hz, 0-480 V
- 0.2-200 kW (overload 110-150%, surge 150-200%)
- Cost: 200-400 $/kW
- Size: 0.3-0.6 kW/lit (5-10 W/in^3)
- Weight: 0.6-1.2 kW/kg (0.7-1.4 lb/HP)
- Communications: large variety available
- Reliability: 10,000-30,000 hrs MTBF?
- Required modifications:
  - Front-End + DC Link $\Rightarrow$ Source Interface Converter
  - AC Filter + AC Voltage Sensing
  - Control

Power Electronics Converters for Distributed (Renewable) Generation

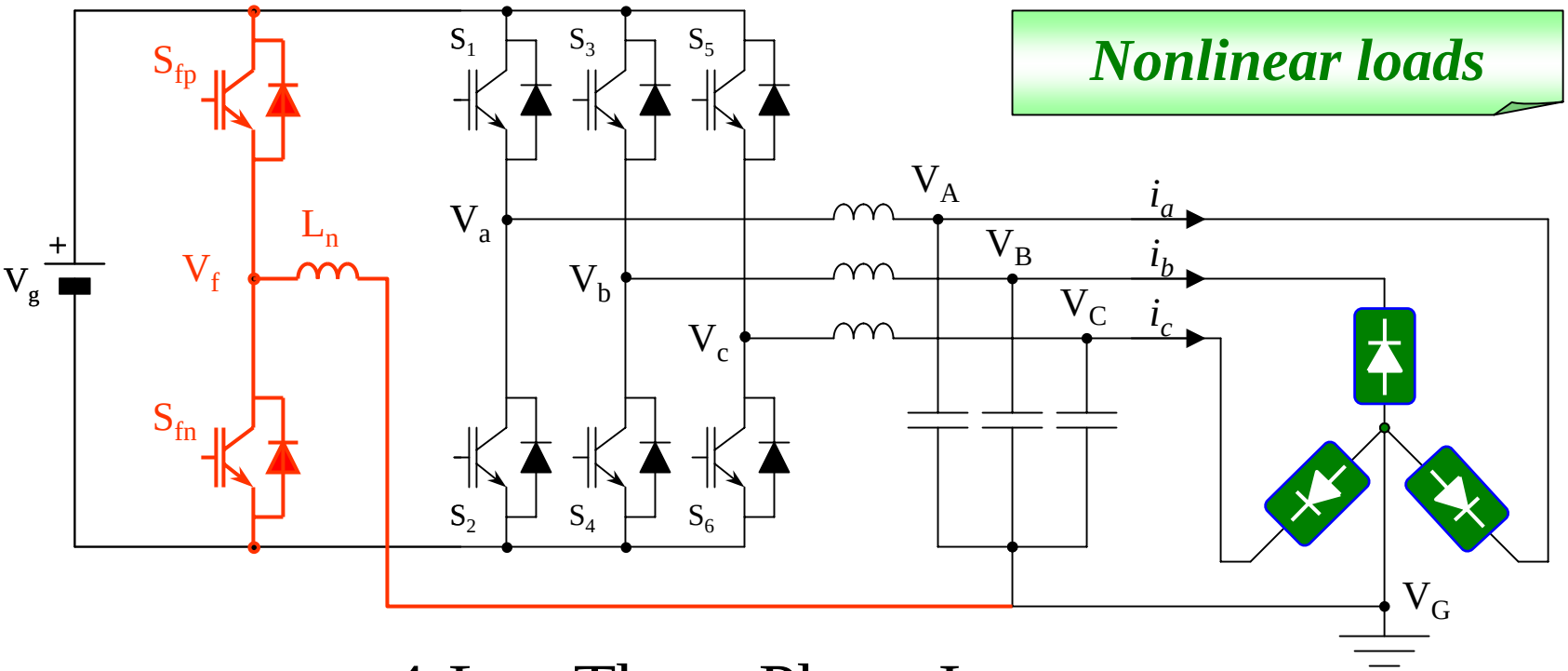


Standard Commercial Gen-Sets



- ☺ Almost unlimited ampere-hour capability
- ☹ Low speed, bulky, high cost engine/generator
- ☹ Poor transient response
- ☹ High voltage distortion with unbalanced and/or nonlinear load

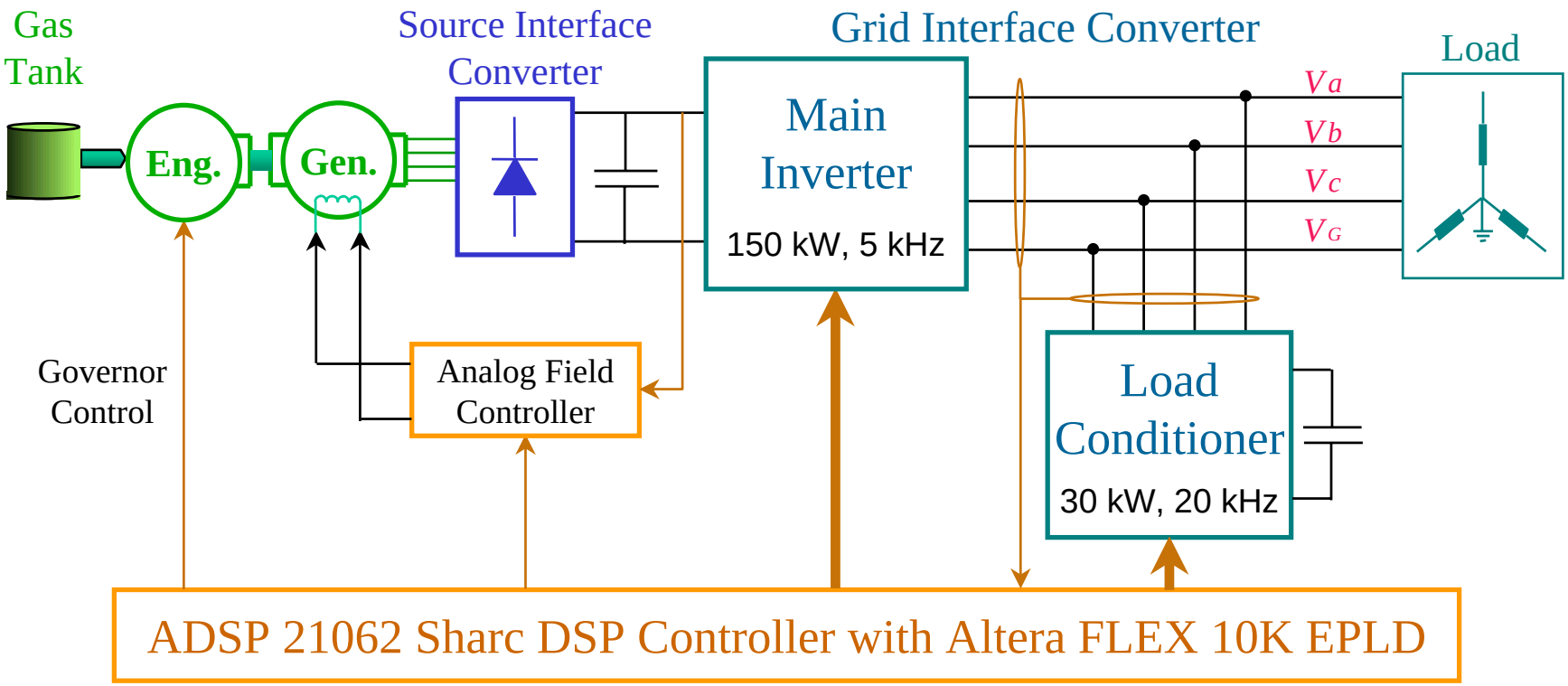
Unbalanced/Nonlinear Loads



4-Leg Three-Phase Inverter

- New space vector modulation
- New control algorithms
- High bandwidth required

Gen-Set with Power Electronics Interface

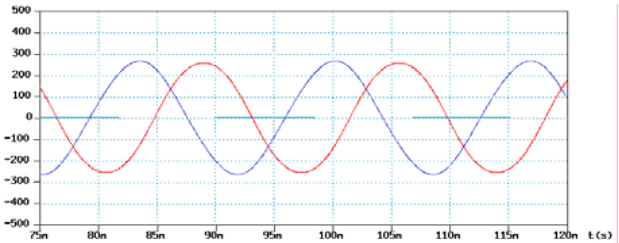


- Suitable for any variable unidirectional ac source:
  - Micro-turbines
  - Wind power
  - Micro hydro power

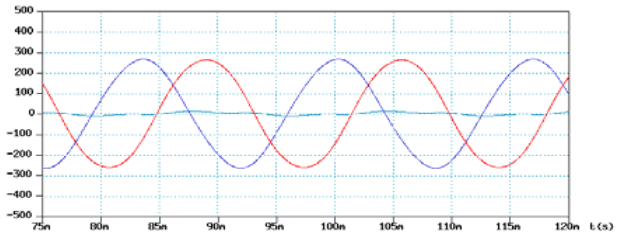
Simulation

Unbalanced loads

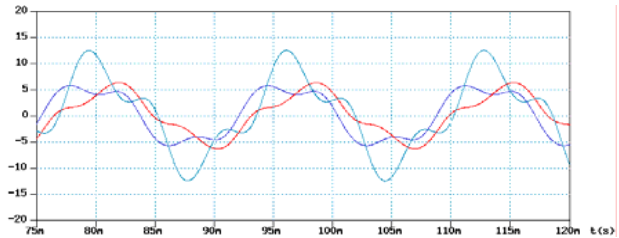
Load Current



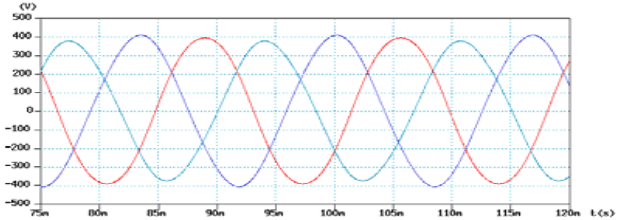
Main Inverter Current



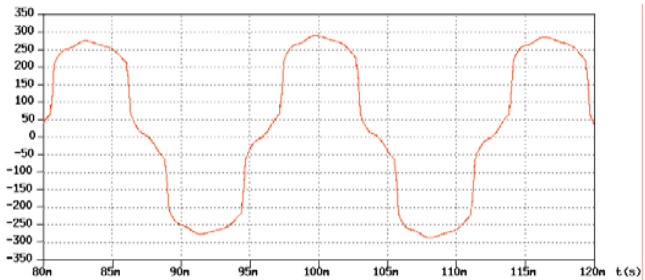
Load conditioner Current



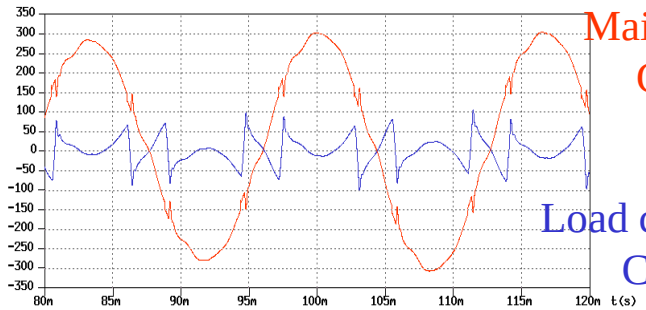
V_{ABC}



Nonlinear loads

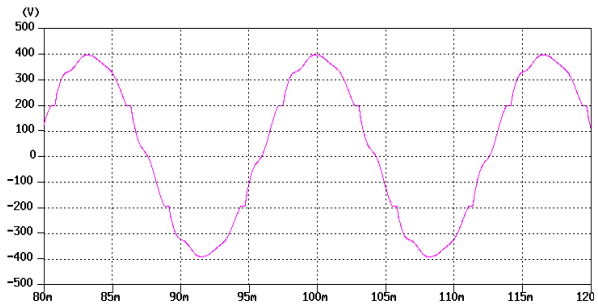


Load Current



Main Inverter Current

Load conditioner Current



Output Voltage Va

THD = 4.2%

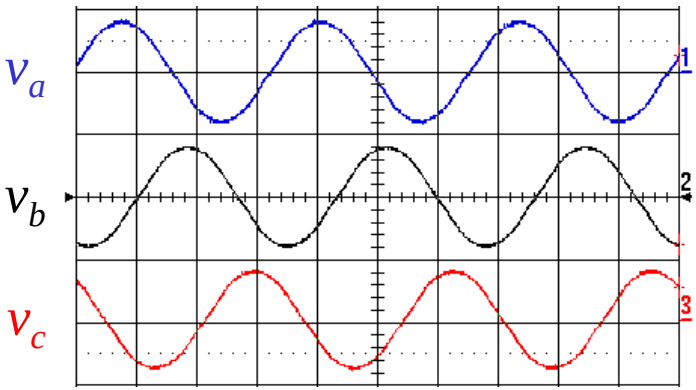
Experiment

CPES

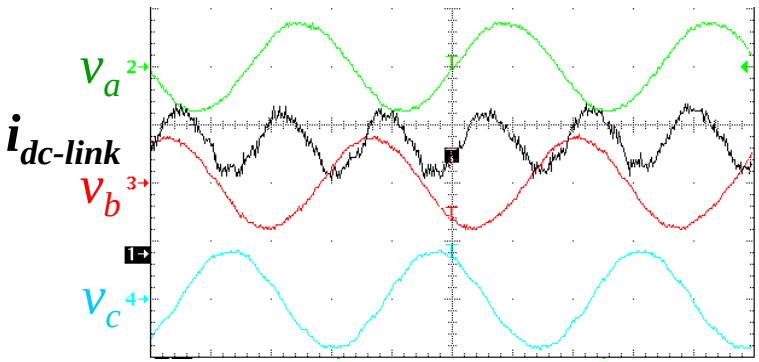
Test Condition:

V_o = 277 V, f_o = 60 Hz, V_{dc} = 815 V

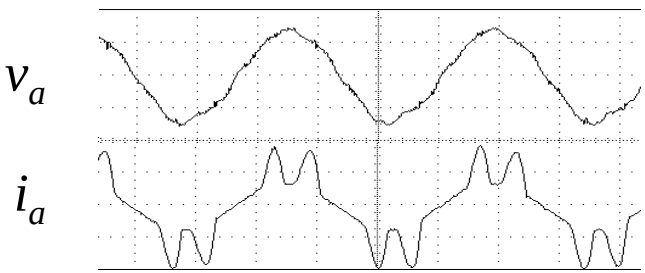
100 kW Balanced Resistive Load



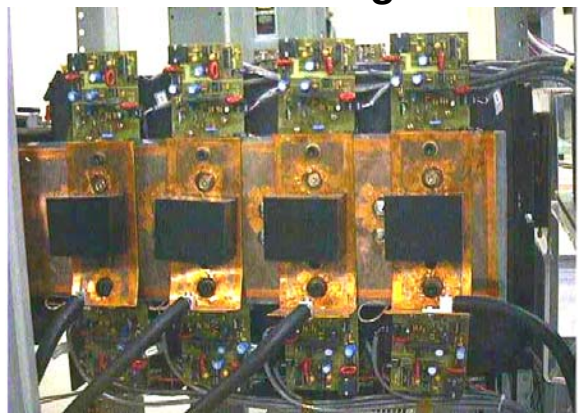
0 - 20 - 20 kW Unbalanced Resistive Load



20 kW Resistive
+
20 kW Rectifier
3Φ Balanced Load

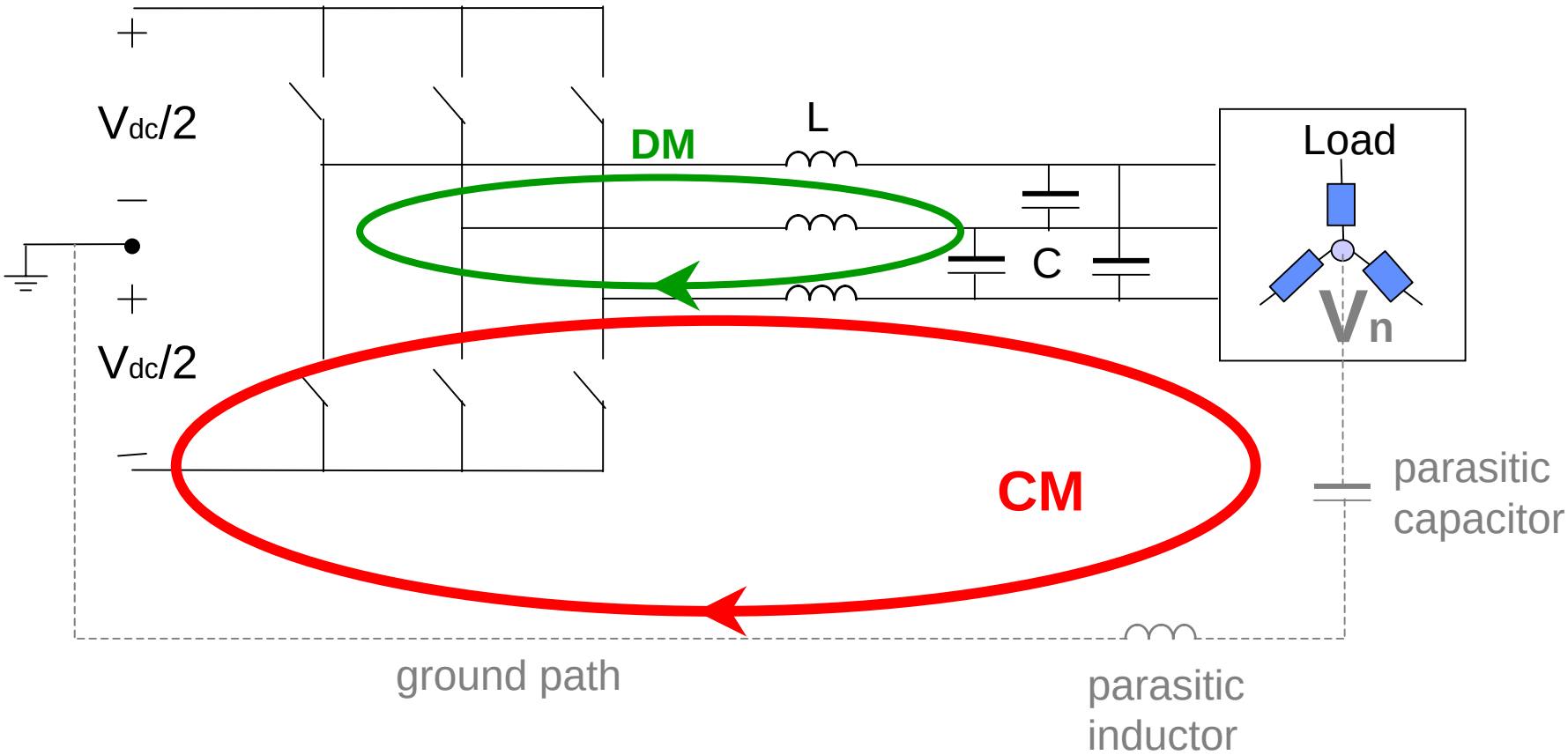


Power Stage



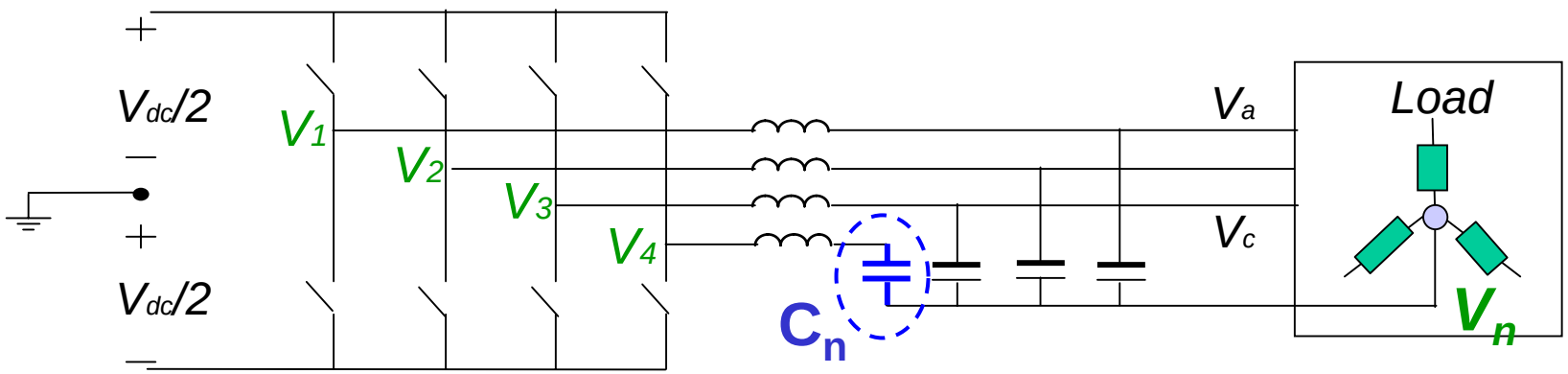
Hardware Setup

Switching Noise of Inverter System



- Differential-Mode Noise: reduced by LC-filter
- Common-Mode Noise: its effect depends on parasitic values

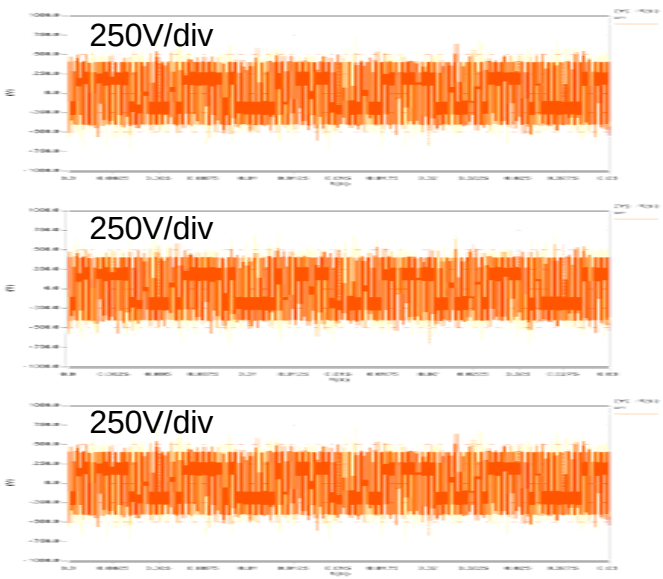
Active Common-Mode Noise Elimination



4-leg inverter for unbalanced/nonlinear loads

V_n

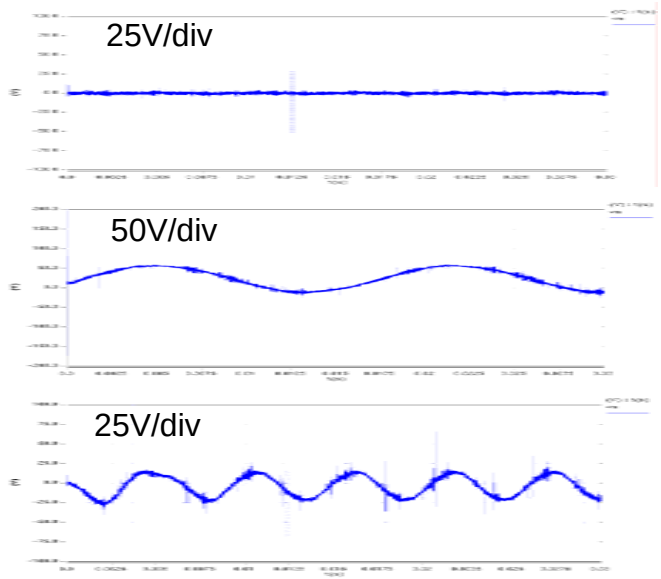
4-leg inverter with common-mode noise reduction



Balanced load

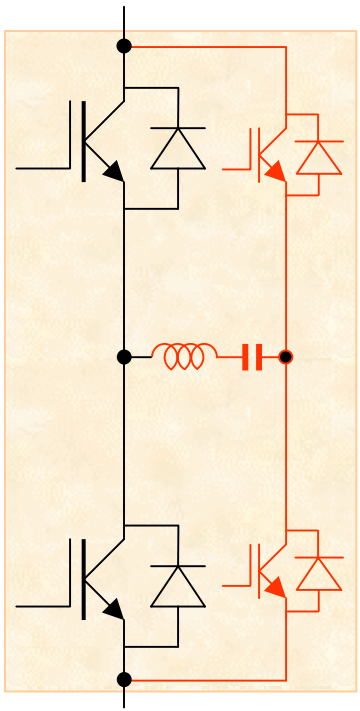
Unbalanced load

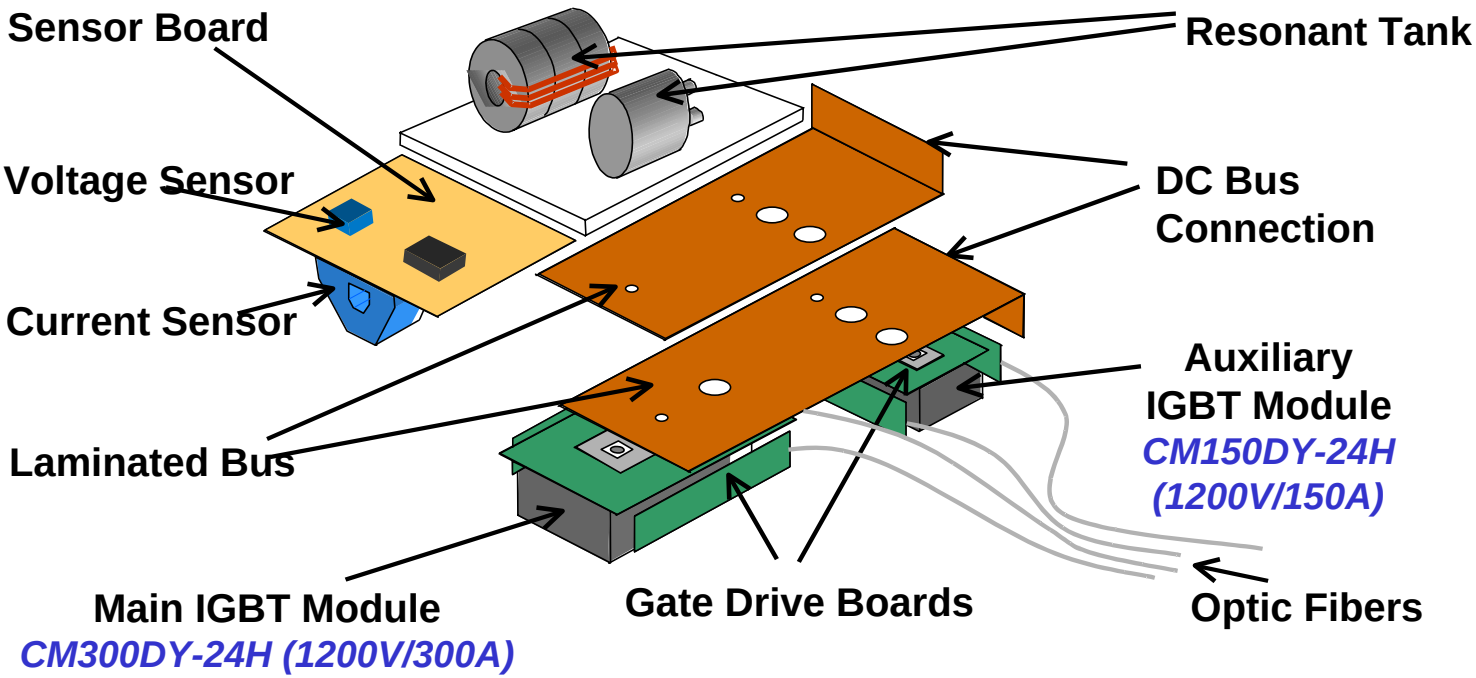
Nonlinear load



Soft-Switched Phase-Leg PEBB Module

- Increase switching frequency and reduce switching noise
- Increased power density and increased system bandwidth

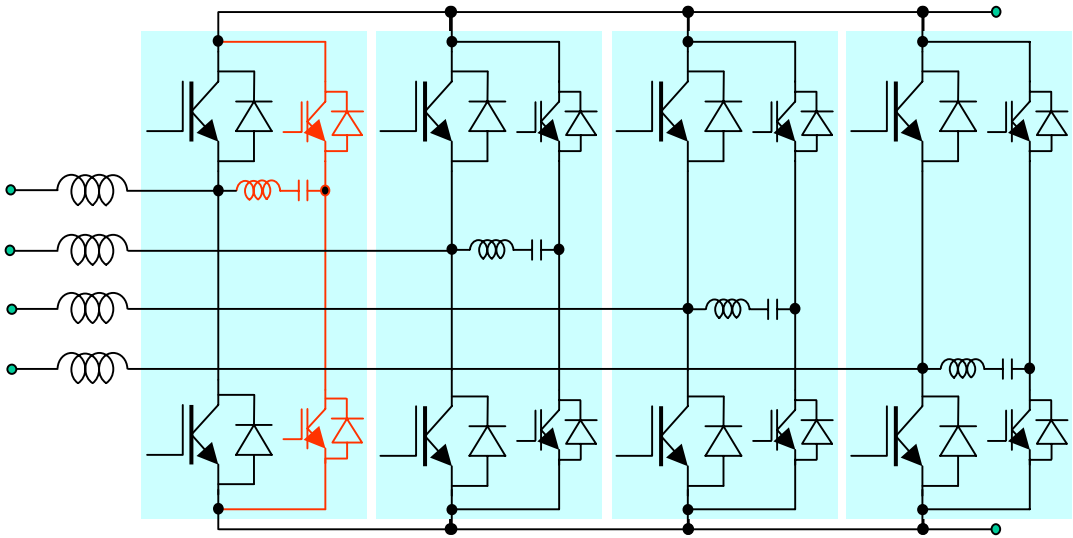




Zero-Voltage, Zero-Current Transition (ZVZCT) Soft-Switching Cell

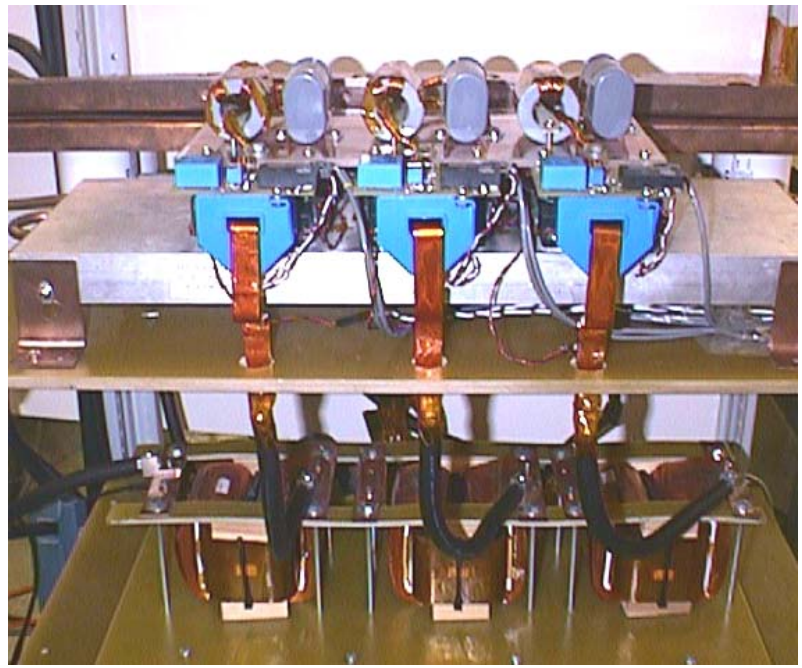
- **Main switch zero current turn off**
- **Main diode zero current turn off**
- **Auxiliary switch soft switching**

Modular, PEBB-Based Converters



ZVZCT
PEBB

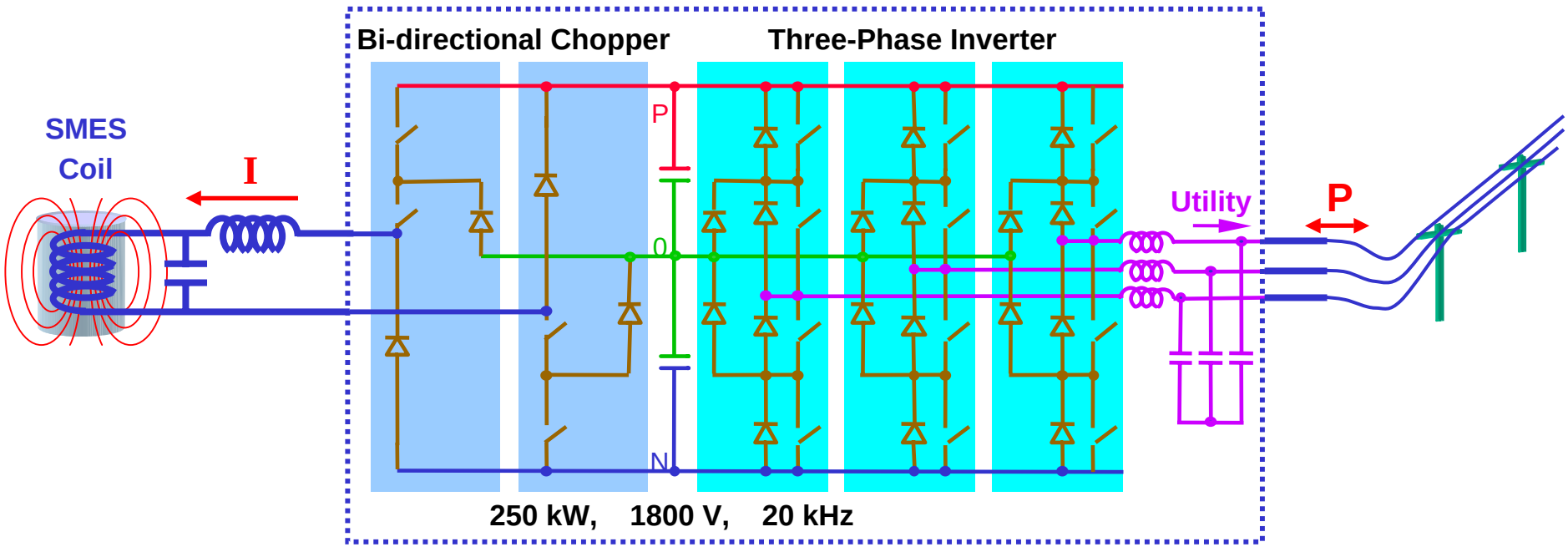
100 kW ZVZCT Three-Phase Inverter / Rectifier



Specifications

- **AC Voltage:** **3Ø, 60 Hz, 480 V**
- **DC Voltage:** **800 V**
- **Power Rating:** **100 kW**
- **Switching Freqy:** **20 kHz**

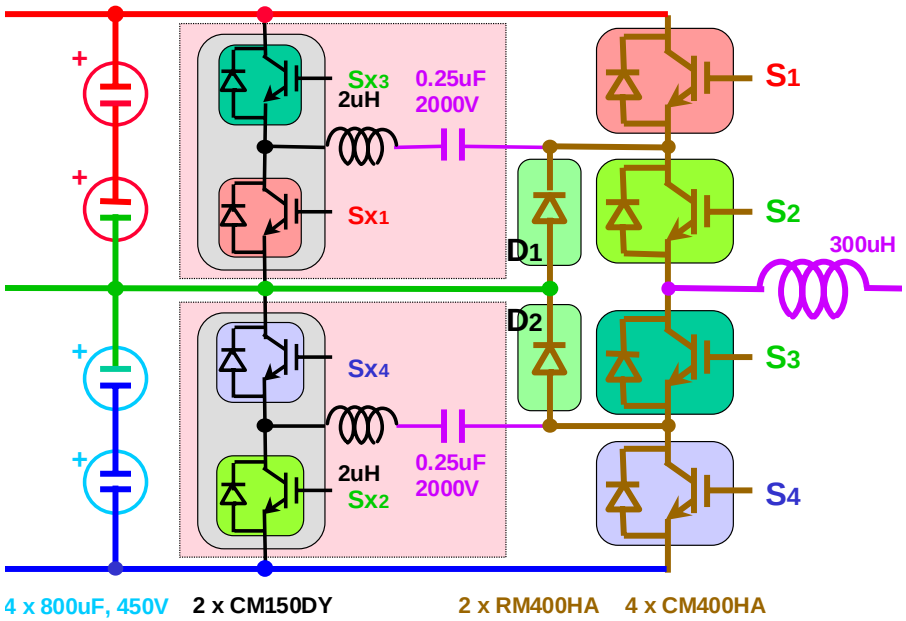
Power Conditioning System for SMES



- Suitable for any variable dc source:
  - Batteries
  - Solar (PV) cells
  - Fuel cells
- With back-to-back inverter, suitable for
  - Flywheel storage

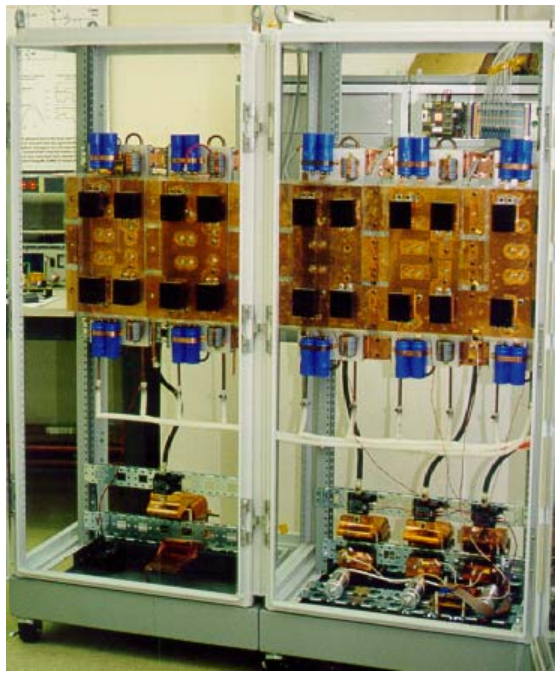
- Energy reserve
- Voltage support
- VAr compensation
- Harmonic filtering

High-Density, High-Bandwidth Prototype



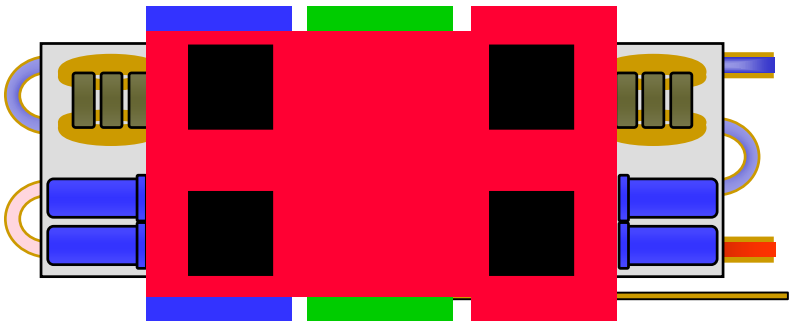
P = 250 kW, f_{sw} = 20 kHz, f_{cl} = 3 kHz

±1750 V dc



1200 V 3Φ ac

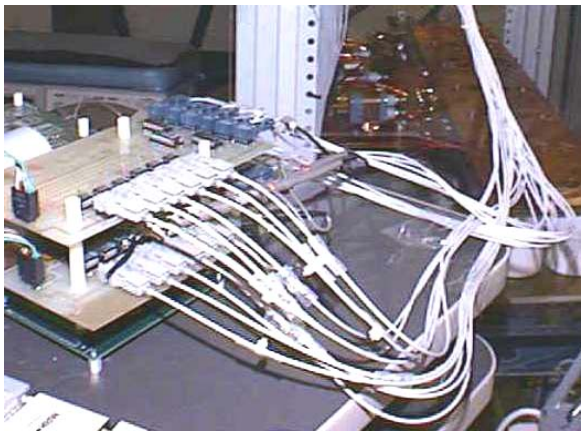
- Zero-Voltage, Zero-Current Soft-Transition



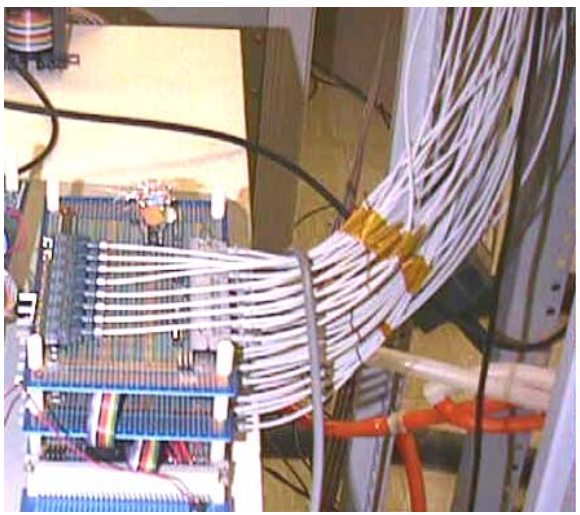
- High power density: 47 W/in^3

- Water cooled
- Laminated bus
- Integrated driver
- Optical fiber interface

Modular "Plug & Play" Control Architecture

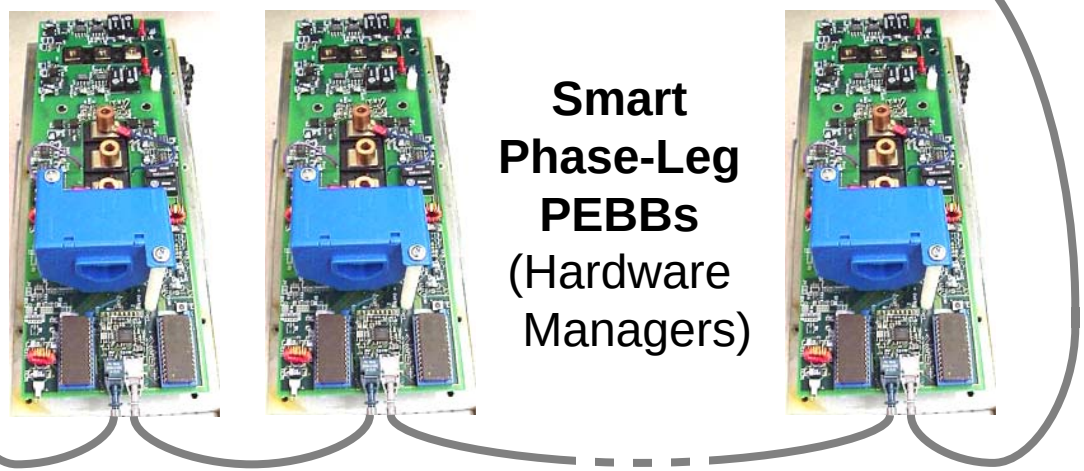


ZVZCT 3Φ VSI



ZVZCT 3Φ three-level VSI

Universal Controller (Application Manager)

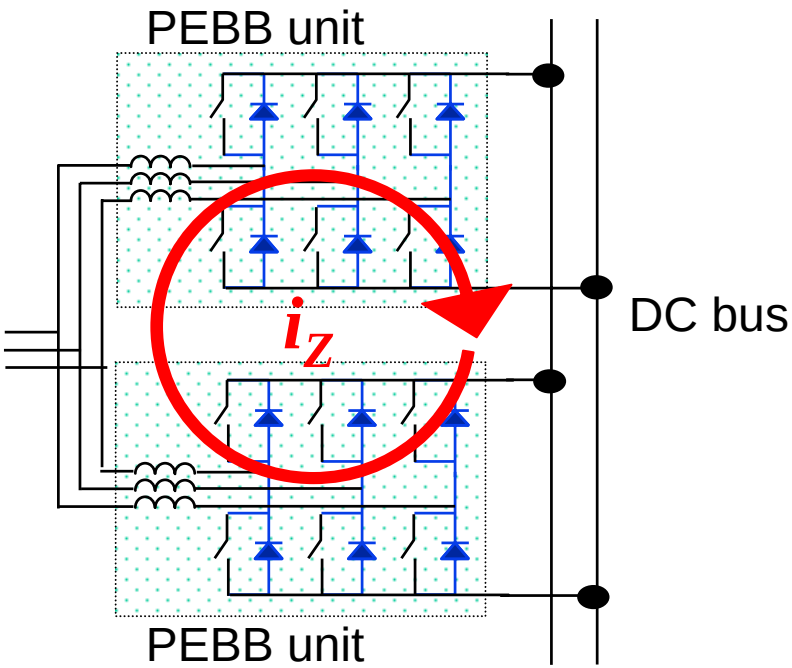


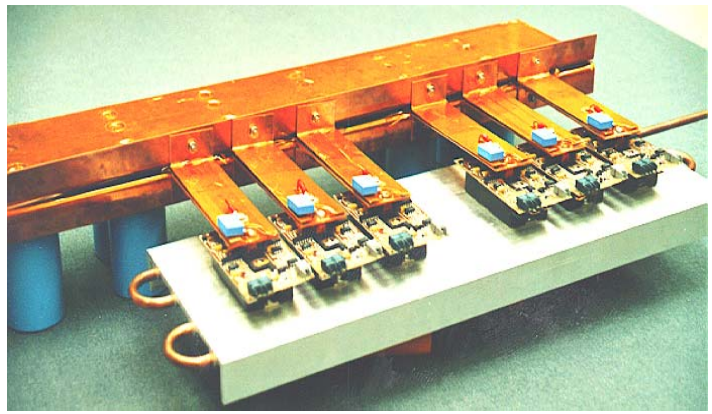
Smart Phase-Leg PEBBs (Hardware Managers)

125 Mb/s POF Daisy-Chained Serial Bus (PESNet)

Modular Converter Systems

- **Example: Parallel Converters**





Specifications

• **AC voltage:**	**208 V**
• **DC voltage:**	**400 V**
• **Power rating:**	**20 kW / unit**
• **Switching freqy:**	**32 kHz**

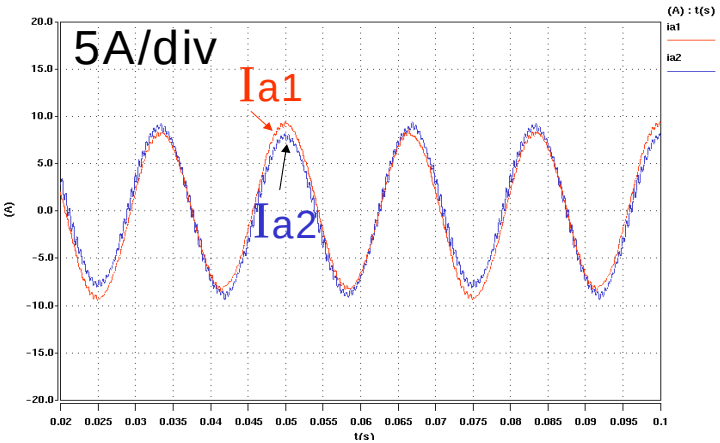
- **Zero-sequence current** must be controlled in (*N*) parallel converters
- For modularity, need independent controllers per converter
- New control algorithm provides for zero-sequence current control by:
  - Small modification in modulation
  - Simple additional (zero-sequence) current controller in *N*-1 converters

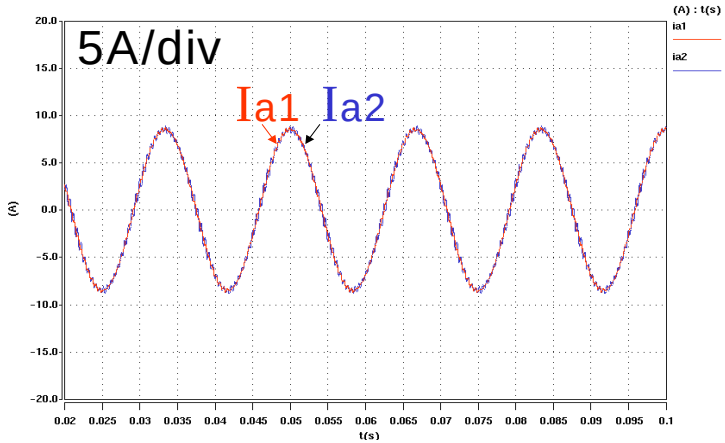
Simulation

CPES

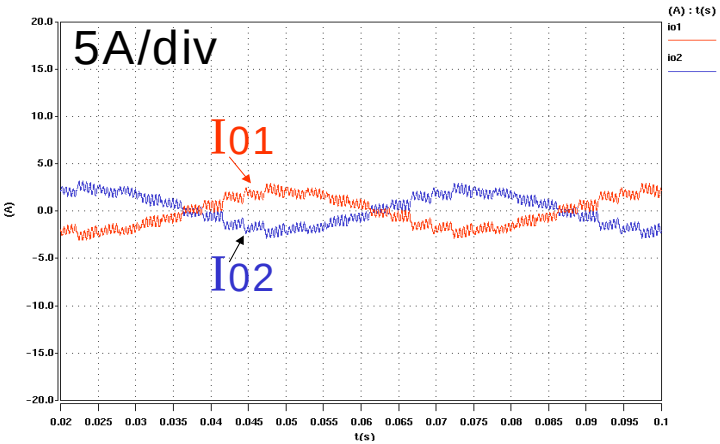
Three-Phase Boost Rectifier Operation

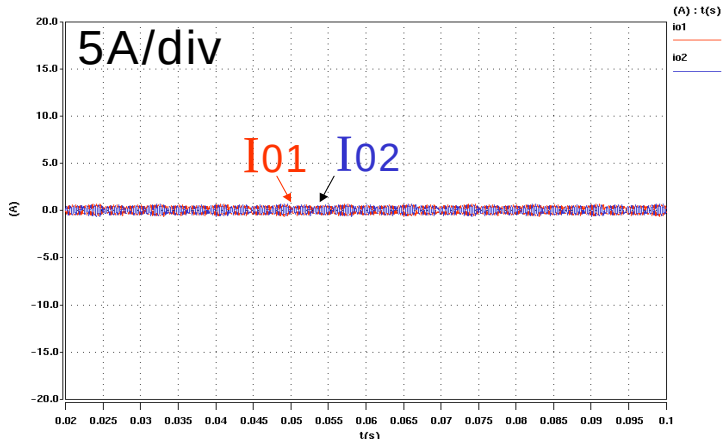
AC Currents





DC Currents





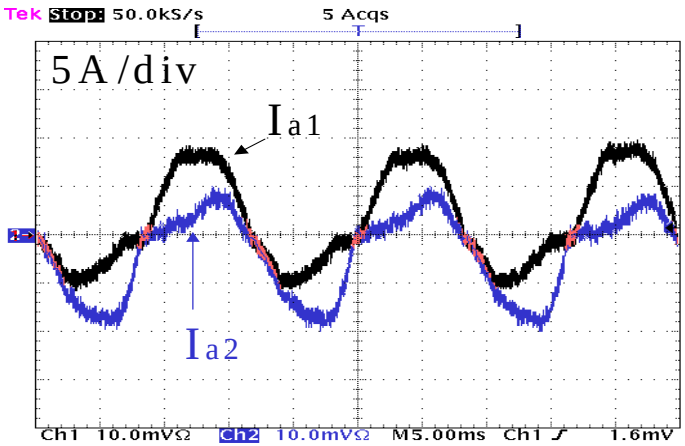
w/o Zero-sequence control

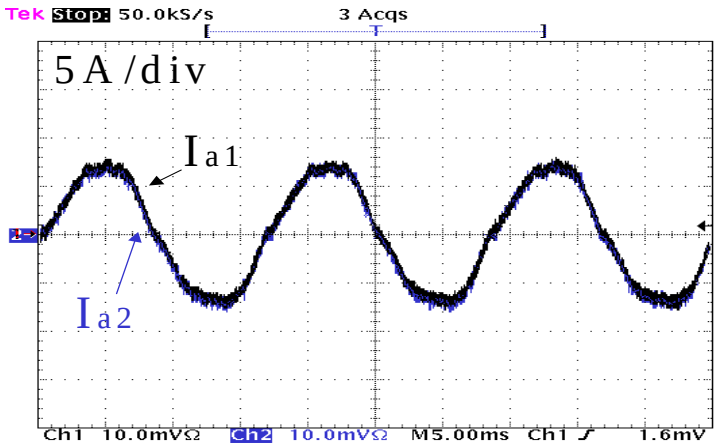
w/ Zero-sequence control

Experiment

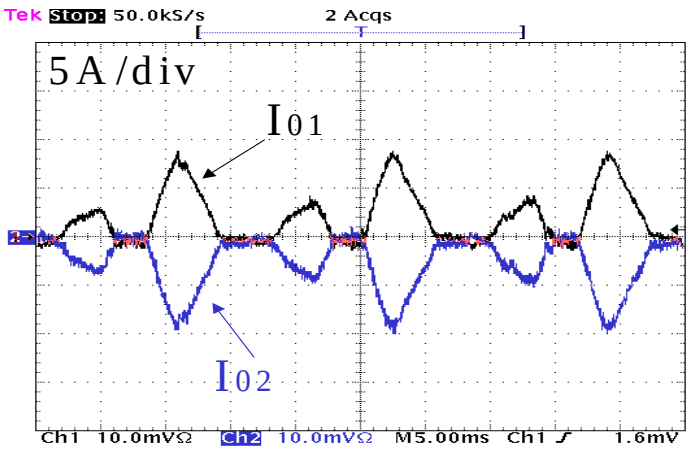
Three-Phase Boost Rectifier Operation

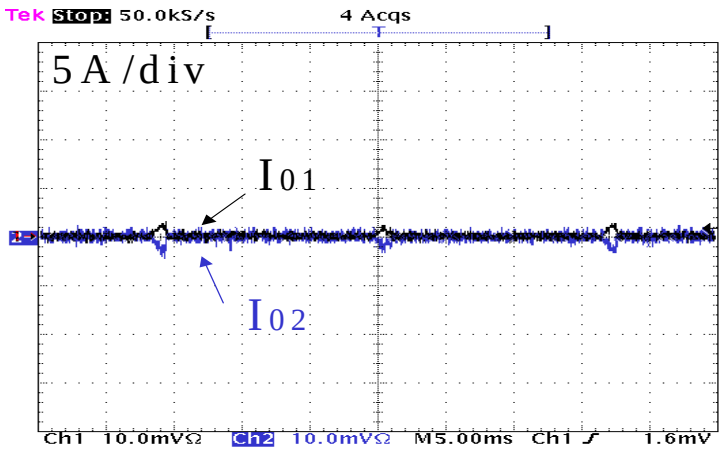
AC Currents





DC Currents





w/o Zero-sequence control

w/ Zero-sequence control

Conceptual Reference Model

CPES

Standard-Cell, Open-Architecture, Electric Power Conversion Systems

	Control	*Modeling and Simulation*	*Energy Processing*
7	**Mission**	**Cost and Quality**	**Generation and Transmission**
6	**Enterprise**	**Power Flow**	**Power Distribution**
5	**Application**	**Application**	**Power Station** parallel, series, or cascade converters with switchgear and enclosure
4	**Data Flow**	**Average**	**Power Converters**
3	**Elementary Control Objects**	**Behavioral**	**Integrated Modules** for energy flow control and energy storage
2	**Real-Time Operating System**	**Physics-Based Lumped Parameter**	**Packaged Components** transistors, inductors, capacitors, heat sinks, …
1	**Physical** (Universal Controller, HM)	**Finite Element**	**Devices** semiconductors, magnetic cores, dielectrics, heat spreaders, …