Power Electronic Converters for Advanced Electric Power Systems

Dushan Boroyevich

Center for Power Electronics Systems

The Bradley Department of Electrical and Computer Engineering
Virginia Tech, Blacksburg, VA 24061-0111, USA
Tel.: 540.231.4381, Fax: 540.231.6390, Email: dushan@vt.edu

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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

Virginia Tech
Rensselaer Polytechnic Institute
University of Wisconsin Madison
University of Puerto Rico Mayaguez
North Carolina A&T State University

Industry Consortium with 75 Partners
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/in³)
- 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 ⇒ Source Interface Converter
  - AC Filter + AC Voltage Sensing
  - Control
Power Electronics Converters for Distributed (Renewable) Generation

DG (Renewable) Source or Storage

Source Controller

Source Interface Converter

Grid Interface Converter (Inverter)

Inverter Controller
Standard Commercial Gen-Sets

- Constant, Low Speed
- High Zo

- Gas Tank
- Governor Control
- Field Control
- Source Controller
- Inverter Controller
- VA
- VB
- VC
- VG
- Load

😊 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 $V_a$

THD = 4.2%
Test Condition:
\[ V_o = 277 \text{ V}, \ f_o = 60 \text{ Hz}, \ V_{dc} = 815 \text{ V} \]

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

Power Electronic Converters for AEPS
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_{dc}/2

V_1

V_2

V_3

V_4

V_{dc}/2

C_n

Load

V_a

V_c

V_{n}

4-leg inverter with common-mode noise reduction

250V/div

250V/div

250V/div

Balanced load

Unbalanced load

Nonlinear load

25V/div

50V/div

25V/div
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

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

ZVZCT
PEBB
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

- Zero-Voltage, Zero-Current Soft-Transition
- Water cooled
- Laminated bus
- Integrated driver
- Optical fiber interface

- High power density: 47 W/in$^3$

$\pm 1750$ V dc

1200 V 3Φ ac

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Power Electronic Converters for AEPS
Modular “Plug & Play” Control Architecture

Universal Controller
(Application Manager)

Smart Phase-Leg PEBBs
(Hardware Managers)

125 Mb/s POF Daisy-Chained Serial Bus (PESNet)
Power Electronic Converters for AEPS

ZVZCT 3Φ VSI

ZVZCT 3Φ three-level VSI

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Modular Converter Systems

- Example: Parallel Converters

- **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

Specifications:
- AC voltage: 208 V
- DC voltage: 400 V
- Power rating: 20 kW / unit
- Switching freqy: 32 kHz
Three-Phase Boost Rectifier Operation

**AC Currents**

- 5A/div
- $i_a1$, $i_a2$

**DC Currents**

- 5A/div
- $i_01$, $i_02$

**Simulation**

- 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