

ECCE 2014 Tutorials Chair

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Tutorial Proposal Form

## 1. Title of Tutorial

Feedback-loop design issues of dc-dc converters in high-power energy harvesting applications

## 2. Abstract

(500 word limit, If the tutorial is accepted, this abstract will be published in the conference web page, program, and proceedings)

Exploiting the energy of sea waves, or recuperating the kinetic or potential energy of mechanical systems (electric vehicles, cranes and elevators, etc.) can be considered high-power energy harvesting. It is a common characteristic of such systems that the input power shows relatively rapid fluctuations, necessitating the need for short-term energy storage and bidirectional energy processing. The power converters used to control the power flow between the various building blocks of the system (electric generators, storage devices, motors, utility interface) must maintain stability and be able to handle the fluctuations under widely varying operating conditions.

This seminar discusses the feedback loop design issues of the dc-dc converters used in high-power energy harvesting systems, including:

- A review of the main control issues with a new and highly visual presentation of the effect of the design parameters on transient response, output impedance, etc.
- Feedback-loop design of the dc-dc converter feeding another dc-dc converter, a motor drive, or a grid-connected inverter
- Feedback-loop design of bidirectional dc-dc converters that are able to rapidly charge and discharge the storage devices
- Feedback-loop design and digital (VHDL) control of modular converters with serial input and parallel output

The seminar presents a complete list of simulation examples, based on a novel fast design/simulation tool. This is an intermediate-level seminar for engineers with background in converter control.

### 3. Outline of Tutorial

(Outline would only define the topics and the subtopics that would be covered. No detail descriptions should be included in the proposal)

- I. Introduction – 15 minutes
  - A. Wave-energy harvesting basics
    - a. Electric generators for wave-energy harvesting applications
    - b. Mathematical model of the current pulse produced by the electrical generators
    - c. Power architectures
  - B. Kinetic and potential energy recuperation systems basics
    - a. Electric generators for energy recuperation applications
    - b. Mathematical model of the current pulse produced by the electrical generators
    - c. Power architectures with and without integrated energy storage
    - d. Power supplies for auxiliary services and essential subsystems
- II. Feedback-loop design summary – 35 minutes
  - A. Refreshing the basic concepts
    - a. Fundamentals of stability analysis
    - b. Crossover frequency, phase margin, gain margin, small-signal transient response
    - c. Audio susceptibility, input and output impedances
    - d. Compensator design with K factor, K plus factor, and manual pole and zero placement
  - B. Designing and optimizing within the valid solutions space
    - a. Achievable phase margin boundary
    - b. Conditional stability boundary
    - c. Fast-scale instability boundary
    - d. Overall optimization of the specifications (audio susceptibility, output impedance, and transient response) at the same time
  - C. Shapes of the solutions space
    - a. Influence of topology and conduction mode
    - b. Influence of the dc operating point (worst-case selection)
    - c. Influence of the compensator type
  - D. Helping the feedback loop with input voltage feedforward
    - a. Feedback limitations under large input voltage variations, as, e.g., in the sea-wave converters
    - b. General small-signal model of the dc-dc converter with input-

voltage feedforward

- c. Optimal feedforward gain coefficients (small-signal) of the basic voltage-mode and current-mode controlled converters
- d. Large signal model of buck derived topologies
- e. Optimal large signal feedforward for buck-derived topologies

### III. Energy storage issues – 20 minutes

- A. Battery and supercapacitor types and models, charging considerations, charge termination
  - a. Lead-acid batteries
  - b. Ni-based batteries
  - c. Supercapacitors
- B. Control loop structures and feedback-loop design considerations
  - a. Block diagram and architectural options (only supercapacitor, supercapacitor and battery combination)
  - b. Loop compensation considerations

### IV. Cascade converters – 35 minutes

- A. Complete characterization of the output port of a dc-dc converter considered as source converter
  - a. Output impedance of the open-loop converter
  - b. Output impedance of the feedback-regulated converter
  - c. “Un-terminated” output impedance (without considering the load resistor)
- B. Complete characterization of the input port of a dc-dc converter considered as load converter
  - a. Input impedance of the open-loop converter
  - b. Input impedance of the feedback-regulated converter
  - c. Back-current gain
- C. Input impedance estimation of commercial load converters under dynamic behavior uncertainties.
  - a. The converter as a constant-power load
  - b. Effect of the input capacitor
- D. Interaction between cascaded converters
  - a. Dc-dc converter and inverter (grid connected) cascade
  - b. Dc-dc converter and inverter (motor drive) cascade
  - c. Dc-dc converter and chopper (dc motor drive) cascade
  - d. Dc-dc converter and dc-dc converter (power supply) cascade
- E. Feedback-loop design considerations for the source converter

- a. Refreshing Middlebrook's stability criterion for input-filter and cascaded dc-dc converter
  - b. Output impedance shaping below the input impedance envelope (load converter or load converters in parallel)
  - c. Effect of increasing the output capacitor of the source converter in buck, boost and buck-boost derived topologies; worst case selection
  
- V. Bi-directional converters – 35 minutes
  - A. Main topologies
    - a. Non-isolated converters
    - b. Isolated converters
  - B. Bidirectional power flow and asymmetrical dynamic behavior
    - a. Buck mode and boost mode transfer functions in the synchronous buck converter
    - b. Step-up and step-down mode transfer functions in the four-switch buck-boost converter
    - c. Step-up and step-down mode transfer functions in isolated converters, e.g., the Dual Active Bridge (DAB)
  - C. Feedback-loop design considerations for the bidirectional converter
    - a. Single compensator; worst case design
    - b. Double compensator; smoothing the power flow transition
  
- VI. Modular converters based on DAB modules with input-series and output-parallel connection (ISOP) – 45 minutes
  - A. Modular converters in sea wave applications
    - a. General considerations
    - b. DAB ISOP converter
    - c. Improved dynamic behavior
  - B. Analysis of DAB ISOP converter
    - a. Steady-state operation
    - b. Small-signal model
    - c. Decoupling the control loops
  - C. VHDL digital control of DAB ISOP converter
    - a. Modulator block design
    - b. Decoupling block design
    - c. Compensator block design
    - d. Co-simulation of the closed loop converter
  
- VII. Final remarks – 5 minutes
  - a. Summary of the main problems and solutions

- b. Summary of the models and tools used to speed up the compensator design

#### 4. Lead Instructor

(Name / Affiliation & contact information)

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#### 5. Other Instructor

(Name / Affiliation & contact information)

#### 6. Instructor Bio

~150 words each (Please provide a brief biography of each instructor, describing the qualifications for presenting the proposed tutorial, including the work and publications that are most relevant to the proposal)



**Antonio Lazaro** was born in Madrid, Spain, in 1968. He received the M. Sc. in electrical engineering from the Universidad Polit cnica de Madrid, Spain, in 1995. He

received the Ph.D. degree in Electrical Engineering from the Universidad Carlos III de Madrid in 2003.

He has been an Assistant Professor of the Universidad Carlos III de Madrid since 1995. He has been involved in power electronics since 1994, participating in more than 50 research and development projects for industry. He holds seven patents and software registrations and he has published nearly 140 papers in IEEE journals & conferences. He is co-author of a book on problems of power electronics. His research interests are switched-mode power supplies and power factor correction circuits, inverters (railway auxiliary power supplies and grid connected applications), modeling and control of switching converters and digital control techniques.