Department of Electrical and Computer Engineering
ECE 792-063 Modeling and Digital Control of Power Electronic Converters

Course Overview

Modeling fundamentals of pulse-width modulation (PWM)-, phase-shift-, and frequency-controlled power conversion; transforming analog control design to discrete-time implementation; principles of time-scale separated cascaded controllers; linear, hysteretic, hybrid hysteretic, and predictive controllers; small-signal vs large-signal analysis and verification; software-in-the-loop (SIL)/ digital twin modelling; grid-following (GFL) and grid-forming (GFM) control; droop and virtual oscillator controls; voltage source converter controls and controller implementations.

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Pre-requisites: ECE 534 or equivalent

Teaching Assistant: To be assigned
Office Hours: TBD

Lecture Schedule: Tue-Thur 4:30-5:45PM

Classroom: EB2 1220

Lectures and Assignments: Lectures will be presented in-person in class. Annotated lecture notes will be posted in Moodle. Homeworks and projects will also be assigned through Moodle.

Recommended Text books:
1. TBD

Reference books
1. TBD

Modeling Projects:

Power electronics modeling, digital control, and simulation projects to be developed with computer simulation tools will be assigned related to the topics covered in the course. Matlab-Simulink will be the primary platform for the simulations. The assignments will be collected and graded.

Homeworks

Homeworks will be assigned to aid the learning and in support of the lecture presentations. In addition to numerical problem solving, homeworks will include computer simulation problems to help prepare for the modeling projects. Homework assignments will need to be submitted online.

Drop Deadlines

Confirm the last day to drop ECE792 from the University Calendar. Lack of prerequisites is not grounds for dropping a course after the deadline.

Policy on Absences

Unexcused absences from exams, homework, or final exam will receive a grade of zero. Make-up exams will not be given except under extenuating circumstances.

Grading and Assignments

The letter grade will be on a 90, 80, 70, 60 scale. Within this range +/- will be used. Grading questions arising as a result of a particular test or exam must be resolved within one week after that test or exam is returned.

Course Contents:

Pulse-width, phase-shift, and frequency- controlled power conversion
Transforming analog control design to discrete-time implementation
Principles of time-scale separated cascaded controllers
Linear, hysteretic, hybrid hysteretic, and predictive controllers
Small-signal vs large-signal analysis and verification
Software-in-the-loop (SIL)/ digital twin modelling
Grid-following (GFL) and grid-forming (GFM) control
Droop and virtual oscillator controls

Additional Health Measures and Guidelines due to the Coronavirus Pandemic

Due to the Coronavirus pandemic, public health measures have been implemented across campus. Students should stay current with these practices and expectations through the Protect the Pack website (https://www.ncsu.edu/coronavirus/).

Grading:

Component	Weight	Details
Homework	25%	Seven to eight homework assignments are assigned during the semester.
Simulation Projects	50%	Two-three digital control & simulation projects will be assigned. The students submit completed Matlab/Simulink programs and reports.
Final Exam	25%	A comprehensive final exam is administered at the end of the semester.

Lec # (75 mins. each)	Topic	Assignments
1	Pulse-Width, Phase-Shift, and Frequency Modulated Power Conversion - • Introducing different types of conversion to be covered in the course • Introduction to different application domains: industrial, automotive, renewable energy	
2	A 2L Phase-Leg: DC-DC & DC-AC operation • Identical small-signal model output voltage and current using LC filter in open-loop for DC and AC outputs • Current-control (DC sources on both input and output); PI and PR compensators for DC and AC current control	#1 Voltage source inverter analysis with average model
4	Simulation and Implementation Reference Frames • dq transformations for three-phase and single-phase • α-β-0 reference frame	
5	Digital/Discrete-Time Control Implementation • Analog to digital transformation • Modeling digital controllers for analysis & simulation • Small-signal response verification	#2: design, discretize, & compare freq. responses of PR current con.
6	Cascaded Control Structure • Output voltage control (DC-DC) • DC bus voltage control (DC-DC operation)	
7	Design for Worst-Case: Part I • Constant-impedance and constant-power loads • Limits of active control: beyond-switching-frequency resonances	
8	Single-Phase & Three-Phase Voltage Source Inverter (VSI) • Unipolar vs bipolar modulation • Three-wire vs four-wire systems • Differential-mode (DM) & common-mode (CM) circuits • Extending output voltage range using CM	#3: design & simulate voltage controller for constant-P load
9	Grid-Following (GFL) Inverters • Control structure (DC bus control) • Phasors vs space vectors • Stationary and synchronous reference frames • Phase-locked loop (PLL) • Double-synchronous PLL	
10	Differential Mode (DM) Filtering: Part I • DM filter design • Resonance damping – passive and active damping • Filter based active damping	
11	Differential Mode (DM) Filtering: Part II • State estimator/observer based active damping	#4: Design DM filter and active damping; simulate current control in 3phase VSI
12	Common Mode (CM) Filtering • AC & DC CM filters for 3ϕ VSI • CM chokes • Generalized 3ϕ choke modeling & testing	
13	GFL VSI Applications in Industrial motor drives, UPS • Active front-end (AFE) in POL application (industrial drives, UPS)	

14	GFL VSI Applications in BESS, MPP for PVs • Battery energy storage systems (BESS) • Maximum power point (MPP) tracking for PVs	
Term Project I: Three-Phase VSI Simulation Assignment (in Matlab-Simulink): Control design and simulation of 3ϕ PV VSI with MPP tracking		
15	Digital Twin/Software-in-the-Loop (SIL) Simulation • Introduction • Code segmentation • Multi-rate control	
16	SIL Simulation: Part II • Coding & SIL Demo •	#5: Digital code & SIL model of a synchronous DC-DC (buck) converter
17	Design for Worst-Case: Part II • Feedback interaction between systems • Middlebrook's Extra Element Theorem (EET) • Impedance-based stability criteria • Frequency-domain passivity	
18	Model-Predictive Control: Part I • Fundamentals of model predictive control (MPC) • Predictive current control • Application Example: ??	
19	Model-Predictive Control: Part II • Finite control set (FCS) MPC • Application Example	#6: Digital code & SIL model of a 3ϕ VSI with current controller (P/Q reference tracking)
20	Large-Signal/Transient Stability Analysis • Introduction • Transient stability analysis of a three-phase VSI	
21	Analysis of Cross-Coupled Dynamics • Complex transfer functions • Small-signal analysis of PLL dynamics	
22	Introduction to Multi-Level Topologies • 3L bridge • Cascaded H-Bridges (CHB) • Modular Multi-level Converter (MMC)	#7: Transient stability analysis of the VSI designed in assignment #6
23	Modulation in Multi-Level Topologies • 3L DNPC modulation with neutral-point voltage balancing • Multi-level modulation for CHBs	
24	LLC Resonant Converter: Part I • Principle of operation	
25	LLC Resonant Converter: Part II • Direct frequency control • Hybrid hysteretic control	#8: Design a hybrid hysteretic voltage controller for an LLC converter
26	Phase-Shift Controlled Power Conversion • Dual active bridge (DAB) converter • Power-flow control • Voltage control	
Term Project II- Design, implement, & validate a grid-forming 3ϕ VSI in SIL environment		

27	Grid-Forming Control: Part I • Power Synchronization • Droop control • Single-loop vs double-loop control	
28	Grid-Forming Control: Part II • Virtual impedance & AC voltage control • Virtual admittance • Small-signal model	
29	Grid-Forming Control: Part III • Secondary frequency regulation • Secondary voltage regulation • Microgrid & grid-tied operation; pre-synchronization	
30	Grid-Forming Control: Part IV • Transient stability analysis • Critical clearing angle	
Final Exam		