Course Number and Title

NAU: EE 502 Advanced Wind Power Conversion

Effort: 3-credits, semester

Prerequisites:

Graduate student status or approval of instructor. The content of this class is best suited for students with an undergraduate degree in electrical or mechanical engineering. The students are required to have knowledge of electric circuits, resistors, inductors, capacitors, series and parallel RLC circuits, Thevenin's and Kirchhoff's laws, magnetic circuits, and single- and three-phase electric circuits from the basic electrical engineering course (such as EE 188 at NAU) to design and analyze power conversion stages and generators in wind energy systems. The student should also have basic knowledge in semiconductor devices such as diodes and insulated gate-bipolar transistor from electronics course (like EE 280 at NAU) to understand different types of power converters used in wind energy systems. This course is math intensive and the students are expected to have a sufficient background in mathematics (such as polar to cartesian conversion, solving second-order differential equations, etc.). Students with a background in the sciences or math may also be sufficiently prepared for the course content, provided their studies included mathematics through differential equations and exposure to the fundamental equations of electric circuits including voltage, current, power, and energy. An exposure to engineering analysis and computer simulation software such as MATLAB/Simulink is recommended. In the case the student studied the fundamental prerequisite topics many years back or have little exposure to electrical engineering, the instructor will provide self-learning module, at the start of the semester, covering all the fundamental topics as well as some exercise problems. The self-learning module along with a video instruction can be completed in 6-8 hours.

Textbook / Resources:

- B. Wu, K. Lang, N. Zargari and S. Kouro, Power Conversion and Control of Wind Energy Systems, Wiley- IEEE Press, 2011 (ISBN 978-0-470-59365-3).
- V. Yaramasu and B. Wu, Model Predictive Control of Wind Energy Conversion Systems – Chapter 1, Wiley- IEEE Press, 2016 (ISBN 978-1-118-98858-9). First chapter is available for free download from Wiley website.
- Additional materials will be posted on BbLearn.
- Each lecture module will include few YouTube videos for graphic illustration and self-learning.
- Graduate students are required to read significant outside research literature in journal papers, technical reports, and books. Some sample readings will be provided in the graduate work assignments.

Course description:

This course will have 2 credit hours of lecture and 1 credit hour of lab each week. Among the renewable energy sources, wind energy is rapidly becoming mainstream and competitive with conventional sources of energy. The conversion of wind kinetic energy into electric energy is of multidisciplinary nature, involving aerodynamics, mechanical systems, electric machines, power electronics, control theory, and power systems. This course will introduce students to the breadth of wind energy systems from the electrical engineering perspective. This course provides a comprehensive and in-depth analysis on wind generators, system configurations, power converters, control schemes, and dynamic/ steady-state performance of various practical wind energy conversion systems (WECS).

The course contains nine modules. The first module starts with an overview of market survey, wind turbine technology, growth in the size of wind turbines, wind energy system classifications, costs, and grid codes (e.g., fault-ride through and reactive power generation) for wind power integration. Next module introduces the fundamentals and control principles of wind energy systems, including wind turbine components (e.g., tower, blades, nacelle, pitch control, yaw control, brakes, wind sensor, cooling system, generator, converter, transformer), aerodynamics, stall and pitch controls, and maximum power point tracking schemes. The module 3 presents commonly used wind generators, including squirrel cage induction generator (SCIG), double fed induction generator (DFIG) and synchronous generator (SG). The dynamic and steady-state models of these generators are also derived to facilitate the analysis of wind energy systems in the subsequent modules.

The module 4 presents a general overview of configurations and characteristics of major practical WECS. In addition, several power converters such as AC voltage controller, boost converter, voltage source converter, current source converter, grid-tied converter will be discussed with respect to the topology, operation and modulation. Module 5 focuses on fixed speed SCIG-based wind energy systems, where important issues such as grid connection, two-speed operation and reactive power compensation are discussed. Module 6 deals with wind energy systems with variable-speed SCIG WECS, in which typical system configurations and advanced control schemes such as field-oriented control (FOC) and direct torque control (DTC) are elaborated. Module 7 is dedicated to variable-speed SG wind systems, in which various control schemes, including zero d-axis current control, maximum torque per ampere control and unity power factor control, are analyzed in detail. The control of boost converter-based SG WECS is also discussed and compared with the traditional back-to-back connected voltage source converters. The last module discusses DFIG systems, where the sub-synchronous super-synchronous modes of operation are investigated.

With the knowledge obtained in this course, the student will be demonstrating deep understanding of technologies employed in the past, present and near-future wind turbines. The students will also perform literature survey on wind energy industry and power converters used in various practical wind turbines. This will be accompanied by an in-class presentation. The student will be able to model the complete wind energy system in MATLAB/Simulink including turbine power versus speed characteristics, maximum power point tracking algorithms, wind generators, power converters, and modulation methods for converters. Additionally, the students design and simulate advanced control schemes such as zero d-axis current control and field-oriented control and verify them through MATLAB simulation studies. For all course-related work, graduate students will be held to a higher standard of professionalism and quality of work than one would expect to find in the equivalent undergraduate course, as befits a graduate level experience.

Learning Outcomes:
Upon successful completion of this course, students will be able to demonstrate the following competencies:

- Demonstrate proficiency in developing MATLAB/Simulink models of wind turbines, wind generators, controllers for fixed-speed and variable-speed wind turbines.
- Demonstrate proficient knowledge in the state-of-the-art wind energy systems; wind turbine electrical and mechanical technologies; grid code requirements such as fault ride-through and reactive power generation for the large-scale wind turbines and wind farms; and power factor compensation.
- Describe the role of power electronics in fixed- and variable-speed wind energy systems.

- Obtain deep understanding of the major electrical and mechanical components of wind turbines, turbine aerodynamic characteristics, and modeling of turbine torque-speed characteristics using computer simulations.
- Understand and implement the reference frame transformation between natural, stationary and synchronous reference frames.
- Understand and apply various power converters for WECS including AC voltage regulators (soft starters), multi-channel interleaved boost converters, voltage source converters, and current source converters. Develop control schemes for grid-tied converters, and for reactive power generation.
- Demonstrate proficient knowledge in squirrel-cage IG based variable-speed WECS with respect to system configurations, operating principle, direct field-oriented control (FOC), rotor flux identification, system dynamic analysis, and steady state calculations. Investigate variable-speed IG based commercial wind turbines.
- Be able to apply zero d-axis current control, maximum torque per ampere control, and transient and steady state analysis to variable-speed SG WECS. Investigate variable-speed SG based commercial wind turbines.
- Demonstrate proficiency in system configurations, super- and sub-synchronous modes of operation, stator voltage-oriented control, dynamic and steady state models, and system dynamic and steady state analysis of doubly fed IG based semi-variable-speed WECS.
- Demonstrate deep understanding in advanced modulation and control schemes for wind turbines and wind farms.

Lecture Topics:

The following lecture modules are organized based on the textbook chapters.

Module #1	Introduction
Module #2	Fundamentals of Wind Energy Conversion Systems
Module #3	Wind Generators and Modeling
Module #4	Power Converters in WECS
Module #5	Fixed-speed Induction Generator Based WECS
Module #6	Variable-Speed Induction Generator Based WECS
Module #7	Synchronous Generator Based WECS
Module #8	Doubly Fed Induction Generator Based WECS

Laboratory Topics:

The following laboratory modules based on MATLAB/Simulink simulations are organized for the conceptual understanding of theoretical topics discussed in the lecture materials. All labs can be accomplished remotely by online students.

Lab #1	Introduction to the MATLAB, Simulink, and Simscape
Lab #2	Modeling and Simulation of Fixed-Speed Wind Turbine
Lab #3	Modeling and Simulation of Induction Generator
Lab #4	Decoupled Voltage Oriented Control of Grid-tied Inverter
Lab #5	Fixed-Speed Induction Generator Based WECS
Lab #6	ZDC Control of Variable-Speed PMSG Based WECS
Lab #7	Variable-speed SG WECS with boost converter
Lab #8	DFIG Based WECS

Assessment:

A weighted sum of assessment components is used to determine final grade in the course. The course grades will be calculated as follows for 100 points and converted to 100% base value:

- Homework assignments (assigned on weekly basis): **20 points**
- Quizzes (conducted during each class): **20 points**
- Lab activities and report submission: **20 points**
- Midterm exam: **20 points**
- Final exam: **20 points**

Final letter grades will be assigned using the weighted sum described above using this scale:

A ≥ 90%, **B** ≥ 80%, **C** ≥ 70%, **D** ≥ 60%, **F** < 60%.